




Spatio-Temporal Impacts of Lake Victoria Water Level Recession on the Fringing Nyando Wetland, Kenya

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Abstract Nyando is the second largest and one of the most economically important wetland ecosystems fringing Lake Victoria, Kenya. Lake level fluctuations and a range of anthropogenic activities degrade its ecological integrity, reduce its area and the quality of goods and services it provides. This study investigated the impacts of spatio-temporal variations in the lake's water levels on the wetland. Satellite images, ground truthing and semi-structured questionnaires were used to collect data on land use and community perceptions respectively. Results indicate that the shoreline receded significantly (t -stat = 5.5328; p -value < 0.0052) with the wetland area decreasing by 31 % between 1984 and 2010. Lake level recession exposed 752 ha of new land at an annual rate of 29 ha/year. The vulnerability of the wetland is worsened by the majority of respondents (60 %) being unable to associate the lake level recession with the wetland degradation. Eighty-six percent cultivate the exposed land for agricultural production with only 4 % of the respondents considering the land as ecologically sensitive and thus needing conservation. Development of a comprehensive and participatory wetland management plan, diversification of agricultural and fisheries

production and introduction of ecologically sensitive alternative livelihood activities are recommended to ensure sustainable management.

Keywords Nyando Wetland · Lake water levels recession · Wetland degradation · Land use change

Introduction

Lake Victoria, the world's second largest freshwater lake with a total surface area of 68,800 km², is located in a basin inhabited by approximately 35 million people with a population density of about 300 persons per km² (LVBC 2007). The inflow to the lake is dominated by rainfall which accounts for 84 %, while the remaining 16 % is contributed by inflows from rivers and tributaries draining some 190,000 km² (Sutcliffe and Petersen 2007; Kiwango and Wolanski 2008). There are 11 river basins draining into the lake from this densely populated catchment area. Evaporation accounts for 76 % of the outflow from the lake, while the remaining 24 %

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($\sim 23.5 \text{ km}^3 \text{ year}^{-1}$) is through the White Nile River at Jinja (Nicholson and Yin 2001; COWI 2002). The inputs and outputs in relation to the surface area constitute the lake water balance. The dynamics and differences between the input and the output components of the water balance often lead to changes in water levels and can be seen as an “integrated” measurement of surface-ground water exchange fluxes over the entire lake (Szesztay 1974; Swenson and Wahr 2009). These fluxes can affect not only life in the lake itself but also life in the ecotonal zones of the lakes such as fringing wetland ecosystems.

The lake-edge area of Lake Victoria and its shores with shallow water areas are covered by an extensive network of wetlands due to a low gradient which impedes rapid flows of the rivers draining into the lake. The Ramsar Convention on Wetlands of International Importance, 1971 defines wetlands as “*areas of marsh, fen, peat land or water, whether natural or artificial, with water that is static, brackish or salty including areas of marine water, the depth of which at low tide does not exceed 6 m*”. These wetlands support an array of aquatic biodiversity and perform crucial socio-ecological functions for sustainable livelihoods in the Lake Victoria basin (LVBC 2011). In view of their importance, a total of 422 wetlands have been mapped around the lake (LVBC 2011), spanning an area of approximately $4,322 \text{ km}^2$ of which 417 km^2 (61 wetlands) are in Kenya, $1,880 \text{ km}^2$ (142 wetlands) in Tanzania and $2,025 \text{ km}^2$ (219 wetlands) in Uganda. Wetlands are often at the boundary of shifting landscape patterns such as areas transitioning from agricultural to urban and other land uses, which normally threaten the areas they cover and their ecosystem integrity (Adler 2005). Emerging evidence indicates that wetland-lake-human nexus is dynamic and shifts according to hydrological patterns, changes in water use and changing population dynamics (Downard et al. 2014). However, increased human population and land use changes, among others, have catalyzed climate change which has led to frequent drought and flooding events, and socio-economic uses such as drainage of wetlands for agriculture and human settlement further threatening these fragile ecosystems (Acreman et al. 2009; MEMR 2012; Mao and Cui 2012).

It is also important to note that wetland hydrology is naturally dynamic, with periodic drying forming an important part of the wetland hydroperiodicity (Euliss et al. 2008; Smith et al. 2008). Hydrological periodicity affects hydrological connectivity of wetlands which is highly important for maintaining a wetland ecosystem. The connectivity provides significant support in terms of nutrients, energy transport and maintenance of ecosystem functions (Mao and Cui 2012). Many lacustrine wetlands are intrinsically connected to the adjacent water bodies and fluctuations in the levels of such water bodies are likely to adversely affect their hydrological connectivity leading to desiccation, disappearance and exposure of these important ecosystems to human encroachment. In the Lake

Victoria basin, knowledge of hydrological connectivity of wetlands to supporting water bodies is however limited, hindering the efficient management of these ecosystems.

Historical information on the fluctuation of Lake Victoria water levels, which is critical in understanding hydrological connectivity to the lacustrine wetlands, extends back to the late eighteenth century (Sutcliffe and Petersen 2007). Regular measurements are available from 1896 with wide fluctuations over the 120 year data series (Sutcliffe and Petersen 2007). However, few studies have made use of this information to understand its effects on the lacustrine wetlands surrounding the lake (Mao and Cui 2012). Past hydrological studies have concluded that the lake’s water balance is controlled both by climatic conditions via net precipitation and catchment inflow as well as human management via dam outflow at Owen Falls at Jinja in Uganda (Kite 1982; Nicholson 1998; Mercier et al. 2002; Kull 2006; Awange et al. 2008; Swenson and Wahr 2009; Adero and Kiema 2011). These studies have revealed that in the last five decades, sharp oscillatory changes in water levels have been occurring in Lake Victoria, a phenomenon which if combined with the increasing population pressure, could negatively affect the fringing shoreline wetland ecosystems such as Nyando wetland. The focus of most of the studies has been on impacts of lake level changes on fish catches, aquatic plants and organisms (Kairu 2001; LVBC 2006; Obiero et al. 2012) with minimal attention to the spatial interrelationships between lake level changes, human encroachment on exposed lands and wetland ecosystem dynamics. Thus many scientists have in the past typically placed insufficient emphasis on social and cultural factors operating within the ecosystems that they study (Morrison et al. 2013). This study focuses attention on these important relationships in Nyando wetland at the mouth of river Nyando on the shores of Lake Victoria.

River Nyando is a 115 km long river system which has a catchment area of $3,450 \text{ km}^2$ and drains the Nyando wetland ecosystem into Lake Victoria (JICA 1992). The wetland is located between latitudes $00^\circ 09' \text{ S}$ and $00^\circ 20' \text{ S}$ and longitudes $34^\circ 45' \text{ E}$ and $35^\circ 00' \text{ E}$ (Fig. 1). It is the second largest wetland ecosystem in the Lake Victoria Basin (LVB) after Yala swamp ($17,500 \text{ ha}$) with an area of more than 9000 ha (Khisa et al. 2013). The altitude of the area ranges between $1,100 \text{ m}$ at the lakeshore and $1,110 \text{ m}$ above sea level on the floodplains. The floodplains are drained by several small rivers and three other ephemeral streams (Nyaidho, Awach Kano, and Asawo) that feed into the wetland. The climate of the area is classified as semi-humid with an annual mean rainfall ranging from about $1,000$ to $1,600 \text{ mm}$ which is bimodal with extremes of frequent droughts and flooding events (Ongwenyi 1983). The soils are mainly alluvium formed by large quantities of silt and sand. Black cotton soils, red sandy soils, and lateritic soils are common in the Nyakach and Kano Plains area. Sediments of lacustrine and fluvialites,

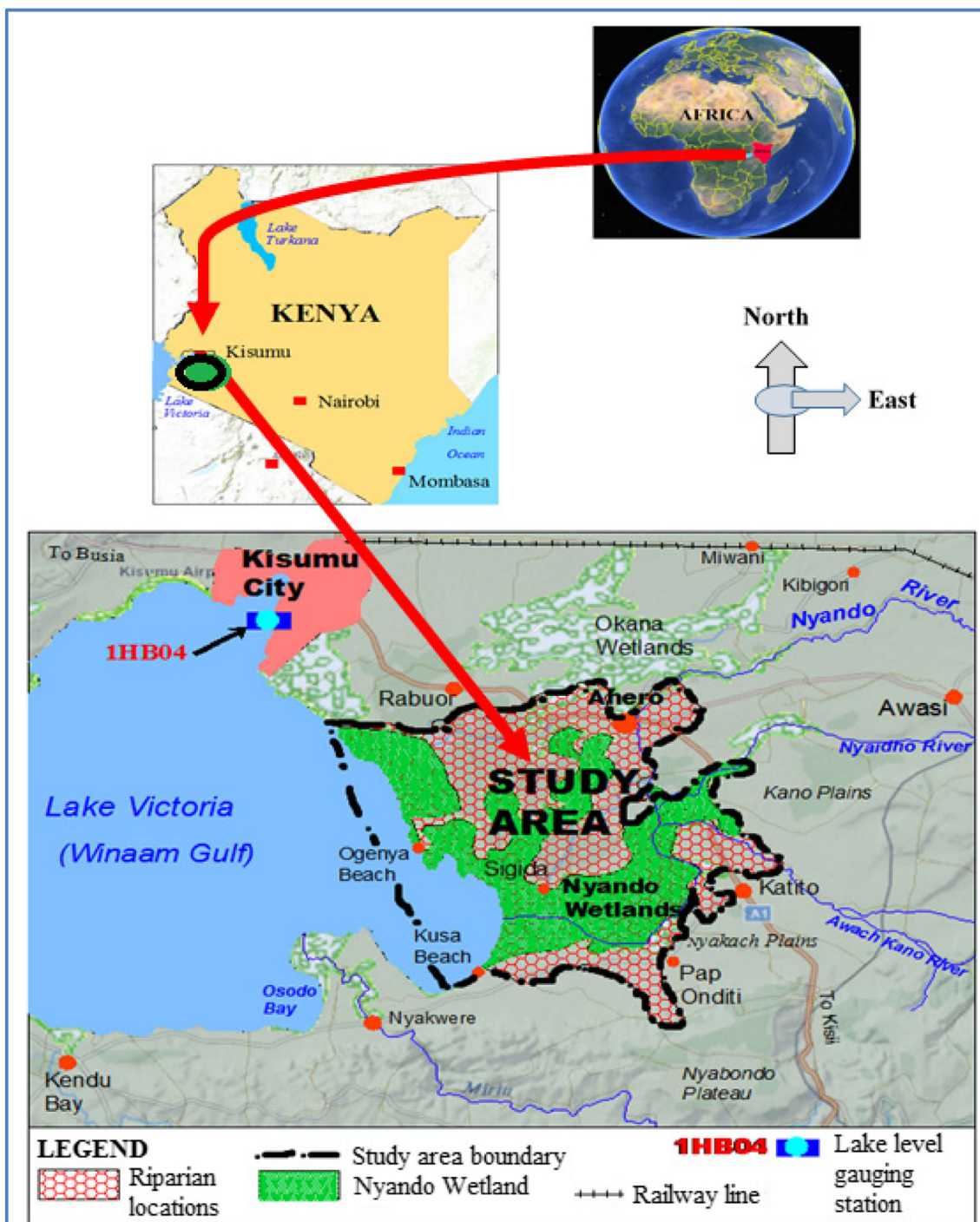


Fig. 1 Map of Africa and Kenya showing lake level gauging station (1HB04) and Nyando Wetland (Source: Modified from <https://www.arcgis.com/home/webmap/viewer.html>)

which are believed to have originated from Lake Victoria (DHV Consulting Engineers 1987), are also common in the area mainly at the edges of the wetland.

The wetland is an important ecosystem fringing Lake Victoria which like many other wetlands worldwide performs important ecological, hydrological and socio-economic functions (Obiero et al. 2012; Khisa et al. 2013; Nasongo et al.

2015). During the last three decades, this wetland and the livelihoods it supports have increasingly been threatened through encroachment by human beings besides the receding lake levels and climatic variability (Maitima et al. 2010; Obiero et al. 2012; van Dam et al. 2013). The multiple stresses the wetland has faced over time has led to the degradation and spatial and temporal loss of the area and biodiversity of this

fragile ecosystem (Davis et al. 2010). Many wetland ecosystems under such stresses sometimes become degraded past their points of resilience (WWF 2014) thus losing the potential to continue providing the much-needed goods and services. This generates increased risks and costs to human well-being, the ecosystems themselves and economies around such ecosystems.

Achieving sustainable solutions to this potentially insidious ecosystem degradation requires spatio-temporal analysis. However, the spatial and temporal dynamics of wetland ecosystems in relation to various socio-ecological stressors in the Nyando river basin have not been assessed to date. The utilization of the spatial and temporal analytical power of GIS and satellite remote sensing provide great gains towards generating data and information that could help in the understanding and management of such ecosystems. This study set out to investigate the impact of spatial and temporal variation of the Lake Victoria water levels and the associated socio-ecological stressors on the Nyando wetland ecosystem over the years to suggest effective ways of addressing the root causes of the adverse changes. The data generated will help the relevant authorities to come up with the right policies on the conservation and management of this and other similar fragile wetland ecosystems.

Materials and Methods

Study Area

The study was carried out in Nyando wetland ecosystem which covered eight administrative locations and 23 sub-locations sharing the wetland area of 25,697 ha. The administrative locations included Kawino South, Bwanda, Kakola, Kochogo, North Nyakach, Nyalunya, Pap Onditi and Kombura locations in Kisumu County of Nyanza region in western Kenya (Fig. 1).

Data Collection

Field reconnaissance study was conducted in Nyando wetlands and its surrounding areas and primary quantitative and qualitative data collected simultaneously between January and March 2010. Secondary data was obtained from published literature.

Socio-Ecological Data

The study population was estimated at 13,817 households distributed in 23 sub-locations within 9 locations in Nyando wetland (Central Bureau of Statistics 2001). A sample of 200 households was randomly selected according to Watson (2001) and interviewed using structured and semi-structured

questionnaires. The sampling transects from the edge of the wetland in each of the sub locations and traversing a “zig-zag” linear bearing away from the wetland were purposively selected. The locations of the respondents’ households were marked as waypoints (georeferenced) using a *Garmin12* Global Positioning System (GPS) with ± 3 m accuracy.

Lake Victoria Water Level Data

Changes in lake level were estimated from data generated by an existing lake level gauging station (1HBO4) (Fig. 1) installed at the shores of Lake Victoria at the Kisumu pier by the Ministry of Water, Environment and Natural Resources. The study was based on lake level data collected for 1970 to 2010, a period of 40 years. The lake level data was based on a local datum at the Kisumu pier constrained to the zero gauge at Jinja and reduced to 1122.8 m above sea level which is an orthometric height referred to an equipotential gravity plane. Monthly mean water levels were calculated and tabulated and missing data values were treated according to Garsison (2015). Extreme environmental pulses such as the “*El Nino*” or “*La Nina*” phenomena or drought and flood events that could unduly influence the distribution were identified and excluded from the analysis. The data was transposed and classified by year and month to enable frequency analysis. A sequence plot was used to visually inspect the time series to identify behavioural patterns and inform model selection. A general linear trend model was then fitted to the time series data to estimate trends. However, due to the potentially additive or multiplicative seasonality that was noted to be present in the trends, the data was further subjected to exponential smoothing using the Holt-Winters method (Goodwin 2010). The method calculated the dynamic estimates for three components which included the levels (i.e. the level that remained after deseasonalization and removal of the effects of random factors such as noise from the data set), trends (i.e. the change in the underlying level that was expected to occur between the current and next time step such as day, month or year) and seasonality (the number of months or quarters in a year considered in the analysis).

Application of Remote Sensing Tools

A multistage remote sensing methodology was used to measure changes in wetland and water area according to Lillesand et al. (2007). Coloured hardcopy images were used to locate sites that typify various observable patterns of cover types occurring in the study area. For each photomorphologic region, three sample sites were selected using a systematic random approach. The sites were georeferenced (marked as waypoints) using a *Garmin12* Global Positioning System (GPS) with ± 3 m accuracy. Features at the sample sites were observed, documented using a hand-held camera and

described. A preliminary classification system suitable for purposes of this study was created during these initial field trips and refined in later stages of the study. Information sources such as government reports, existing vegetation maps and other relevant studies were also collected at this stage to be used as ancillary data to assist in explaining the image measurements and interview data.

Three full scene satellite images were selected from path 170, row 60 with a north up orientation each with 7 bands, a spatial resolution of 30 m (Table 1) and pre-processed at source to level 1G. The selected images were downloaded as single band Geographic Tagged Image File Format (GeoTIFF), 8-bit digital files from http://landsat.usgs.gov/search_and_order_Landsat_scenes.php. One other image (1995) was secured from the Regional Centre for Mapping of Resources in Nairobi. The images used were those acquired during the dry period with less than 15 % cloud cover (December through to March) when maximum contrast among wetland vegetation, water area and other different land cover/uses could be assured (Wilde et al. 1996). The year 1984 was chosen as the base year with the two intermediate time steps to stabilize the analysis because most dates before then had very coarse resolution imagery (56 m by 79 m = 1.1 acres) which could not adequately meet the needs of the study.

A 2nd order polynomial image transformation was applied to the images to improve accuracy and re-register the images on to the Universal Transverse Mercator (UTM) projection, zone 36, south on the World Geodetic System (WGS) 84 Datum and corrected for any image displacements that could distort results of spatial measurements (Pala and Pons 1995). Twenty Ground Control Points (GCPs) were used per image to achieve a Root Mean Square error of 0.7687 m. The images were sub-setted from the full scenes to generate sub-scenes that covered the Area of Interest (AOI) only. The file values for the rectified images were recalculated to the nominal resolution for TM images of 30 m × 30 m using a bilinear interpolation algorithm (re-sampling). The method was chosen to ensure that the original image radiometry was preserved as much as possible. The de-hazing algorithm in ATCOR extension in ERDAS IMAGINE 9.2 and a crisp filter were used on

the images to remove the effect of haze, improve quality and sharpen the overall sub-scene luminance as well as feature edges without distorting the inter-band content variance. A piecewise linear stretch using a polyline transfer function was applied on the images in ERDAS IMAGINE 9.2 to increase contrast over different ranges of the image data (ERDAS Field Guide 1999).

The study also employed an unsupervised classification algorithm on the images to identify spectrally homogenous (photomorphic) groups within the image that were assigned to informational categories as suggested by Richards (1993) which yielded a total of nine classes. The products were then manually refined in a supervised classification process using a standardized number of classes derived from the most recent image and which could be consistently applied to all the images. The rules of correspondence between the spectral and the land use-land cover categories were then established and using a maximum likelihood classifier, each image was classified into five broad classes by merging classes which had strong signature similarities. This hybrid approach was adapted from Estes et al. (1983) and Fung (1992).

A total of 256 random points were generated in the classified image using a random generator to calculate the overall accuracy of the classification process. The pixels falling on the points were selected as field sample plots (2 × 2 pixels (60 m²)) according to Biging et al. 1999; Baker et al. 2007; Everitt et al. 2008; Laba et al. 2008. The sample field plots were visited, described and the groundtruth data compared with the classified images. The measures of association and accuracy were evaluated in ENVI 5.0 (Exelis Visual Information Solutions 2010). The classified images were used in both ENVI 5.0 and ArcGIS 10.1 software desktop version (Environmental Systems Research Institute, ESRI 2011) to extract estimates of areas covered by the wetland cover type (WTLA), shoreline shifts and the area exposed by the shifting shoreline.

Two variables: Wetland Area (WTLA) and Water Area (WATr) were measured for the time steps of 1984–1995, 1995–1999, and 1999–2010 to analyze spatial and temporal changes. Simple differencing change detection procedures were run on the classified images to produce maps and quantify the changes in WTLA and WATr in each time step. A table of extracted classified pixel data was created in ENVI version 5.0. A geodatabase was created incorporating feature classes of the two land-use categories from the classified images. Measures of change were calculated for each time step using simple statistical functions and also spatially rendered in maps.

Data Analysis

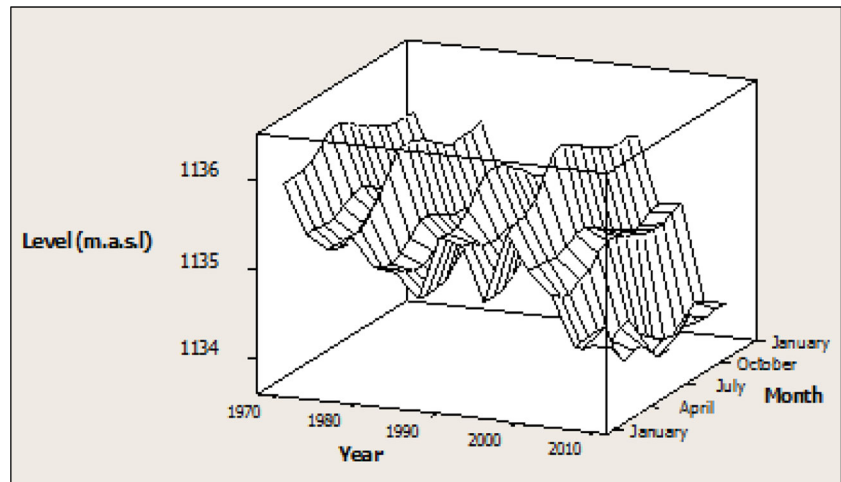
Data analysis was performed using the ERDAS IMAGINE version 9.2, ENVI version 5.0, ArcGIS 10.1, Minitab version

Table 1 Description of characteristics of image scenes of 1984, 1995, 1999 and 2010 from which the study area was clipped out

Satellite Name	Date of Image	%ge Cloud Cover	
		Scene	Sub-Scene
Thematic Mapper (TM)	Mar. 08 1984	20 %	0 %
Thematic Mapper (TM)	Mar. 01 1995	8 %	0 %
Thematic Mapper (TM)	Dec. 17 1999	9 %	0 %
Thematic Mapper (ETM)	Jan. 23 2010	15 %	0 %

Source: http://landsat.usgs.gov/search_and_order_Landsat_scenes.php, 2010

Fig. 2 A three dimensional plot showing the annual vs monthly variations in the Lake Victoria water levels at Kisumu gauging station from 1970 to 2010 (m.a.s.l)



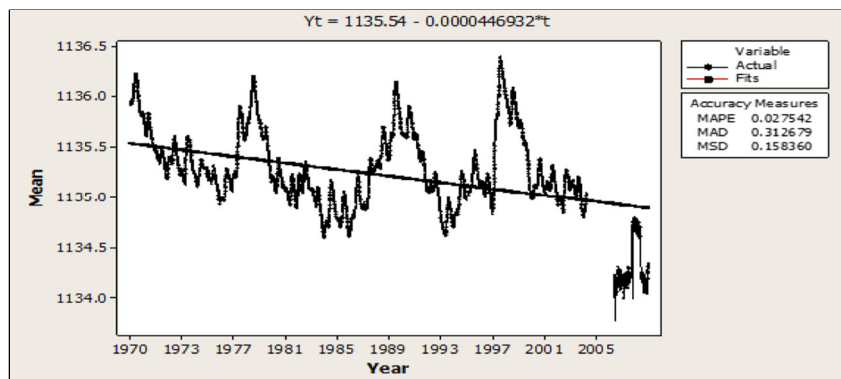
16 and Microsoft Office Excel 2007 software packages. A multivariate correlation analysis was carried out on the dataset to determine the nature of the relationship between the dependent variable (Wetland Area - WTLA) and the explanatory variables (Water Area - WATr) and the mean lake level. The data was further subject to multiple regression analysis to determine the existence of causal relationships between the dependent variable and the independent variables in time and space. Socioeconomic data was analysed using SPSS version 11.5 (SPSS Statistics for Windows, Armonk, NY: USA). Standard logistic regression was used for analysis of dichotomous and ordinal data sets.

Results

Lake Victoria Water Level Changes

Heterogeneity tests performed on seven classes of data taken on a daily basis over a 40-year period revealed that the frequency distribution of the lake level is heterogeneous. The decline in lake water level over the study period is significant ($\chi^2 = 19734.12$, $DF = 234$, $p = 0.0005$) with peak levels in June/July of each year (Fig. 2).

Fig. 3 A linear trend model of actual vs fitted trend of Lake Victoria levels at Kisumu gauging station from 1970 to 2009



The following equation represents the general linear trend model fitted to the lake level data:

$$\text{Lake Level} = 1135.54 - 0.0000446932 * \text{Year} \dots\dots\dots (1)$$

Three measures of accuracy of the fitted model (Mean Absolute Percentage Error-MAPE, Mean Absolute Deviation-MAD, and Mean Squared Deviation-MSD) calculated gave results presented in Fig. 3. An MSD value of 0.1584 was obtained. Combined fits from trend analysis and decomposition (Figs. 3 and 4) were found to be close to the actual lake level values except for the post 2005 data points which were not well fitted. Figure 4 presents dynamic estimates for the three components; seasonality, trends and levels calculated to integrate and smooth their effects on the data using Holt-Winters exponential smoothing approach.

In the analysis, the difference between observed value (y) and its corresponding fitted value (\hat{y}) indicated low residual values as presented in Fig. 5. This indicates a good model fit.

The average water levels of Lake Victoria between 1970 and 2010 were found to be 1135.21 m with the maximum level being 1136.05 m recorded in the year 1998. A minimum lake level of 1134.17 m was recorded in the year 2007. The time series exhibited a generally decadal cyclic pattern with a variance of 0.1916. The highest variations in

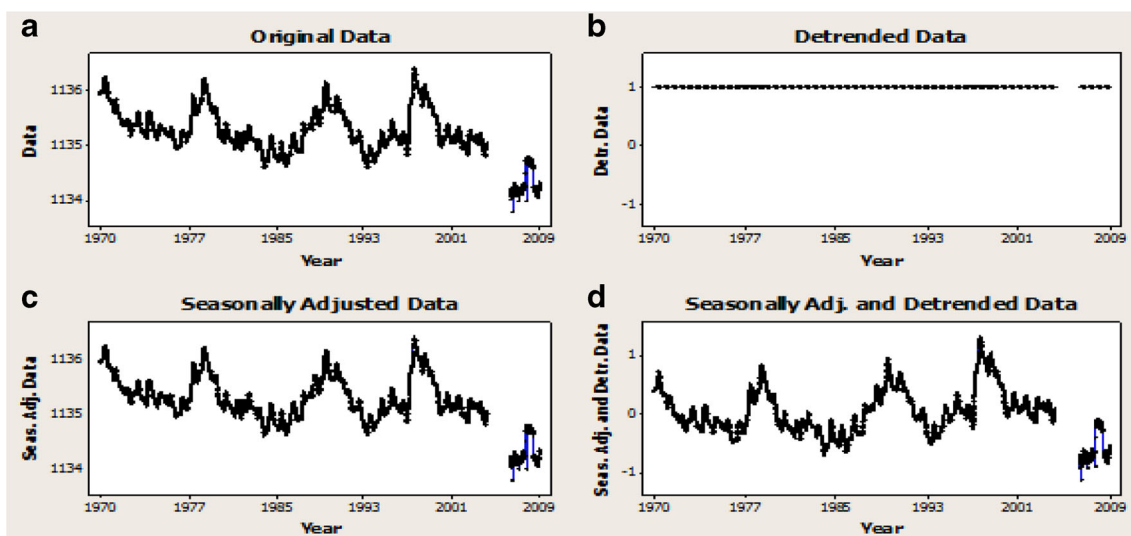


Fig. 4 Component analysis of the Lake Victoria levels (m.a.s.l) in terms of (a and b) trends and (c and d) seasonality at Kisumu gauging station from 1970 to 2009

lake levels were recorded in the year 2000 at 0.063 while lowest variation was recorded in the year 2003 at 0.003. The month with the highest variance was May (0.2407) and the least was December (0.1359) across the study period.

The highest fluctuation peaks were experienced in the months of May, June and July 1990 and 1998 when the levels rose to 1136.40 m. Such high levels were also observed in the same months in 1999. The lowest levels were recorded in months of March and October over the 39-year period. It was also observed that the first decade between 1970 and 1979 recorded the highest average lake level of 1135.48 m while the lowest average level was

experienced in the final decade of 2000 and 2009 (1134.82 m). In regard to the daily levels observed, the highest level was 1136.40 m from 30th May to 1st June, 1998 and the lowest level observed was 1133.78 m on 29th March, 2007. Consequently, the fluctuations of Lake Victoria levels were observed to have attained negative maximum amplitude of -2.62 m during the period between 1970 and 2010.

Image Classification Accuracy Assessment

The images that were classified to produce polygon maps for measuring the decline of the Wetland area (WTLA) yielded a producer’s accuracy of 90 % and a user’s accuracy of 83 %

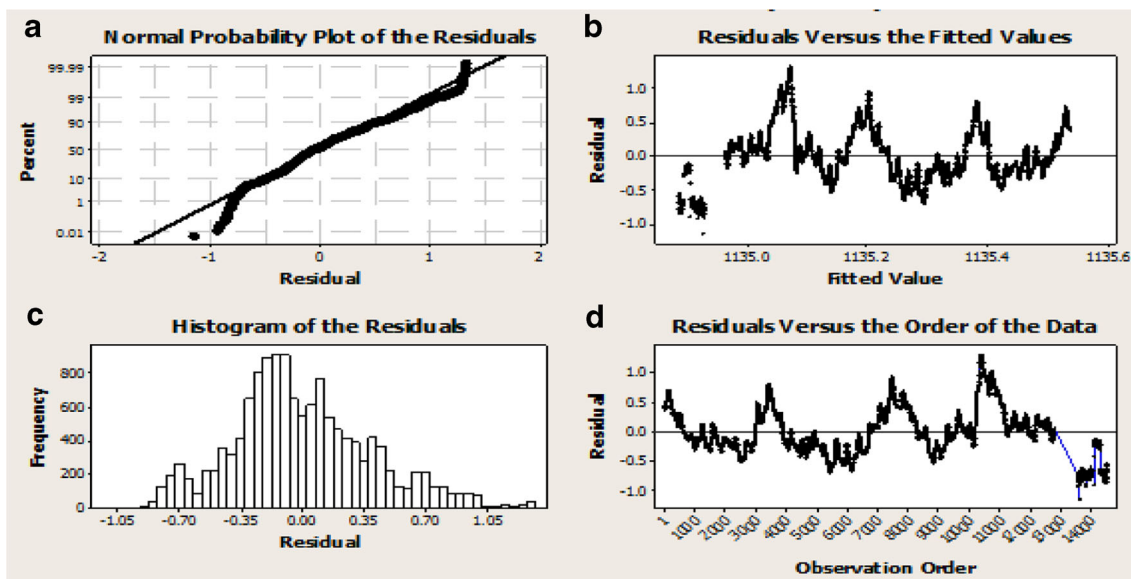


Fig. 5 Residual plots of the mean Lake Victoria levels (m.a.s.l) at Kisumu gauging station showing (a) The normal probability plot, (b)

Residual vs fitted values, (c) Histogram of residuals and (d) Residuals vs order of the data

with a conditional Kappa per category (K^{\wedge}) of 0.88. The WATr category however achieved a slightly lower producer's accuracy of 89 %, a user's accuracy of 78 % and a conditional Kappa per category (K^{\wedge}) of 0.67. The overall classification accuracy and the overall kappa statistic were 87 % and 0.86, respectively.

Shoreline Recession (WATr) and the Decline of Nyando Wetland Area (WTLA)

The Lake Victoria shoreline in the study area covered about 27 km trending in a south-easterly direction. Figure 6 shows that the shoreline has been shifting over time and space. Results indicated that the area of WATr declined consistently from 2,746 ha in 1984 to 2,448 ha in 1995 to 2,173 ha in 1999 and 1,994 ha in 2010. The receding shoreline was noted to have exposed a total of 752 ha of land at the rate of 29 ha per year between 1984 and 2010. The exposed land areas on the lake-ward side of the wetland had dried up and became arable with 73 % currently used by local communities for agricultural and livestock activities.

Figure 7 presents the spatial and temporal distribution of the changes in WTLA. The wetland area (WTLA) decreased by 10 % from 6,514 ha in 1984 to 5,582 ha in 1995. The changes which occurred during this period were especially noted in areas such as West Kano Irrigation Scheme, Ogenya and Ugwe and minimally at Siginda in Kakola Ombaka sub-locations. This lost WTLA area forms a band of about 0.2–1.0 km in width stretching inwards along the edges of the wetland. Some incursions were also noted in Wasare and Magina sub-locations' areas ranging from 0.2 to 3.3 km into the wetland (Fig. 7a). Between 1995 and 1999, the WTLA area decreased further by about 3 % from 5,582 to 5,411 ha with the highest decline rate of –118 ha per annum recorded during this period. Figure 7b shows that spatial incursions of between 0.2 and 5.5 km (measured south-easterly into the wetland) were observed in Singida (Kakola), parts of Kochogo, Magina, and Wasare in northern parts of Jimo middle sub-location. In Magina sub-location area, nearly all the wetlands had been cleared by 1999.

Results also show that between 1999 and 2010, the area covered by the wetland further declined by 17 % from 5,411 to 4,489 ha at an annual rate of change of –84 ha. This is the period when the largest loss in area was incurred in the wetland. The spatial state of the WTLA at the end of the study period in 2010 is presented in Fig. 7c. The figure shows that by the end of the study period, Nyando wetland had lost 2,025 ha of wetland area which is about 31 % of the area that it covered in 1984 (light brighter green colour in the map). The lost belt stretches 9.2 km by 1.8 km (approximately 1,600 ha) in a south-westerly direction from Magina-Wasare area to Singinda. It then extends some 7 km by 0.8 km (about 560 ha), in a north-westerly direction from Singida to the

end of west Kano irrigation scheme, along the outer edges of the wetland.

Results of multivariate correlations show that mean lake levels had a 45 % correlation with the Wetland Area (WTLA) while the Water Area (WATr) had a strong correlation of 94 % with the WTLA (Table 2). The multiple regression analysis (Table 3) found that the probability statistic (t -stat = 1.1447; p -value < 0.3162) of the Mean Lake Level is higher than the common alpha level of 0.05 at 95 % confidence level. This suggests that the Mean Lake Levels do not have a meaningful contribution to the regression model. There is, however, a significant (t -stat = 4.22; p -value < 0.02) relationship between water area, which was a proxy for the changes in lake levels.

Community Perception and Attitudes on Changes in WATr and WTLA

Fifty-eight percent of the respondents indicated that the level of Lake Victoria had reduced over the years (Fig. 8) but they were not able to associate the decline in lake level with the decline in wetland area. Thirty-one percent of the respondents indicated that the lake level had not changed but keeps moving back and forth in cyclic patterns – a phenomenon they variously refer to in local dialect as “Nger”, “Nam dar”, “Oro”, “Pi opong” “Nam dwono”, “Nam otwo,” “Nam Rumo” and “Pi odok” all of which means the same thing. Approximately eleven 11 % of the respondents were not sure.

In Fig. 9, multiple responses were given about the use of the areas left behind by the receding lake levels. The majority (86 %) of the respondents indicated that they cultivate the areas left after water has receded while only 4 % of the respondents felt that such areas are ecologically sensitive and should be left fallow.

Discussion

Lakes are vulnerable to multiple stressors because of the wide range of uses that they offer compared to other water bodies (Chidammodzi and Muhandiki 2015). Such vulnerability can also affect ecotone ecosystems that interact with them such as wetlands. This study has shown that the average lake level reduced by 1.88 m with the highest levels (1136.05 m) recorded in the year 1998 to its lowest (1134.17 m) recorded in 2007. If the period between 1970 and 2010 is considered, the decline reached maximum amplitude of 2.62 m over a 40-year-period. There were clear decadal cyclic patterns (9 to 10 years) of high and low peaks and an overall variance of 0.1916 with a generally declining gradient during the study period. Similar results were obtained by several authors (Kull 2006; LVBC 2006; Kiwango and Wolanski 2008; Ambeje et al. 2009; Omondi 2010; Adero and Kiema 2011) who found the lake's

Fig. 6 Water area and shoreline recession between 1984 and 2010 along Nyando wetland area fringing Lake Victoria

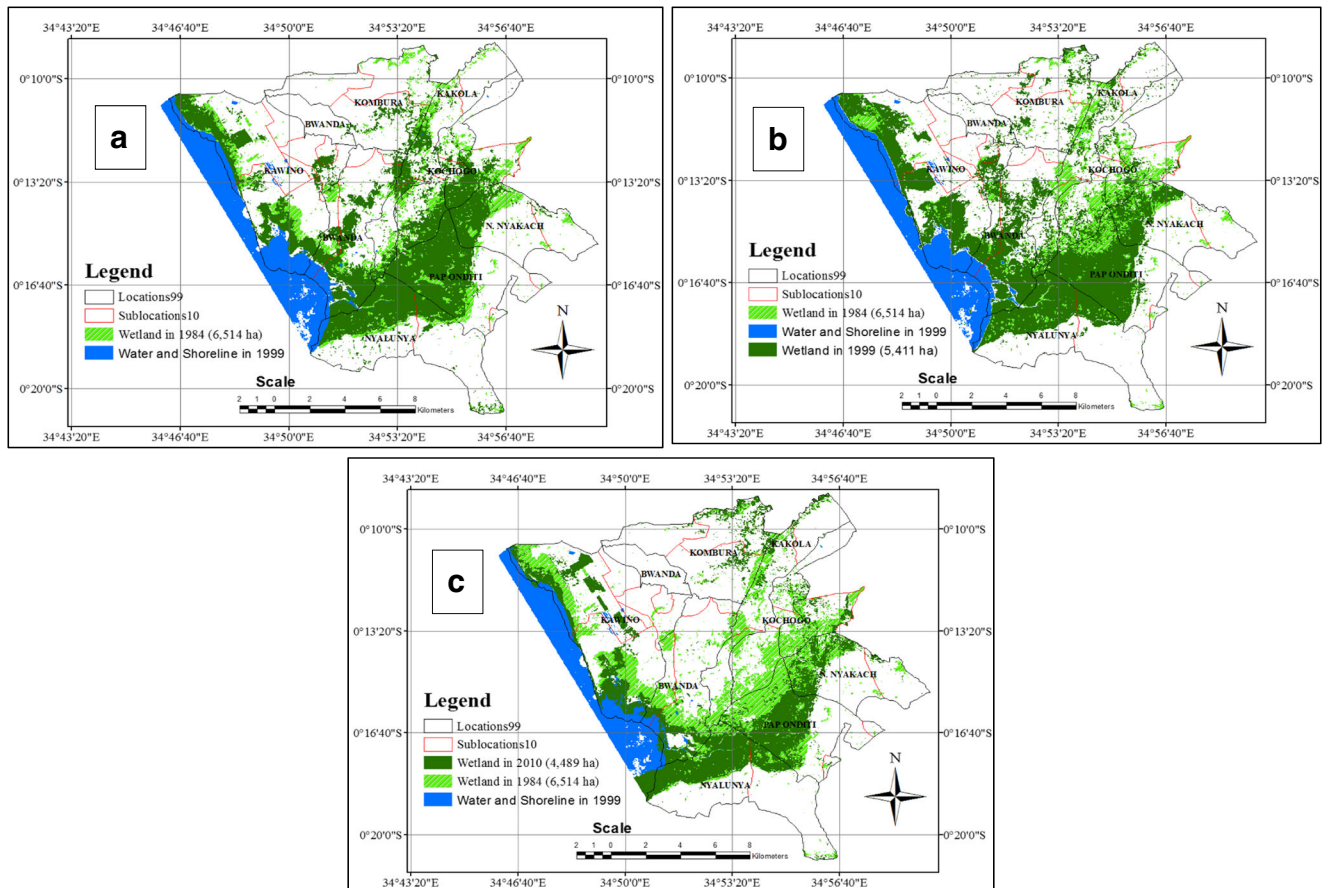
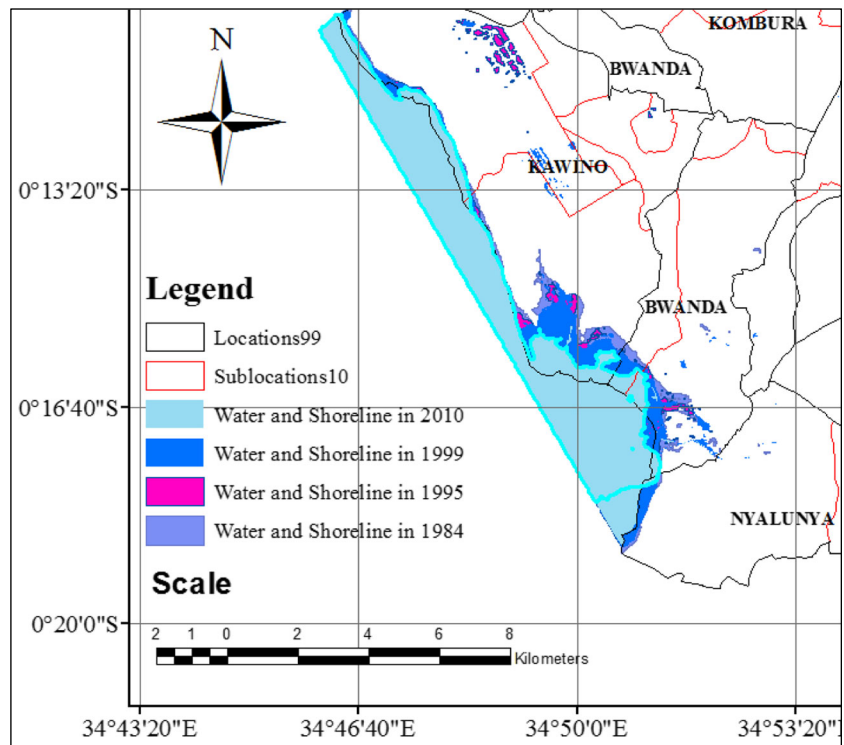


Fig. 7 Changes in area of Nyando wetland during the study period (a) 1984 state overlaid with 1995, (b) 1984 overlaid with 1999 and (c) 1984 overlaid with 2010

Table 2 Correlations between variables (water area, mean lake level and wetland area) in a multivariate relationship model in Nyando wetland during the study period

	Wetland Area (y)	Water area (x4)	Mean Lake Level(x6)
Wetland Area (WTLA) (y)	1		
Water area (WATr) (x1)	0.94	1	
Mean Lake Level(x2)	0.45	0.46	1

levels to have receded by 2.3 m between January 1998 and November 2004. This study established that while the lake's levels have been declining over the years, it remained above the long-term mean of 1135.0 m. However, abnormally low decadal peaks observed after the year 2005 distort this relatively stable cyclic pattern and suggests a sudden and significantly accelerated decline. This dramatic drop in the lake's level was also reported by Awange et al. (2008); Adero and Kiema (2011) and Khisa et al. (2013) based on the data analysed for the lake level gauging station at Jinja in Uganda. The fact that this trend is also noticeable in the analysis of data from other gauging stations such as that located at the Owen falls dam in Jinja, (Kull 2006) suggests that it is a phenomenon beyond the disturbance of the gauging station at Kisumu pier (the study site). Consequently, apart from natural events, it is postulated that human activities have also contributed to the lake level changes to a significant extent.

For instance, it is believed that the ambitious expansion programme of the Owen Falls Dam (Nalubaale) in Uganda which resulted in the dredging and widening of a hydropower bypass channel at Ruzizi after 1977 could have modified the lake level regime considerably (Adero and Kiema 2011; Khisa et al. 2013; Muvundja et al. 2014). The increased outflow for power generation is believed to have resulted in a further fall in lake levels by 0.34 m in 2001 when the lake was at its lowest of 1133.45 m above the mean sea level, only 0.47 m above the historic lowest of March 1923 (Okong'a et al. 2005). Using lake level modelling, Kull (2006) noted that the accelerated decline is 55 % explained by increased withdrawal of water for increased hydropower generation and 45 % by frequent droughts. Incidentally, the results of this study also tend to show that Nyando wetland incurred the largest loss of its area (992 ha) in the decade between the year 1999 and 2010 when the lake also recorded the lowest levels implying a close relationship with the recessions. Whether naturally or anthropogenically induced, it is a fact that the lake

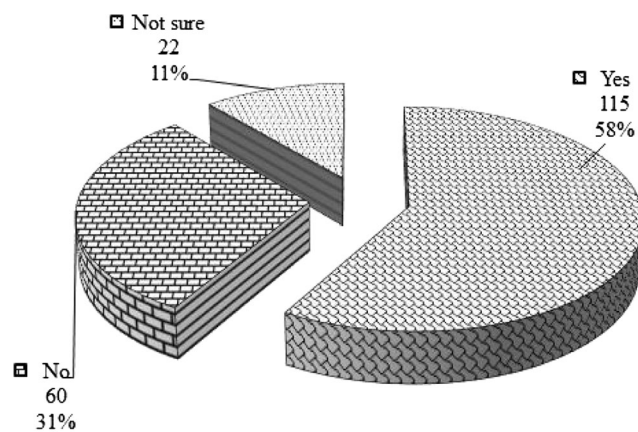
level recession affects the area of the fringing wetlands. A reduction in the area of the wetland exposes new land areas originally under the wetland conditions which induces ecosystem fragmentation and interference with ecological integrity. This study provides an indication towards this. However, a lake-wide study on the impact of lake level recession on all fringing wetlands may be a priority to avert possible future catastrophes of massive wetland ecosystem loss. Such catastrophes may arise from the loss of valuable wetland goods and services on which the livelihoods of millions of communities riparian to Lake Victoria are anchored.

Heterogeneity tests show that the continued fall, even though clearly exhibiting a decadal cyclic and bimodal pattern, cannot be explained by chance alone. For instance, Mistry and Conway (2003) found a strong correlation between the lake rainfall series and the decreasing water levels, with a temporal lag of about 1 to 2 years which could be attributed to the baseflow contributions from the lake's catchment. This may lag behind precipitation and/or local impoundment of inflow producing a lag in inflow flux to the lake (Hoerling et al. 2010). However, it is believed that a combination of factors ranging from the depressed precipitation and variability in rainfall trends, prolonged long-term and short-term droughts, and decrease in river flows to crustal movements in the Lake Victoria and its basin could be the main drivers of observed downward lake level trends.

Even though no meaningful direct relationship (p -value < 0.3162) was found in the study between the decline in water area (WATr) and the lake levels measured at the lake gauging station 1HB04 at Kisumu bay, a strong association (p -value = 0.0052)

Table 3 Multiple regression analysis between variables (water area and mean lake level on wetland area) in a Multivariate Relationship Model in Nyando Wetland during the Study Period

	Coefficients	Standard Error	t Stat	p -value
Intercept	-35740.14	330874.85	-0.11	0.92
Water area (x1)	1.97	0.47	4.22	0.02
Mean Lake Level(x2)	32.39	291.96	0.11	0.92

**Fig. 8** Community perception of lake level recession in Nyando wetland during the study period

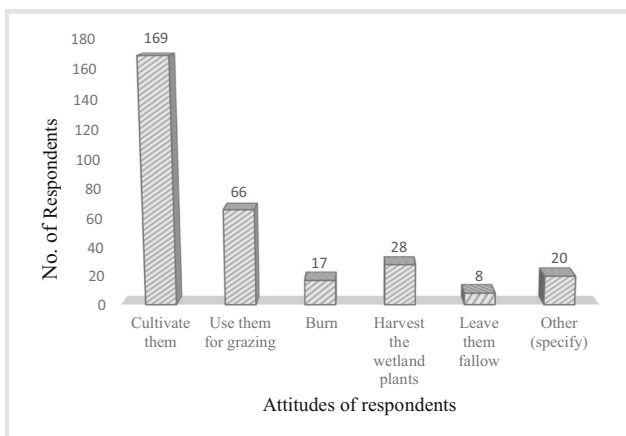


Fig. 9 Attitudes of respondents towards land left behind by receding Lake Victoria waters in the wetland area during the study period

was established between the decline in wetland area (WTLA) and the decline in WATr. While Adero and Kiema (2011) also reported on the declining lake levels, this relationship between wetland area and lake water level recession was also reported by Obiero et al. (2012), Rongoei et al. (2013) Khisa et al. (2013). This study however revealed that lake level recession is having an impact on the area of Nyando wetland and as a result, approximately 752 ha of new lands were exposed at the land/wetland interface at an annual rate of change of 29 ha/year over the 26-year period of study. The observation concurs with that of Obiero et al. (2012) which found that 1,336.3 ha of the Nyando wetland had been exposed by the receding lake level. Despite giving different figures, there is concurrence in these two studies that as the Lake Victoria water level recedes, a significant drawdown zone exists which is exposed and exploited by the local community for agricultural and other purposes detrimental to the Nyando wetland ecosystem. The magnitude of the quantitative differences however, could be explained by the differences in the time frames, the spatial extent of the area of coverage and methodologies used.

A drop in lake water level leads to a shift of the shoreline away from its original landward boundary making the littoral zones and adjacent wetland areas exposed and accessible for agricultural activities, livestock grazing and settlement (Owino and Ryan 2007; Khisa et al. 2013). It could also affect the lateral hydrological connectivity of the lake to certain parts of the wetland especially those at the outer edges due to a depressed drawdown that can result in prolonged lack of this connectivity leading to considerable loss of wetland functions in those specific areas (Boulton 2003). In this way, the wetland vegetation also loses its key ecological functions (Harper and Mavuti 2004) as they become more accessible for human clearance, animal trampling and livestock grazing (Khisa et al. 2013). Another factor linked to the lake water recession in the Nyando wetland area was a shift in mixed land use systems from subsistence to small-scale commercial economy, as intensification of agricultural crop production took

advantage of the newly exposed fertile agricultural land and ease of irrigation since the lands are closer to the source of water. This concurs with the observations of Obiero et al. (2012) and Rongoei et al. (2013). Changes in the size of Nyando wetland were therefore largely a response to the prevailing hydrological factors and anthropogenic activities.

The core management concern is the attitudes of riparian communities towards the wetland areas being exposed by the receding shoreline. Whereas a good proportion of the community members rarely see the connection between the lake level recession and loss of wetland area, a large proportion (86 %) would go ahead and cultivate the wetland areas left after water has receded. This points to the fact that the level of awareness of the fragility of wetland ecosystems is either still very low or exists but ignored probably for some livelihood reasons by the riparian community. Such a perception poses a major threat to the wetland ecosystem and may lead to over-exploitation and/or depletion of the wetland goods and services the Nyando Wetland with serious future consequences to the ecosystem and community livelihoods. This calls for a critical assessment of natural resources governance, taking into account the needs of the community and at the same time ensuring resilience, particularly against a backdrop of uncertain climate change. A wider catchment-based participatory approach that integrates technology with local knowledge (Mironga 2005; Chidammodzi and Muhandiki 2015) and a careful and pragmatic balancing of these scenarios is required to stem the decline of lake levels and human encroachment in the wetland.

Conclusions and Recommendations

The receding water levels of Lake Victoria is closely linked to the declining area of the fringing Nyando Wetland. These linkages result from both human-induced and natural factors including climate change related factors. The receding lake water levels led to a loss of wetland area and increased availability of land for farming through reclamation and conversion of exposed wetland areas into new agro-ecosystem areas. The attitudes of the riparian communities on such areas poses a great threat to fringing wetland ecosystems.

The study recommends development of programs that include environmental awareness, diversification of high quality and drought resistant food crops, and introduction of sustainable agricultural and fisheries practices in the neighbourhood of the wetland. Nyando wetland would also benefit greatly from a comprehensive participatory wetland management plan which promotes wise use and maintenance of long-term ecological integrity of the wetland ecosystem.

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