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ABSTRACT

Since 2011 the Eastern Africa Rift Valley lakes in Kenya have experienced unprecedented lake-level changes of significant proportion. Rainfall records from the Kenya Highlands are highly correlated with the increases in the Eastern African Rift Valley lakes levels that to some extent occur regularly in September following the July to September short rains that are influenced by the S.E. Trade Winds. Previous lake level records show a response to the extent of the penetration of moist air from the Congo Basin between the trade winds and the easterly winds. Undocumented historical records indicate a flooded lakes regime in 1901 and in 1963 implying that the current flooding is a result of a 50 year climatic cycle event. Mapping of the current spatial extent of the flooding in the lakes was prompted while the researcher were conducting a reconnaissance survey for the project: “Understanding the environment, promoting health in Lake Baringo and Bogoria Drainage Basin under the 5th Science, Technology and Innovations Grant on the Theme: Health, Water and Sanitation”. Documentation of the rising water levels in the four Ramsar sites was made using Geographic Information System (GIS) digital techniques and information extraction and representation from Landsat satellite image data for January 2010, May 2013 and September 2013 and October 2013. The mapping procedure and ground truth survey provided the cartographic ability to interpret and map the patterns of flooding. Lake Naivasha showed an increase in its flooded area from a low area of 107.7 Km² in January 2010 to a high of 169.9 Km² in October 2013, an increase of 62.2 Km² (57.9 % increase by area). The entire fringe of papyrus (Cyperus papyrus) and the inner fringe of yellow fever acacia (Acacia xanthophloea) around Lake Naivasha are under flood waters. Lake Nakuru showed an increase in its flooded area from a low area of 31.8 Km² in January 2010 to a high of 54.7 Km² in Sept 2013, an increase of 22.9 Km² (71.9%) affecting 60% of the transport infrastructure in the park, the tourism and the park main gate which is currently closed. Lake Bogoria lies in a deep depression and the volume of the water increase has only flooded a small area compared to the lakes mapped, increasing its flooded area from 32.6 Km² in January 2010 to 41.1 Km² in September 2013 an increase of 8.6 Km² (26.3%). Of the lakes studies the worst affected because of its geomorphic structure is Lake Baringo. Much of the riparian area of the lake is a lowland area that is largely settled and therefore a significant population size is affected with accompanying loss of agriculture and pasture land, impacts on infrastructure such as schools, dispensaries and tourist hotels. The impact of the flooding in Lake Baringo has seen the area under water rise from 143.6 Km² in January 2010 to a high of 231.6 Km² in September 2013, an increase of 88 Km² (61.3%). The changes are illustrated in the image data and digitize maps of the lakes. The detrimental effects on the ecosystem, the settlements, the infrastructure, the tourism and the biodiversity is immense as witnessed from a ground truth survey which indicated dying of acacia vegetation and no presence of flamingos in Lake Nakuru. The increase in water volumes between the months of May and September 2013 has been significantly high.
indicating that the situation will not cease soon. The effects of the increasing water volume in the Kenya Rift Valley lakes are yet to be comprehensively evaluated and documented.

**Key Words:** Lake level rise, Flooding, Ecosystem change, Biodiversity loss, infrastructure damage.

**INTRODUCTION AND BACKGROUND INFORMATION**

The terrain under study is a part of a section of the Central Kenya Rift Valley (Gregory Rift Valley - Gregory, 1896). The Rift Valley is a Cenozoic intra-continental oceanic rift system separating the Somalia Sub plate from the rest of Africa (Chorowicz, 1992; Chrorowicz 1990, Smith and Mosley, 1993; Delvaux et al., 1992) and has a linear N-S geographic (sub-meridian) trend delineated by flank faults and step escarpments. The intervening smaller faults are in places marked by low, narrow horst-graben structures (Baker et al., 1972). Baker and Mitchell (1976), Clarke et al. (1990), Bosworth et al. (1986) and Baker and Wohlenberg (1971) suggest that the main evolution of the escarpments in Central Kenya Rift Valley took place from 1.9 0.8 Ma and was followed by plateau trachyte lava emplacement. The faulting of the plateau trachytes occurred at 0.8 0.4 Ma, marking the last major tectonic episode. The Eastern Africa Rift Valley lakes in Kenya are remnants of a much larger Pleistocene lake. Lake Naivasha Pleistocene high levels is predicted to have been at about 120 m above its present lake level (Thompson and Dodson, 1963).

Lake Naivasha, Nakuru and Bogoria sit on the Aberdare Detachment System sub-basin whereas Lake Baringo is associated with Baringo-Turkana Detachment. In the study area, data relevant to determining lakes variability and especially lake level fluctuations are scarce because of lack of long instrumental climate records and the unavailability of potential of standard high-resolution proxy records such as tree rings and ice cores (Verschuren, et al., 1999). Vincent, Davies and Beresford (1979) however indicate that the rainfall records from the Kenya Highlands are highly correlated with the increases in Lake Naivasha levels in September following July to September rainfall that are influenced by the S.E. Trade winds. The level changes indicate the changes in the extent of the penetration of moist air from the Congo basin between the trade winds and the easterly winds.

The lakes considered for the mapping of spatial extent of the flood waters from the rising lake levels, first reported September 2011, are lakes Naivasha, Nakuru, Bogoria and Baringo; all listed as Ramsar sites because of their significant biodiversity. Of the four lakes, two; Lake Bogoria and Nakuru are alkaline while Lake Naivasha and Baringo are fresh-water. All the lakes have no surface outlet. They are all fluctuating tropical lake ecosystems whose sustainable management remains a pressing priority on account of impact from degraded catchment due to intensive cultivation, subsistence farming and ever expanding urban settlements (Onywere et al 2012) that influences the quality of the runoff and discharge feeding the lakes and subsequently the faunal and foral community in the lakes. Oduor and Schagerl (2007) have for example shown that the lakes’ chemical, physical and biological properties are influenced by the catchment hydrological cycle affecting the conductivity and alkalinity of the lakes with significant effect on phytoplankton population. The effects of the invasive water hyacinth present in Lake Naivasha due to high nutrient loading on the on the Physico-chemical characteristic and phytoplankton productivity has also been documented Mironga et al, 2012, Mironga et al, 2011). Previously unpublished records of the Eastern African Rift Valley lakes levels in Kenya show significant rise and flooding of the mudflats.
and the ring of acacia forest around the lakes in 1901 and 1963. The current flooding being witnessed suggest a return of a 50 year cyclic climatic event

**Climatic condition**

Data of meteorological observations from various stations indicate that the total annual rainfall averages from various stations in the study area, varies between 1000 - 1400 mm in the forested areas of the rift escarpment shoulders, and 600 mm - 800 mm in the plains of the rift floor (Table 1.1).

Table 1.1: Annual rainfall averages (in mm) calculated for twelve stations in the study area and measured in a standard rain-gauge (12.7 cm diameter and set 30 mm above the ground) - the figures are courtesy of the Kenya Meteorological Department.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>St. No.</th>
<th>Altitude (m)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Annual average Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perkerra Irrigation Scheme</td>
<td>8935163</td>
<td>1067</td>
<td>0°28’N</td>
<td>35°58’E</td>
<td>647.4</td>
</tr>
<tr>
<td>Marmanet Forest Station</td>
<td>8936023</td>
<td>2300</td>
<td>0°06’N</td>
<td>36°18’E</td>
<td>930.4</td>
</tr>
<tr>
<td>Nyandarua Agricultural Station</td>
<td>9036135</td>
<td>2378</td>
<td>0°02’S</td>
<td>36°21’E</td>
<td>979.2</td>
</tr>
<tr>
<td>Nakuru Railway Station</td>
<td>9036020</td>
<td>1851</td>
<td>0°17’S</td>
<td>36°04’E</td>
<td>874.1</td>
</tr>
<tr>
<td>Elburgon Forest Station</td>
<td>9035011</td>
<td>2378</td>
<td>0°19’S</td>
<td>35°51’E</td>
<td>1081.0</td>
</tr>
<tr>
<td>Njoro Plant Breeding Station</td>
<td>9035021</td>
<td>2165</td>
<td>0°20’S</td>
<td>35°57’E</td>
<td>938.1</td>
</tr>
<tr>
<td>Kweetu Farm, Gilgil</td>
<td>9036029</td>
<td>2348</td>
<td>0°21’S</td>
<td>36°18’E</td>
<td>1020.9</td>
</tr>
<tr>
<td>Gilgil Railway Station</td>
<td>9036034</td>
<td>2008</td>
<td>0°30’S</td>
<td>36°20’E</td>
<td>635.5</td>
</tr>
<tr>
<td>Kinangop Forest Station</td>
<td>9036025</td>
<td>2631</td>
<td>0°35’S</td>
<td>36°38’E</td>
<td>1154.6</td>
</tr>
<tr>
<td>Naivasha KCC</td>
<td>9036073</td>
<td>1936</td>
<td>0°40’S</td>
<td>36°23’E</td>
<td>631.2</td>
</tr>
<tr>
<td>Naivasha D.O.</td>
<td>9036002</td>
<td>1900</td>
<td>0°43’S</td>
<td>36°26’E</td>
<td>670.9</td>
</tr>
<tr>
<td>Kerita Forest Station</td>
<td>9036061</td>
<td>2439</td>
<td>0°59’S</td>
<td>36°38’E</td>
<td>1382.1</td>
</tr>
</tbody>
</table>

Except for local rainfall variations at the major volcanic centres, there is a general decrease of rainfall from the rift shoulder escarpments into the rift floor and from the highest part of the rift floor at Menengai, towards the south and north. A large part of the study area receives less than 700 mm annual rainfall, with Elmenteita "Badlands", Gilgil and Marigat areas receiving the least (< 500 mm). Rainfall reliability is very low in Solai, Lake Bogoria and lake Baringo areas and in the plains around Lake Naivasha and Longonot volcano.

Annual mean evaporation (1580 mm) is higher than annual mean precipitation (912 mm) for all the stations, accounting for high (73 %) losses of moisture. Daily sunshine hours are on average 8.6 hours for most of the area, making the area warm and sometimes hot throughout the year. There is a marked hot spell in January-February, when the area is dry, and the average maximum monthly temperatures are higher than in the other months, reaching monthly average of 34°C around Lake Bogoria. A cold spell is observed in the months of July and August when maximum mean temperatures are lower than in the other months. Generally, drier areas experience higher temperatures and wetter areas lower temperatures. There are, however, extreme variations with a daily range of over 14°C, sometimes resulting in frost at the highest parts of Mau, in the months of January and June.

**The Eastern African Rift Valley Lakes in Kenya**

Lake Naivasha (1886m a.s.l. ) is a Ramsar site of wetlands of international importance (Kenya 1KE002- 1995). It is located in a trough between Eburr and Olkaria/Longonot volcanic massifs
centred at 00°45'S, 036°21'E. The lake is at the highest part of the Rift Valley floor, from where the floor slopes to the south and north, attaining low altitudes at lakes Magadi (600m a.s.l) to the south, and Bogoria (985m a.s.l) to the north of the area. Lake Naivasha supports a high diversity of fauna and flora offering a rare opportunity for scientists to simultaneously study geological, climatological, hydrological, paleolimnological, evolutionary, and ecological phenomena. The lake has a fringing swamp and submerged vegetation, and a riverine floodplain at the mouth of Malewa and Gilgil Rivers. The shoreline vegetation consists of emergent plants, and floating and submerged species, which are home to hundreds of bird species. The entire wetland ecosystem has over the years been surrounded by woodland of yellow fever acacia (*Acacia xanthophloea*) and papyrus (*Cyperus papyrus*) that protected it from losses due to evaporation and that also filter the rainfall runoff entering the lake. The vegetation cover now consists of isolated groves of *Acacia xanthophloea*, and patches of papyrus at the lakeshore as a consequence of unsustainable human settlement. Lake Naivasha is on average 150 Km² with a significant population of water-birds. Her lake levels are reported to have fluctuated between 4 and 19 m over the period ~1870–1991 (Verschuren *et al.*, 2000). The drainage into Lake Naivasha is mainly through Malewa and Gilgil Rivers.

Lake Nakuru lies in a graben between Lion Hill fracture zone in the east and a series of east downthrown step-fault scarps leading to the Mau Escarpment to the west. The lake is elongate in the N-S direction in the trend of the axial rift faults and dammed to its north by Menengai caldera. It is a shallow soda lake, rich in algae, and attracts millions of flamingos, for which the lake is famous. The flamingos often migrate to other lakes because of the frequent fluctuations and drying up of the lake in response to climate variability. The lake show rapid fluctuation covering an area of between 30 – 50 Km² (Bennun and Njoroge, 1999) with the lake becoming slightly deeper in the wet seasons. During prolonged drought, its waters are greatly reduced from evaporation, and its surface increment is poor, or non-existent, due to drying up of the streams feeding the lake. In this period, the only surface increment into the lake is from sewage water from the Nakuru sewage treatment works, located just to the north of the lake. There is also a perennial supply from small springs off Lion Hill. Undocumented information indicates that in the February - April 1994 and in January 2010 period the lake nearly dried up on account of no recharge to the lake. There has also been high sediment influx into the lake through all the rivers feeding the lake.

Recharge to Lake Nakuru is mainly by direct rainfall and increments from surface runoff through Enjoro, Makalia, Larmudiac and Enderit rivers that drain the Mau escarpment. The rivers reach the lake through surface runoff only during exceptional rainfall conditions. The rest of the drainages rising from Eburru, Bahati and the rest of the Mau escarpment, carry runoff only during prolonged rainfall, but never reach the lake by means of surface recharge. These drainages are short and quickly taper off on their approach to Kiwi and Bahati plains that lie along the axis of the Rift Valley. The highly pumiceous and porous ash formations in the Mau Escarpment also lead to poor surface runoff from the escarpment. Large sections of the catchment area is under increased cultivation on the poorly consolidated soils, leading to increased soil erosion and accelerated surface runoff during the rains. Surface infiltration and percolation of water into the water table has been reduced and no longer maintain the springs that feed the rivers and the lake.

Lakes Baringo and Bogoria lie within the ASAL area in the northern part of the Central Rift Valley in Kenya and is, like the rest of the ASAL areas in Kenya characterized by low and erratic rainfall, low fertility, fragile soils with low nutrient content, low organic matter content and poor physical properties for water infiltration and storage (Muchena and van der Pouw,
Lake Baringo is centred at 00°32'N 036°05'E and is Kenya’s third largest freshwater lake. It is internationally recognized for its biodiversity (Ramsar Site no. 1159 - www.ramsar.org/). The larger part of Lake Baringo watershed is characteristic of semi-arid environment and faces many challenges among which soil erosion and water pollution ranks highest and directly affects human health. More recently there have been environmental impacts of far reaching dimension on both human and livestock health, brought about by an invasive plant species *prosopis spp.* (*Prosopis juliflora*) introduced to the area to control erosion and provide fodder for livestock, the basis of livelihood in the area. The concerns on *prosopis spp.* are on lowered water table and lack of alternative plant species for pasture in the areas that have been invaded by the plant. In addition the area is a highly fragile ecosystem with impacts on water quality from geothermal manifestation. The drainage into Lake Baringo is via Molo River which collects water from the Mau Escarpment as far south as Elburgon Forest, and is structurally controlled, following the troughs between the fault scarps or the base of the fault scarps in its flow northward. It flows through the Loboi plain into the lake. Ndoloita hot springs are also controlled by the Ndoloita fault scarp, and take its waters into the Loboi Swamp on the northern end of Lake Bogoria. From the swamp the river flows north into Ngarua swamp where it joins the Molo, into Lake Baringo, 23 km north of Lake Bogoria. Perkerra River also provides significant recharge into the lake.

Lake Bogoria (985 m a.s.l.) is a narrow soda lake lying in a trough formed between a fault-fragmented, eastward sloping Kipngatip plateau of phonolite lava to its west, and Lake Bogoria fault scarp immediately to its east. Lake Bogoria Escarpment rises to 1634 m at Sirken Hill, (750 m above the lake shoreline). The lake is replenished and sustained by a number of springs, most of which emerge along the N-S fissures at the shores of the lake (Onywere, 2005). Some of the springs are hot and boiling. Emsoss warm spring flows in from the south through fissures in the Emsoss Escarpment. The larger part of the Bogoria drainage area, 1075.5 km2, is occupied by Waseges river. The lake waters are highly saline and contain sodium carbonate, chloride and fluoride. There is a supply of low saline waters from the hot springs due to solution of alkaline igneous rocks and recirculation of groundwater by the hot springs. Mahon (1972) and Burgess (1986) suggest a possibility of an influx, to the subsurface, of deep geothermal waters underlying an extensive area of the Rift Valley. This could be a source of water contamination in the area.

**METHODOLOGY AND DATA ACQUISITION**


Image enhancement and digital image analysis were performed using ERDAS (Earth Resources Data Analysis System) software applied to Landsat Thematic mapper images. Digital image enhancement, directional edge enhancement (derivative) and convolution filtering, were performed on the image data. These methods of image processing were particularly suitable in delineating linear features and land use boundaries which were
digitized to design the GIS data on the ArcGIS Platform and that also facilitated computation of the area under water.

Full scenes (scene 169/060) of Landsat TM digital data for January 2010 (when the lowest levels of the lakes were reported) December 2010, May 2013 and September 2013 (when the study was being made and the highest water levels reported) were sourced for the study. Various band combinations were made to derive false colour composite products from where visual interpretation and delineation of the lake boundaries was made. Road infrastructure vector products from archived data were then overlaid on the images products to determine the impact of the flooding on the infrastructure.

Field work involved two separate trips one to Lake Baringo and Bogoria area in the beginning of September 2013 and the other to Lake Nakuru and Naivasha at the end of September 2013. The ground truth survey was for support observations and data gathering and involved documents the areas and infrastructure affected by the flooding.

RESULTS AND DISCUSSION

Recent events in the Rift Valley in Kenya and at least since the September 2010 rains have seen a consistent and increased recharge into all the Rift Valley lakes. The lake levels rise is unprecedented with an event of similar magnitude being observed in 1963. Historical records also indicate a flooded lakes environment in 1901. Remote sensing images for January 2010 (dry season), December 2010, May 2013 and September 2013 show a drastic increase in water volume of the lakes. An attempt is made here to illustrate the extent of the flooding but the effects of the increasing water volume on the lake ecology, the biodiversity, the tourism industry, the infrastructure and the community in the Rift Valley lakes are yet to be comprehensively evaluated and documented.

The extent of the flooding in four (4) lakes mapped and that are also Ramsar sites (Lake Naivasha, Nakuru, Bogoria and Baringo) is evaluated using time series Landsat satellite imagery and ground truth survey. The increase in water volume has been significantly high and the input from the rivers recharging the lakes has been consistent, indicating that the flooded situation will not cease soon. The flooding has had immense and detrimental effects on the ecosystem, the settlements, the infrastructure and the biodiversity.

Lake Naivasha

Mapping of the most recent level of Lake Naivasha utilized Landsat image of October 2013. The image of September was obscured by a cloud cover. The lake show increasing water levels since the short rains of September 2010 as seen in a significant lake level increase in Dec. 2010. The lake increased its surface area from a low area of 107.7 Km² in January 2010 to a high of 169.9 Km² in Oct. 2013, an increase of 62.2 Km² (57.8% increase by area). The extent of the flooded area and the impacts are illustrated in the image data and digitize maps (Figure 1 and 2). Thus 62.2 Km² is flooded submerging all the area ringed by papyrus vegetation.

The increased recharge of the lake is from Malewa and Gilgil rivers draining the Kinangop escarpment. At the low water level in January 2010, the Small Lake (Lake Oloidien) had developed alkalinity that allowed a large population of flamingos to inhabit it. By March 2011 the lake level rose to an extent that the main Lake Naivasha and the Small Lake connected on
the southern part of the topographic feature separating them. Significant impact on lake biodiversity then, included reported cases of dead tilapia floating on the main Lake Naivasha after the alkaline water intruded. The flamingos have since migrated from the Small Lake. The raised water level dislodged any loosely anchored papyrus along with water hyacinth and salvinia molesta that is now scattered all over the lake. The submergence has significantly affected the acacia and the papyrus ring around the lake and therefore associated biodiversity.

Figure 1: Lake Naivasha low level in Jan. 2010. Note the emergent land in the Crescent Island.
Hotels and camping facilities previously constructed close to the lakeshore have all been submerged significantly affecting tourism. In January 2010 the Crescent Island had all been reduced to a crater lake but the true crescent shape has re-emerged after the flooding. Accessibility and crossing to the Island is now only by boat. The flood water is likely to remain for some time and thus pose new challenges that now require preparedness and monitoring of the following key areas:

- Loss of biodiversity e.g. loss of papyrus and acacia and along with other vegetation due to submergence and its implication on the ecosystem.
- Infrastructure damage and its implication on the tourist industry
- Health risk from possible malaria epidemic
- Health risk from rift valley fever
- Health risk from waterborne diseases
- Contamination of groundwater in nearby boreholes
- Decreased and/or loss of tourism potential and income/revenue – a key concern of KWS

Lake Nakuru

Lake Nakuru has shown increasing water levels since the short rains of September 2010 and was the first of the rift valley lakes to burst its bank. The lake increased its surface area from a low area of 31.8 Km² in January 2010 to a high of 54.7 Km² in Sept 2013, an increase of 22.9 Km² (71.92% increase by area). The extent of the flooded area and the impacts are illustrated in the image data and digitize maps (Figure 3, 4 and 5).
Figure 3: Lake Nakuru lowest level in Jan. 2010. Note the familiar shape and the biodiversity of the lake.

Figure 4: Lake Nakuru high level in Sept 2013. Note the submerged infrastructure.
The increased recharge of the lake is from Enjoro, Makalia, Larmidiak, and Enderit Rivers and has led to dilution of the lake water thus decreasing its salinity (alkalinity). The low salinity and siltation has led to loss of algae on which the flamingos feed causing them to migrate. All flamingos have left the lake, initially settling in the Lake Oloidien (Small Lake – Naivasha) and lake Bogoria. There is change in aquatic life and biodiversity with increased presence of birds of the duck family. Most of the length of the inner circuit road around the lake is submerged and therefore destroyed. The loss of, and damage to road infrastructure is making it increasingly difficult and dangerous for tourists to access the park. The destruction of development infrastructure including the office facilities at the main gate from flooding is evident. Loss of biodiversity e.g. loss of acacia trees and other vegetation due to submergence and/or from introduction of saline water from the rising level of the lake is an area of concern. There is need to put in place a procedure and actions to document and monitor the changing ecology of the lake and its effect on biodiversity and regeneration of vegetation to adapt to the changing conditions. As in Lake Naivasha the flood water is likely to remain for some time and thus pose the same challenges that now require preparedness and monitoring.

**Lake Bogoria**

Lake Bogoria lies in a deep depression and the volume of the water increase has only flooded a small area compared to the other three lakes. It has increased its area from 32.6 Km² in January 2010 to 41.1 Km² in Sept. 2013 an increase of 8.6 Km² (26.32% increase by area). The changes are illustrated in the image data and digitize maps (Figure 6 and 7).
Figure 6: Lake Bogoria Lowest level in Jan. 2010. Note the familiar shape of the lake.

Figure 7: Lake Bogoria time series extent (over 8.6 Km² is currently under flood waters).
The increased recharge of the lake is from River Waseges, now reaching the lake directly through surface recharge leading to siltation and dilution of the lake water thus decreasing its salinity. The low salinity and siltation has led to loss of algae especially on the northern side of the lake leading to lack of food for the flamingos. The depth of the lake has increased compromising its ability to support any wading birds such as flamingos. The flamingos present have flocked the banks of the lake. This poses another risk at the birds most of which are caught amongst the thorn trees as they fly off.

The flood waters have displaced the Jemps community living along the northern shore of the lake within the River Waseges Flood plain. The flood waters have affected the quality of the geysers located on the western side of the southern half of the lake. Most of the length of the inner circuit road around the lake is submerged and therefore destroyed and impassable.

**Lake Baringo**

Of the 4 lakes studies the most affected is Lake Baringo both from the point of view of the size of the human population affected and the loss of infrastructure such as schools, settlements, dispensaries and the size of the area under water. Much of the area surrounding the lake is a lowland area that is largely settled up to the lake shoreline. The impact of the flooding in Lake Baringo has seen the area under water rise from 143.6 Km² in January 2010 to a high of 231.6 Km² in Sept. 2013, an increase of 88 Km² (61.3% increase by area). In December 2010 the lake level had risen by 28.8 Km². The changes are illustrated in the image data and digitize maps (Figures 8, 9 and 10).

![Figure 8: Lake Baringo lowest level in Jan. 2010. Note the familiar shape & biodiversity of the lake](image-url)
Figure 9: Lake Baringo Extent of flooding by Sept. 2013 the impacts. Note the changed shape of the lake.

Figure 10: Lake Bogoria time series extent (over 88 Km² is currently under flood waters).
The increased recharge of Lake Baringo is from mainly Molo and Perkerra Rivers, now both reaching the lake directly through surface recharge and bringing in a large amount of sediments load. The spread of the flood waters have seen villages like Salabani, Logumukum, Loiminange, Ngamboni, Nosoguro and Loruk and Kokwe submerged displacing the communities living in those areas along with their livestock. There is an accompanied loss of cultivated land especially the irrigated areas within the flooded areas. At least 6 Schools in the villages listed above along with Health Centres are submerged. All the Hotels and Lodges located at Kambi Samaki, notably Soy Lodge, Lake Baringo Lodge and Roberts Camps are submerged.

2 islands have emerged as the flood waters fill the grabens marking the fault blocks on the northern side of the lake while Ol-Kokwe and the other regular islands on the lake have considerably shrunken in size due to the raise lake levels. The fish in the lake has spread far and wide within the flooded areas and villagers are fishing from within the flood plains. The crocodiles in the lake are now not confined to the lake but are now coming out to the flood areas. The snake that infest the Lake Baringo area have migrated to dryer areas increasing the risk of snake bite. Increased amount of floating mats of water weeds (Nile Cabbage) are seen as islands in the lake and now are the main undergrowth in the flooded areas. Loss of biodiversity e.g. loss of acacia and other vegetation due to submergence. Prosopis juliflora (Mathenge) has prolifically increased in its growth, limiting accessibility to many areas and also posing a risk to injury from the flood buried thorns. In addition to monitoring the challenges faced in Lake Naivasha, other areas that require attention are:

- Risk from snake bites
- Risk from crocodile attacks
- Risk from contaminated lake waters that is largely consumed directly by the community
- Water borne diseases such as Bilharzia (schistosomiasis) and intestinal worms
- Change in biodiversity of the area
- Loss of agricultural and grazing land – issues of land tenure
- Internal displacements of communities and livestock

Within the lake Baringo area, increase in human population and livestock numbers over the years has caused pressure on the available natural land resources, including vegetation, soils and water. This has resulted in past as well as current land degradation processes of different types and magnitude. The dynamics of population and livestock pressure when considered in the light of the changing land tenure as a result of the changing lifestyle of the inhabitants from pastoralism to sedentary or accommodation of agro-pastoralism practices has increased the vulnerability of the communities to the current flood risk.

The current flooding events in the rift valley lakes are not new. The Rift Valley lakes have had a history of fluctuations which have been recorded since 1860 (Richardson, 1966). In general, as indicated by Richardson and Richardson (1972), there has been an overall fall in the water level since 1917. The annual rainfall and evaporation figures from meteorological station around the lake, although fluctuating over the years and showing significantly low volumes in the ten year drought cycle, reveal no overall decrease or increase in precipitation. Yet, in recent years the lake Naivasha and Nakuru in particular have shown significant drops during prolonged droughts, especially in the year immediately following the ten year drought cycle of 1965, 1976, 1984 and 1993, and 2010 when most rainfall stations in the study area recorded less than 700 mm of total annual rainfall. In 1994, and 2010 for example, following the drought of 1993, and 2009 respectively there was a significant drop in the lake levels of all Aberdare Detachment lakes,
except Lake Bogoria. In these two periods, the entire crater rim of the Crescent Island in Lake Naivasha, whose eastern section is always under water, was exposed. Large sections of both Lake Naivasha and Nakuru lake bed were exposed, with the resulting changes causing significant ecological imbalance in the lake and affecting their normal ecological vitality and the fishing industry in Lake Naivasha. The flamingo populations in Lake Nakuru, Elementeita and Bogoria were also significantly reduced and attributed to various cause among them migration and mass mortality.

Ballot et al (2004) in their study of the cause of the frequent mass mortalities of Lesser Flamingos (*Phoeniconaias minor*) in Lakes Bogoria, Nakuru and Elmenteita, have linked the causes to presence of cyanobacterial blooms and mats. These are as sources of potent toxins in *Arthrospira*, the main diet of the Lesser Flamingo. The invasion of potentially toxic species of cyanobacteria is thought to be influenced by physicochemical conditions in the lakes determined by the condition of the input into the lakes from the watershed.

Verschuren, et al. (2000) used paleolimnological techniques to document the dynamics of benthic invertebrate community inhabiting a shallow fluctuating Lake Naivasha in Kenya and show that in the period ~1870–1991 the lake depth fluctuated between 4 and 19 m, and lake-water conductivity between ~250 and 14000μS/cm. The fluctuations also reflected the recorded sediment texture, plant macrofossils, and fossil diatom assemblages which in the past developed in response to lake level, salinity, and papyrus-swamp development.

**RECOMMENDATION**

The current lake level rise represents an opportunity for scientist to study *in-situ* ecological changes taking place as a result of the increased water volumes and the flooding of the riparian areas of the lakes from the raised water levels. The rise in the lake levels for example is bound to have affected the salinity (alkalinity) of the soda lakes. Verschuren, et al. (2000) for example considers salinity as the dominant environmental factor regulating aquatic community structure in the hydrologically closed lake Naivasha and wetland. There is need for monitoring and documenting the faunal and floral community response to the changed hydrological balance and its linkages to the physiological effect of reduced salinity or as a result of habitat restructuring that will accompany the changes in lake level and lowered salinity.

The raised lake levels and subsequent flooding of the riparian areas of the lakes could be attributed to the 50 year climatic cycle that was witnessed in 1963 and in 1901. This possibility can be assessed by studying the present and past climatic records from the weather stations in the watersheds of the lakes. The flood water is likely to remain for some time and thus pose new challenges that require preparedness and attention by a number of stakeholders among them:

1. NACOSTI (Research, Science, Technology and Innovation)
2. KWS (Kenya Wildlife Services - wildlife biodiversity and tourism, wildlife conflicts)
3. KMD (Kenya Meteorological Department - Rainfall and climatic impacts – rainfall data)
4. KFS, KEFRI (Kenya Forestry Research Institute - biodiversity, forestry resources)
5. KEMFRI (Kenya Marine and Fisheries Research Institute - Marine and lake fisheries and biodiversity)
6. NMK (National Museums of Kenya - Biodiversity, small animals, invertebrates, archives)
7. WRMA (Water Resources Management Authority - River discharge, water quality and abstraction)
8. UNDP (United Nations Development programme)
9. DSSR (Department of Diseases surveillance and Response)
10. DRMD and NDOC—Disaster Risk Management Department and Nationla Disaster Operation centre Ministry of Interior and Internal Security
11. Baringo County Government(Baringo/Bogoria, Chief Warden, Chair Environment Committee, Speaker of County assembly, Governor, Education Dept.) – Human population displacements, infrastructure damage
12. Lake Nakuru National Park
13. Lake Bogoria National Park
14. Hell’s Gate National park
15. Neglected Tropical Diseases (NTDs) (emerging diseases – malaria water borne, yellow fever, Schistosomiasis
16. DRSRS Department of Resources Survey and Remote sensing
17. NEMA – National Environmental management Authority – Riparian zone regulation against settlement and infrastructure development

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REFERENCES


