Assessment of Impacts of Climate Change on Hydro-meteorological Ecosystem Services and Water Stress in Lake Kyoga Catchment

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Abstract: Through a review of several studies on climate change, an attempt was made to investigate the sensitivity of water resources to climate change over Lake Kyoga catchment. Climate change is predicted to increase the frequency of climatic extremes that can lead to loss of life and property. This study was mainly to analyze the water stress arising from the impacts of climate change on hydro-meteorological ecosystem services. The methodology of the study consists of an analysis of available meteorological and hydrological observations, analysis of Global Weather Data for ArcGIS/SWAT output data and finally the seasonal performance of precipitation and temperature using Climate Predictability Tool outputs.

The Correlation Percentage change was used to estimate the rate of change of flow and water levels under a changing climate. The outputs for different stations showed that climate change has already affected water resources in Lake Kyoga catchment with continuous reduction in water levels of 6%. The results of the study revealed that climate change is likely to increase precipitation by 10-20% received during the wet seasons resulting in higher stream flow and a reduction of 20-40% of precipitation during the dry seasons. The GCMs also demonstrated an increase in maximum and minimum temperatures of 1 to 3°C by 2065 with minimum temperatures increasing more rapidly compared to the maximum temperatures for the two scenarios (RCP4.5 and RCP8.5). The strategies for adaptation and mitigation measures have been identified.

Keywords: Climate extreme, Water stress, CPT, ArcGIS/SWAT Kyoga Basin, and Hydrological simulation.

I. INTRODUCTION

Climate is expected to continue to change in the future in spite of being many uncertainties, which will affect natural and human systems such as forestry, fisheries, water resources, and human health (IPCC, 2001). Scientists around the world now agree that the climatic changes occurring internationally are the result of human activity. Although responsibility for the causes of climate change rests primarily with the developed and industrialized nations, the costs of climate change will be borne most directly by the poor. This is for a number of main reasons, including but not limited to the following:

(i) Many of the region most likely to be adversely affected fall in the developing world; (ii) The poor are disproportionately dependent on occupations, such as farming, that are adversely affected by climate change; and

(iii) Because the poor have very limited resources, they do not have the ability to adapt to climate change in the way that wealthier households can. In particular, changes to water quality, quantity and availability will be an impact of ongoing climate change in many areas. (Ruddiman 2001)

Water Scarcity

Water is not only an essential part of life but also a fascinating element on earth. It’s the prime medium through which climate change is likely to affect ecosystems and economies (Sadoff & Muller 2009). According to the IPCC AR5, Climate Change is manifested through changes in the climate mean properties e.g. Global Mean Surface Temperatures (GMST) have certainly increased since the late 19th century. The warm periods have persisted and the past three decades have been warmer than all the previous decades due to natural or anthropogenic changes in the composition of the atmosphere or in land use (IPCC 2013). The global climate change impacts water resources, ecosystems and that its impact will consist largely of shifts in altitudinal and latitudinal distributions, and extinction of some living species (James 2008).
Water scarcity threatens food security, increase Tensions within and between nations sharing water resources, North African countries are most in danger of experiencing desiccation due to their large projected reductions in rainfall (Eliot et al. 2016).

In 2015 about 370 million people live in the Nile Basin countries, of which about 200 million live in the catchment area. By 2030, these numbers are expected to rise to 600 million people and 400 million respectively. Thus, it is of the utmost importance to know whether there will be more or less water in the Nile, especially as parts of the Nile Basin already experience high water stress and scarcity. (Terje Oestigaard 2016)

**Temperature Increase**

A general linear trend shows an increase in global average land and ocean temperatures of 0.89°C [0.691.08] over the period 1901–2012 and about 0.72°C [0.49-0.89] over the period 1951–2012 (IPCC 2013). This has been influenced by different factors such as ozone depletion, atmospheric aerosols, and the El Nino phenomenon (IPCC 2001). Surface temps will vary depending on natural pressures (e.g., volcanic eruptions) and anthropogenic pressures in the form of CO2 and CH4 (IPCC 2013).

In Africa average annual temperatures have been rising steadily the mean temperature anomalies over Northern Hemisphere Africa, is similar to the series for the whole of Africa. Over the period 1979–2010, there is a significant (to the 1% level) upward linear trend noted with an estimate of 0.18°C decade⁻¹ based on the results of the regression. The temporal series of the annual mean temperature anomalies over Southern Hemisphere Africa shared some of the similarities of the other two African series described above. The results from the OLS regression show a trend also with an estimate of 0.11°C decade⁻¹ significant to the 10% level. (Collins et al.2009)

During the 20th century the continent experienced an increase in temperatures of about 0.5°C. Future warming will be greatest over the interior of semi-arid margins of the Sahara and central southern Africa (Eriksen et al. 2011). Rainfall has increased by 0.2 to 0.3% per decade over the tropical zone (10°N to 10°S) with a decrease over the Northern Hemisphere sub-tropical zone (10°N to 30°N) during the 20th century by about 0.3% per decade (IPCC 2001).

**Changing Rainfall Patterns**

Due to increases in precipitation, annual average river runoff and water availability are projected to increase by 10-40% during the mid-century in some wet tropical areas and at high latitudes, and decrease by 10-30% over some dry regions (Parry, 2007). The changing rainfall patterns and temperature increases will affect availability, supply and demand for water at river basin and watershed levels by altering in uncertain ways the prospects for more drought and or floods (Frederick & Major 1997).

Climate change is most likely to affect more developing countries due to high poverty levels, limited financial capacity, great dependence on rain fed agriculture and lack of awareness to adapt to global change. The change in rainfall and river flow patterns will affect all water users’ especially those who depend on rain fed agriculture as the crop water requirements will increase due to temperature increase thus making most communities vulnerable (Orindi & Eriksen 2005).

Uganda as a developing country dependent on agriculture, is vulnerable to climate change since the agricultural sector is the largest consumer of water resources, and variability in water supply has a big effect on health and welfare in poor areas (NAPA 2007).

Forests and fresh water resources are increasingly threatened due to rapid population growth across the globe thus leading to a series of chain reactions to the ecosystem (MWE 2010b). With the rapid population increase, sectors more dependent on water and environment especially agriculture, tourism, energy and health are at high risk if the water resources are not well managed. This is due to increase in temperatures leading to high evaporation rates thus affecting water availability, rainfall uncertainty, variability and or shift in seasons. (NAPA 2007)

**Climate Change**

Climate variability has had significant socio-economic impacts in Uganda in the past with floods in 1961/62, 97/98 and in 2007 which left widespread infrastructure damage, displacement and destruction of livelihood (Eriksen et al. 2011). In the 93/94 event, droughts affected a significant number of people (1.8 million)

**Representative Concentration Pathways (RCPs)**

Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014.

It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse
gases are emitted in the years to come. (IPCC - Fifth Assessment Report (AR5) in 2014).

Adaptation and Mitigation

Therefore there is need to develop informed and effective adaptation and mitigation measures that can be taken now to alleviate adverse impacts of global change in the future. Many studies according to UN-Water show increased uncertainty in weather and climate predictions and this influences our strategies related to adaptation and mitigation to a changing climate through hydrologic and climatologic scientific point of view, as well as those of decision and policy makers (UN-Water 2012).

Climate change is likely to increase the frequency and intensity of extreme weather events such as floods, landslides, droughts and heat waves. Frequency of droughts has already increased in Uganda: for example, seven droughts were experienced between 1991 and 2000 alone. A catastrophic landslide occurred in Bududa in March 2010. The intensity and frequency of heavy rains, floods and landslides in the highland areas, as well as outbreaks of associated waterborne diseases with the floods, has also increased (UNDP 2010).

Therefore due to these impacts, there is need for adequate institutional capacity strengthening and policy framework to address climate change impacts through mitigation and adaptation strategies within the River Basin management Plan (RBMP) to tackle the possible hydrological vulnerabilities. This is because RBM recognizes the drainage basin as the logical management unit for integrated land and water. Therefore coordinating conservation, management and development of water, land and related resources across sectors within a given river basin is possible with a view of maximizing economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems (MWE 2013b). The overall goal of this study was to determine the water stress arising from the impacts of climate change on hydro meteorological ecosystem, identify adaptation measures which can help alleviate water stress using the ArcGIS/SWAT and CPT models. This report have investigated the impacts of climate change and variability on Hydrological Services of River Malaba, and Kapiri one of the sub basins of Lake Kyoga in Uganda. It has examined the consequences of climate change on the social, economic, political and environmental aspects, adaptation and mitigation measures to water resources management and test the homogeneity of stage data with spatial data.

II. STUDY AREA

Lake Kyoga drainage sub-basin is part of the upper Nile River basin system formed by 10 districts, it is about 1,720 km² (660 sq mi) in area. Lake Kyoga is part of the Great Lakes system; it is not itself considered a great lake. The Victoria Nile flows through this lake on its way from Lake Victoria to L. Albert. Uganda (NEMA). The Lake Kyoga has a surface area of 2636km², with a mean elevation of 1034m above sea level (amsl). Its maximum depth is 10.7m, mean depth is 3m with a total volume of 7.9km³ (UNWDR 2005).

![Figure 1 - Showing Lake Kyoga catchment](image)

III. DATA AND METHODS

Introduction

This chapter illustrates different procedural steps carried out for the research to achieve the objectives using different methods such as Climate Predictability Tool (CPT) model for climate satellite data collection, processing and analysis. Different approaches like ArcGIS tool was applied to determine the role of meteorological parameters such as (Temperature and Rainfall) in climate change and the impact to Hydrological ecosystem services in Lake Kyoga catchment. The present situation and future expectations have been identified in the next chapter.
Impact of climate change was assessed from different literature with key emphasis on areas that depend directly on the hydrological cycle like water resources, agriculture, energy and environment. The aim of the study was to understand the impact of climate change on water cycle leading to water stress and future projection scenarios for target year of 2030 and 2055 against the baseline period of 1959-2016 based on IPCC AR5 scenarios (RCP4.5 and RCP8.5). The findings were used to streamline the water resource management policies to address socio-economic, environmental and institutional impacts by mainstreaming and integrating climate change adaptation measures in river basin management.

Data and Materials

Data collection and pre-processing are the most important steps in conducting research on hydrological Processes in a catchment. Here daily temperatures for Malaba and Kapiri Basins (Tmin and Tmax from 1950 - 2016), daily point rainfall from different gauging stations and flow observations from 1950-2016 was obtained from Uganda National Meteorological Authority and Directorate of Water Resources Management respectively. Global Precipitation Climatological Project (GPCP) satellite rainfall data was obtained at a site at 0.50 N and 34.50 E representing the center of the catchment. This was done to supplement the rainfall observations since only three rainfall gauging station was available in the catchment and with limited data. Assessments of climate change require long-term climate data, historical data for Rainfall and temperature which was collected from Uganda National Meteorological Authority.

Discharge and water levels

Correlation Percentage Change (CPC): Percentage change of average monthly water levels and flow in the time period 1948-2016 with base line period from 1948-1982.

\[
\text{\%change} = \frac{\text{Avg}(y) - \text{avg}(x)}{\text{Avg}(x)} \times 100
\]  

(1)

Where:

X: Average monthly water level or flow (1948-1982),  
Y: Average monthly water level or flow (1983-2016)

Representative Concentration Pathways (RCPs)

The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radioactive forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively). In this research three greenhouse gasses (CO2, N2O, and CH4) were analyzed to determine the rate of concentration of greenhouse gasses leading to climate change processes. (IPCC- Fifth Assessment Report (AR5) in 2014).

Autoregressive model (ARM) illustration

This method was used to fill missing gaps in the data set. Autoregressive is a stochastic process used in statistical calculations in which future values are estimated based on a weighted sum of past values. An autoregressive process operates under the premise that past values have an effect on current values; in statistical analysis is a model that uses time series data to predict future trends with the help of the following formulae.

\[
\hat{y}_t = m + \Phi_1(y_{t-1} - m) + \varepsilon,
\]  

(2)

\[
\varepsilon = \text{Nom-Inv}(\text{Rand}(\cdot), 0, \sigma_\varepsilon).
\]  

(3)

\[
\sigma_\varepsilon^2 = s^2(1 - \Gamma_1^2),
\]  

(4)

\[
(\hat{y}_t) = m^* + r_1(Y_{t-1} - m^*) + \varepsilon,
\]  

(5)

Where \( Y_t \) = generated value.

IV. RESULTS AND DISCUSSIONS

Climatology

Rainfall is the main source of water over the Lake Kyoga drainage sub-basin. An analysis of the climatic conditions over entire Uganda for the period 1981–2010 is given in this section. Figure 2 shows seasonal rain performance derived from Climatic Predictability Tool (CPT) the meteorological stations and associated observed time series that were used in the analysis including the associated rainfall characteristics for DJF, JJA, MAM and SOND as illustrated on maps below.
From the analysis using CPT it was observed that there is reduction in rainfall performance that have affected flow in rivers contributed much impact to hydrological ecosystem in the region.

**Water Levels analysis**

![Lake Kyoga Water Levels](image)

Figure 2 – Fluctuations of water level in Lake Kyoga basin.

From the analysis Lake Kyoga showed a decrease of 6% in 34 years (April, August, October, December) though some extreme change was identified in Feb, June and September as trends shows bellow (Figure 2 (a, b))

![Percentage change in water levels over Lake Kyoga basin](image)

Figure 2(a) - Percentage change in water levels over Lake Kyoga basin.

![Performance of wet seasons in Lake Kyoga water levels](image)

Figure 3(a) - Performance of wet seasons in Lake Kyoga water levels.
and nitrous oxide (N2O) in 2014 exceed the range of concentrations recorded in ice cores during the past 800,000 years.

Recent studies suggest that anthropogenic greenhouse gas (GHG) increases are likely responsible for increasing temperature (Crowley 2000). This is evident from the increasing GHG concentrations in the atmosphere, positive radiative forcing, and observed warming with a clear indication of human influence (IPCC 2013). According to AR5, the high GHG emissions are due fossil fuel combustion, cement production, deforestation and land use changes. Cumulative anthropogenic CO2 emissions have accumulated in the atmosphere and natural terrestrial ecosystems and also taken up by the seas and oceans. In 2011, annual CO2 emissions from fossil fuel combustion and cement production were 54% above the 1990 level (IPCC 2013).

According to the UN Climate Change secretariat (UNCCS), emissions/removals of six gases namely Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6) were addressed from five sectors in Uganda (UNCCS 1994). The study showed that methane had the highest percentage of GHG emissions of up to 64.15% as in Figure 7. This is an indication that human activity was among the contributors of the emissions are GHGs with 60% of the global methane as a result of anthropogenic activity (EPA 2014).

**Representative Concentration Pathways (RCP)**

Greenhouse gas analysis were analysed (Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O)) and found increase of gasses emissions with time as elaborated in figure 6a,b bellow.

**Causes of Climate Change Emission of Main GHG in Uganda**

According to AR5 (IPCC 2013) concentrations of the atmospheric GHGs carbon dioxide (CO2), methane (CH4)
In this study three major greenhouse gases were analysed: Carbon Dioxide (CO2), Methane (CH4), and Nitrous Oxide (N2O). All forcing agents' atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to four RCPs. As evidence from observations and from simple to complex models for many scenarios, peak warming is approximately proportional to cumulative (total) emissions. Cumulative total anthropogenic CO2 emissions from 1870 (GtCO2) Cumulative carbon determines warming.

Temperature: There is a large magnitude of observed warming in Uganda, especially since mid-19th century with the mean annual temperatures having increased by 1.3°C since 1960, at average rate of 0.28°C per decade. (MWE 2010b) and (USAID 2012).

According to IPCC 2013, it is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale (IPCC 2013). This has been observed in Uganda too. From 1950 to 2008 an increasing trend in temperature has been observed with the mean minimum temperatures increasing faster than the mean maximum temperatures as in Figure 8. The implication of these observations is that the day and night temperatures are becoming warmer (Mubiru et al. 2012).

V. CONCLUSION AND RECOMMENDATION

Conclusion: Anthropogenic activities have contributed to changing patterns of extreme weather across the globe, ranging from longer and hotter heat waves to heavier and erratic rains. These events are all anticipated to be as a result of climate change. (Gervais.F. 2014). While climate variability and change continue to impact as more extreme events are anticipated to occur as a result of increased temperatures and change in rainfall intensities, both extremes will have an impact on the river flows as erratic and heavy rains will lead to more floods, soil erosion among others and a reduction results into prolonged droughts/ water scarcity. As more understanding of how climate change will affect extreme weather is still developing, it’s more likely that extreme weather may be affected even more than anticipated as the extremes are on the rise an indication that they will continue both in predictable and unpredictable ways.

There is need to assess vulnerabilities and identify more adaptation and mitigation measures that will reduce the consequences of extremes. As climate change continues to affect communities, it’s crucial to identify effective and cost efficient management plans to cab the possible outcomes. Therefore catchment management approach is key as it identifies the drainage basin as the logical management unit for integrated land and water use.

Recommendation: Improvement of meteorological data collection and analysis through Strengthening Meteorological Services.
In the past, local climate was predictable with minimal annual and seasonal variations particularly the onset and cessation of rains. Therefore climate predictions could be based on relatively few climate-observing stations. However due to the high uncertainty associated to climate change and variability, sufficient and reliable data is vital for research to increase knowledge and awareness about climate change. This is through strengthening meteorological stations as studies on climate change would be based on more reliable information thus better forecast of climate extremes and trends. This would ensure better preparedness to disasters associated to climate change to the vulnerable communities and more reliable information would facilitate better functioning of early warning systems.

**Improvement of agricultural land use practices and farm support service enhancement**

This can be achieved by training more rural agricultural extension workers with the aim of deepening knowledge of indigenous people on agricultural and land use best practices in order to cope with the changing environment as a way of adaptation, and halt or reverse land degradation in climate change vulnerable and resource constrained communities. This can be through:

- Promoting agroforestry as a method of soil conservation.
- Promoting crop diversification and introduction of disease resist varieties.
- Developing and promoting the growth of suitable high value trees especially those that can produce edible fruits as a mechanism of food security.
- Promoting of small scale irrigation schemes to reduce on the shock of droughts as most communities are poor and require cheaper systems.
- Promotion of post-harvest handling, value addition and marketing infrastructure.

**Research development and capacity-building**

Government and other partners need to support research especially at river basin scale. This will enable a clear understanding of the catchment thus being able to disseminate reliable information at the right time.

**Proper management approaches and institutional reforms**

- Policy support, technical assistance and funds should be given to people who are undertaking their own mitigation measures in the areas of building small-scale energy systems, engagement with emissions trading, biodiversity conservation among others as a way of promoting environmental conservation.
- Prepare flood mitigation and prevention plans in the context of the entire river basin.
- Enhancing adaptive capacities for vulnerable communities in drought prone areas especially those in the arid and semiarid cattle corridor zone to cope with the increasingly frequent droughts. This is to enable them not only to be prepared for seasons when rains fail, but also to mitigate the effect of droughts. This can be through developing and promoting appropriate rainwater harvesting technologies, water storage facilities, and pasture production among others.
- Need for an independent policy that addresses climate change as a key issue in order to abate emissions GHGs.

Results of climate change assessment are highly dependent on the input data and uncertainty of the models. Thus, further study in the area with updated data and a variety of models is required. In addition, possible adaptation options to the impacts on the basin must also be studied in the future research.

A complete study should also take into consideration integrating other factors such as anticipated developments in agriculture, industry and population growth in the basin, and the parallel impacts of climate in these sectors.

**VI. ACKNOWLEDGEMENTS**

We would like to thank anonymous reviewers from IJRE who helped us to improve the quality of this paper. The data used in this study was provided by Directorate of Applied meteorology Data & Climate Services (DADCS) and Directorate of Water Resources Management (DWRM).

**VII. DECLARATION**

All authors have disclosed no conflicts of interest. The project was internally funded by Uganda National Meteorological Authority.

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