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Assessing impacts of climate change on Lake Victoria Basin, Africa

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The Nile River is mainly sourced by the Lake Victoria basin catchment. Potable water is vital in this region. Greenhouse gases induced climate change is believed to affect the water resources system leading to alteration in planning and management. Previous studies had been carried out in focus on the pollution, fisheries, wetland of the Lake Victoria basin, while limited research in view of the effects of climate change on hydrological regime. In view of the importance of water in that region, assessing the potential climate change impacts is necessary. Factors such as downscaling of climate scenarios obtain from general circulation models and climate scenarios should be taken into consideration.

Introduction

The Nile River - the longest river in the world - has been serving as a source of life to the people living in its basin for centuries. Throughout the course of history, the Nile has supported livelihoods and played a considerable role in enriching diverse cultures within its basin. Hence, the Nile has been the centre of attention of explorers, tourists, researchers and historians for many years. The Nile traverses almost 6,700 kilometres from the remotest head stream – the Ruvyironza River in Burundi- northwards through ten different countries and out to the Mediterranean Sea. The Nile river basin extends over a wide area of more than 3,349,000 sq km, covering latitudes from 4oS to 32oN (Sutcliffe & Parks, 1999). It serves an estimated of 160 million people within the boundaries of its basin and approximately 300 million living within the ten countries dependent on its waters.

Lake Victoria is one of the main water sources of the Nile River . The basin of this lake is situated in the east of Africa and is known for its importance as a source of potable water and in supplying water for irrigation and hydropower generation for the surrounding countries. The basin has drawn attention of many researchers due to its significance by nature. At present, the basin is facing considerable challenges such as the increase in the demand for fresh water due to the rapid growth of population and the changes in its flow regime. Other challenges are political instability and poverty of the surrounding nations as well as environmental degradation and frequent natural disasters. The current research works on Lake Victoria basin have focused on the pollution of the Lake Victoria due to human activities (Mwanuzi et al. 2003, Kishe and Machiwa, 2003 etc.), fisheries and biodiversities of lake (Goudswaard et al. 2002, Geheb and Crean, 2003) and wetland management (Kassenga, 1997). However, there are only a few research studies exploring the impacts of climate change on the hydrological regime of Lake Victoria basin. Climate change issues have been a concern for water planners throughout the world (Sene et al., 2001). Climate change causes changes in rainfall, runoff and evaporation, which in turn affect the water availability and variability worldwide.

Climate change

In the last decades, 'climate change' has attracted the attention of the public as well as researchers in different fields ranging from physical science, engineering, to social science and politics. Signs of the impacts of climate change observed around the world include the increase in surface temperature, sea-level rise, changes in precipitation and decreased in snow cover (IPCC, 2001). The chain effect of these impacts would likely bring in issues such as human health, shortage of water supply, biodiversity and ecosystem. Literature on climate change impacts has grown considerably especially in the area of vulnerabilities of ecological systems (e.g. Lal et al., 1998, Jones et al., 1994; Aspinall & Matthews, 1994) and human systems (e.g. Gall et al., 1992; McMichael, 1995; Martens et al., 1995). Arnell (1996) noted that the increasing amount of papers published in several key journals illustrates that the focus and interest are drawn to the study of effects of climate change on hydrological regimes and water resources.

The term "Climate change" principally refers to any change in climate over time, whether due to natural causes or as a result of human activities (IPCC, 2001a). However, it is widely accepted that the term 'climate change' is equivalent to 'global warming'. However, global warming is essentially a special type of climate change (Arnell, 1996).

The Earth goes through a natural greenhouse effect as part of its usual energy balance. The result of natural greenhouse is that it keeps the Earth surface temperature at a relatively higher temperature of 14oC rather than at the freezing tem-

perature of –19oC when there is no the greenhouse effect . The greenhouse effect takes place when the atmosphere of the Earth behaves in a similar fashion to the glass walls and the roof of a greenhouse in trapping heat received from the Sun. Similar to the greenhouse, it is largely transparent to solar radiation, but it strongly absorbs the longer wavelength radiation from the ground. Heat is trapped in the atmosphere through the greenhouse gases which consists of water vapour, carbon dioxide, methane and nitrous oxide. Global warming is the overall increase of heat on the Earth surface due to the increase in the concentrations of the greenhouse gases in the atmosphere which reduce the ability of the heat of the Earth surface to escape to space. Strong evidence was found that most of the warming observed over the last 50 years is attributable to human activities (IPCC, 2001). Human activities such as the usage of fossil fuels, changes in land use (e.g. deforestation), agriculture and industrial activities contribute to the emissions of greenhouse gasses thereby increasing the concentration of greenhouse gases in the atmosphere. IPCC (2001) reported that the surface temperature of the Earth has increased by 0.6+0.2oC over the 20th century with the 1990's likely to the warmest decade and 1998 the warmest year since the instrumental record. In the present paper, the term 'climate change' is used to refer to the resulting climatic conditions under greenhouse forcing.

The climate system affects all aspects of the hydrologic cycle. A change in the climate is likely to affect water supplies and demands as well as ecosystems. A severe change in climate may cause migration of population (Environmental refugees), which would alter the demand and supply of water and pose significant social, economical and political problems. In view of hydrology, precipitation and evaporation will be affected directly by climatic change (Liu & Woo, 1996). A warmer temperature accelerates the hydrologic cycle which in turn alter precipitation amounts, magnitude and timing of runoff as well as intensity and frequency of floods and droughts. Higher temperatures would increase the energy available for evaporations which would alter soil moisture and infiltration rates. With all those changes above, river flows and groundwater recharge would be altered, which then affect the catchment water balance. The assessment of the likely impacts of future global warming on water resources system is crucial for the sustainable management of water resources. The study of the impacts of climate change also helps to provide scientific information to enhance public awareness and form a sound base for political decisions to be made on the mitigation of the impacts global warming.

Climate change impact assessment studies are concerned with the estimations of what might happen under specified climate change scenarios and with the comparison of the results of these scenarios with conditions that might be expected in the absence of climate change (Arnell, 1996). In the climate change assessment, a baseline is used to represent the current conditions with which climate change information is usually combined to create a future climate scenario. The baseline also serves as the reference period for the model to calculate the future change in climate when climate model results are used to construct scenario (IPCC, 2001).

Hydrological background

Lake Victoria basin is one of the eight major sub-basins identified within the Nile Basin (Conway, 1993), the others sub-basins are Equatorial Lakes, Sudd, Bahr el Ghazal, Sobat, Central Sudan, Blue Nile and Atbara. Lake Victoria has a surface area of approximately 67,000 km2 which constitutes a large proportion of its basin. The total area Lake Victoria basin is 190,000 km2 (see Figure 1) and extends over areas in Uganda, Kenya, Tanzania, Burundi, Rwanda and a small part of Congo. The mean water depth in the lake is only 40m and the maximum depth is 92m (Nicholson, 1998). Lake Victoria is considered to be the second largest fresh water body in the world after Lake Superior in North America. Lake Victoria receives inflow from 17 tributaries contributing only about 13 percent of the water entering the lake while the rest is by rainfall (Nicholson, 1998). The White Nile is the only outflow of Lake Victoria exiting the lake at Jinja, in Uganda (north of lake). From Jinja, it flows through Lakes Kyoga, then Mobutu Sese Seko (Albert) before crossing into Sudan. Near Khatroum (Capital of Sudan), the While Nile merges with the Blue Nile, which drains the Ethiopian highlands, to form the main Nile River. The Nile flows through Sudan and Egypt until it reaches the Mediterranean Sea .

Most of the region around the Lake can be classified as arid or semi-arid (Nicholson, 1998; Yin & Nicholson, 1998). However, the areas around the Lake Victoria have a relatively high mean annual rainfall of 1200-1600mm (Nicholson, 1998; Yin & Nicholson, 1999). The precipitation has a bimodal seasonal distribution with peaks occurring during March-May and November-December (Conway, 1993). Lake Victoria has a unique diurnal circulation system, which is, the enhanced rainfall over lake as a result of a strong nocturnal land breeze (Yin & Nicholson, 1998). This diurnal circulation system plays an essential role in understanding
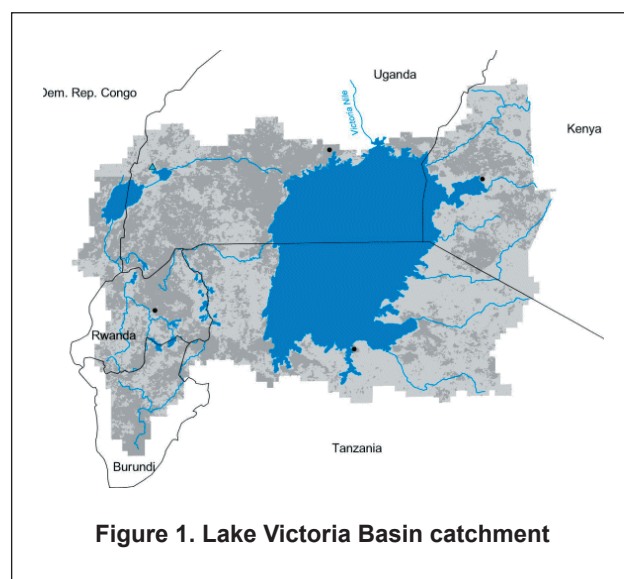

Figure 1. Lake Victoria Basin catchment

the water balance of the lake. The circulation produces a strong convergence of flow directly over the lake at night. This takes place because the water of lake is warmer than the air, cumulonimbus clusters produced by lake breeze and thunderstorms developed over the centre of the lake. The nocturnal rainfall due to the easterly winds, is found on Victoria's north and west shores which is found evident in the rainfall data from stations over or near the lake (Yin et al. 2000). Most of the rainfall occurs at night and generally associated with strong thunderstorms (Yin & Nicholson, 1998; Yin et al. 2000).

Water balance model of Lake Victoria

Yin and Nicholson (1998) developed a simple water balance for Lake Victoria expressing the balance between its inputs and outputs. This model is given by :

$$\Delta H = P_w + \text{Inflow} - (E_w + \text{Outflow}) \tag{1}$$

where ΔH is a change in lake level, while the inputs to the lake are the lake rainfall (P_w) and inflow from the 17 tributaries, and the outputs are the lake evaporation (E_w) and the outflow via the White Nile at Jinga.

Several methods for calculating the mean areal rainfall estimations over area were used such as the traditional Thiessen Polygon (Conway, 1993). In some studies the mean areal rainfall obtained by the traditional methods is weighted by a factor derived from a satellite analysis of rainfall over the lake and over land area of the basin (Yin & Nicholson, 1998). The calculated annual inflow varies between 199 mm and 539 mm with a mean value of 343 mm over 23 years with a standard deviation of 106mm (Yin & Nicholson, 1998). The outflow of the Lake Victoria at Jinja is most probably "the most accurately known component of Lake Victoria's water balance" (Yin & Nicholson, 1998) as it holds records of discharge for more than a century. The Owen Falls Dam constructed in 1954 has regulated the discharge since 1956. However, the flow of the dam has been maintained in such a way to retain the original lake level/discharge relationship (i.e. rating curve) described as a regression equation.

Evaporation of Lake Victoria would make a particular sensitive indicator for climate change (Nicholson, 1998) as 90 percent of its water input is lost by evaporation. Yin and Nicholson (1998) noted that the only direct method of calculating evaporation is eddy correlation. However, the approach is found to have technical difficulties, hence to estimate evaporation over a lake surface Yin and Nicholson (1998) use the energy balance and Penman's combined energy-budget mass-transfer approach. These methods depend on the calculations of the radiation balance and heat transfer terms over the lake, which requires multitude of input data including cloudiness and wind speed over the lake, surface water temperature and surface vapour pressure of the air. Yin and Nicholson (1998) estimated the evaporation term in the above equation using the energy balance method. They found that these evaporations estimates are in a good

agreement with other published values of evaporation from Lake Victoria. They also found that the mean of estimated evaporation from the lake, varies between 1370 to 1600 mm. These evaporation estimates show that the mean annual evaporation is more or less equal to annual rainfall in the Lake which is very interesting when assessing the impacts of climate change.

Fluctuations of lake levels

Lake Victoria faced abrupt level fluctuations and anomalous hydrological behaviour. The variability of the Lake affects the Nile flow. Hence, changes in the lake water balance would have far reaching significant consequences in terms of their affects on the downstream countries dependent on the Nile water, namely, Sudan and Egypt. Nicholson (1998) studied the historical fluctuations of Lake Victoria since 1800 (see Figure 2). The figure shows that the lake levels were low during the early 19th century, with peak levels occurring the late 1870s, then declined to the 20th century levels. The decline briefly ceased by the occurrence of high levels in the early 1890s. Lake levels were low during the 20th century. It is worth noting that the low lake levels causes drought to the local people not only in the immediate vicinity of Lake Victoria basin but along the stretch of Nile River, resulting in people migrations (Nicholson, 1998). Lake levels rose significantly in 1961 to 1962, and continue to be high until now. Mistry and Conway (2003) investigated the climatological factors responsible for the rise in the lake level. It was found that there is a significant correlation between the Lake rainfall series and the Lake levels. It was also noted that there is a time lag of 1 to 2 years between rainfall episodes and the water level peaks of the lake. Since the rainfall series are based on land-based observation, and the Lake itself is roughly one quarter of the whole basin, the lake level variability is partially explained by the over-lake rainfall.

Climate change impact assessment

In a climate change impact assessment, climate scenarios are used to provide quantitative assessments of climate impacts. Climate scenarios are defined as possible representation
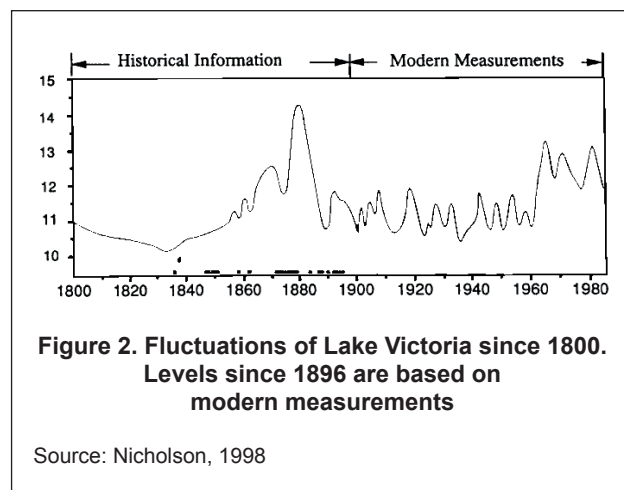

Figure 2. Fluctuations of Lake Victoria since 1800. Levels since 1896 are based on modern measurements

Source: Nicholson, 1998

of future climate which have been developed to be used exclusively in conjunction with investigating the potential impacts of anthropogenic climate change (IPCC, 2001). These scenarios take into account both human-induced climate change as well as natural climate variability. It is most common to develop climate change scenarios results from General Circulation Models (GCMs). General Circulation Models include complex atmosphere and ocean models – Atmospheric General Circulation Models (AGCM) and Ocean General Circulation Models (OGCMs). GCMs are currently the most advanced tools available for simulating the response of the global climate system to changing atmospheric composition (IPCC, 2001). In general, the GCM is a numerical representation of the atmosphere and its phenomena over the entire Earth and it incorporates a variety of fluid-dynamical, chemical or even biological equations. These equations used in the GCMs are highly non-linear, and are solved numerically. GCMs allow experiments to be done to investigate the response of the global climate to changes in the atmospheric concentrations of greenhouse gases. Most GCM models run on a grid (pixel) network such as the Cartesian grid-point, which allows experiments to be run at a variety of horizontal and vertical resolutions. The GCM is run using different climate change scenarios and produces outputs, which enable the determination of the likely changes in precipitation, temperature and runoff as a result of these scenarios taking place.

Factors to consider in climate change impact assessment

It is vital to assess climate change impacts on the hydrological regime and present information on the nature of future streamflow at Lake Victoria basin basin under greenhouse climatic conditions. There are several which would affect the outcome of the assessment. The following are some of the factors that worth noting while assessing impact of climate change in the Lake Victoria basin.

1. Streamflows as surrogates: Streamflows are usually used as surrogates rather than rainfall (precipitation) in a climate change impact assessment, as it is easier to detect climate change in runoff than precipitation since changes in precipitation are usually amplified in runoff (Chiew and McMahon, 1996). Furthermore, stream flow data may be perceived as representing the integrated effects of the spatial variability of precipitation within the catchment. Therefore, the streamflow data may provide as much information as precipitation time series derived from several rainfall stations in the catchment (Chiew & McMahon, 1996). Furthermore, the runoff directly influences the management of land and water resources that makes the study important.

2. Downscaling: The output from GCMs simulates the present climate well with respect to annual or seasonal averages at large spatial scales, that is, a spatial resolution orders of 2.5o latitude (250km) and 3.75o longitude

(350km). However, in assessing climate change impact on hydrological regime, using the raw GCMs output is widely regarded as inappropriate due to the mismatch in spatial scale (e.g. Arnell, 1996; Russo & Zack, 1997; Robock et al., 1993). Another mismatch is the temporal resolutions, the hydrological models and usually operates at daily or hourly time scale, even though GCMs does run as a time scale as short as 15 minutes, there is little confidence in the predictions especially for variables such as rainfall for time scales shorter than 1 month (Prudhomme et al., 2002) due to the coarse spatial resolution. GCM is also noted to be unreliable at individual and sub-grid box scales (Wilby et al., 1999). Hence in assessing the climate impacts of Lake Victoria basin, downscaling approaches should be adopted. Downscaling is a mean of relating large scale atmospheric predictor variables to local- or station- scale meteorological series (Semenov & Barrow, 1997).

3. Various climate scenarios. The climate change impact assessment may vary due to the usage of different scenarios obtained from different GCMs. The projected scenarios may indicate different level of impacts on the catchment, as the difference between scenarios has the tendency to be magnified in hydrological systems (Arnell, 1996). In Australia, Schreider et al. (2000) estimated the potential flood damage using the results of climate climate change scenarios obtained from two sources. The results revealed that simulation using scenarios prepared by a GCM showed minor changes to urban flood damage; while simulation using scenarios prepared by a Stochastic Weather Generator indicated that will lead to significant increases in building damage. Therefore, future studies should adopt scenarios from various climate models that consider different variables and parameters. Hence, future studies on the impact assessment of climate change for Lake Victoria should include various climate scenarios with different assumptions and emissions patterns in order to allow better grasp of the possible implications.

Summary

The Lake Victoria basin is part of the Nile basin and one of its main water sources. The Lake Victoria basin has attracted the attention researchers due to significant fluctuations in lake levels in the past century. These fluctuations of the lake levels affect the Nile flows, which in turn may have significant consequences on the countries dependents on the water of the Nile. However, the consequences may vary from country to a country depending on the availability of alterative water sources.

Climate change caused by the increase in the concentration of greenhouse gases poses global challenges for water planners as it affects water variability and availability worldwide. In view of the importance of water in that region of Lake Victoria assessing the potential climate change impacts is very vital.

For a better prediction in the climate change impact

assessment, factors such as downscaling and variation between climate scenarios should be taken into consideration. Downscaling of climate scenarios generated from the general circulation models is necessary for hydrological studies due to the mismatch in spatial and temporal resolutions (e.g. Arnell, 1996; Russo & Zack, 1997; Robock et al., 1993).

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