

## **EFFECTS OF WATER VARIATION ON HYDROPOWER PLANT FUNCTIONALITY**

### **A case of Ntaruka hydropower**

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#### **Abstract**

This study aimed at assessing the effects of Burera Lake water level variation on functionality of Ntaruka hydropower plant, over last ten years. The existing bathometric data of the lake ranges an approximate depth of 163-169m with a number of underground caves. Direct measurement of Lake water level has been done. The systematic recording began from 2005 to 2015. Historical data on situational and physical characterization of the study area, hydro-meteorological data, status of Cyeru, Rusumo and Kabwa affluent rivers, energy production and Lake water level were collected using reports and visitation of different areas that are affected and therefore draw on aspects of a case study of Ntaruka. The data were analyzed using statistical tools. In two separate rainy seasons with daily peaks varying around 10.00mm of rainfall in every April, May and November. The rainfall over the catchment is approximately 1163.00mm. The catchment registered a high annual evaporation of 1356.47mm due to the high water content from Rugezi Wetland and the lake itself. The lowest level was 1857.04m of altitude with reference to the sea level. When the three electrical tribunes are working at maximum capacity, the plant takes a discharge of 12 m<sup>3</sup>/s whereas the inlet in Burera Lake is 4.83 m<sup>3</sup>/s. Energy production relies on water availability, most of time it is necessary to shut down the plant so that water level should increase. This happens most of time during dry season or the time when energy demand is low. When the plant is shutdown; the lake water level is recovered. The critical production of energy is 1.4GWh which corresponds to 1860.00m of altitude; Burera lake water level is recuperated. This research is highlighting the need for alternative source of energy in order to balance water level in Lake Burera which is expected to be affected by several environmental hazards including climate change.

**Keywords:** *Water, Catchment, Energy production, Burera Lake, Ntaruka Hydropower Plant.*

## 1. INTRODUCTION

Water is an indispensable resource for sustaining human, animal and plant life by making a country powerful through production of food, energy, transport and other needed services (MINIRENA, 2011).

The ‘*Land of a Thousand Hills*’ with its numerous rivers and lakes, is highly suited to the establishment of hydropower to meet the growing demand for electricity from its expanding population, industries or factories in urban areas and rural agro-processing investments. Only 10 to 11% of households in Rwanda presently have access to electricity and 60% of these households are located in the capital of Kigali (MININFRA, 2015).

Available lakes in Rwanda include Kivu, Bulera, Ruhondo, Muhazi, Cyohoha, Sake, Kilimbi, Mirayi, Rumira, Kidogo, Mugesera, Nasho, Mpanga, Ihema, Mihindi, Rwampanga and Bisoke (REMA, 2009).

Moreover, the surface water bodies in Rwanda occupy a total of 135,000 hectares or 8% of the country’s surface area (RADA, 2005). These include 101 lakes (1,495 km<sup>2</sup>), 861 rivers totaling 6,462 Km (REMA, 2010). The in-land lakes are sustained by inflows from the dense network of rivers, streams and wetlands (MINIRENA, 2011:17).

In Rwanda, hydroelectric power production is widely recognized as having a significant role to play in achieving its economic development and poverty reduction goals (Hove *et al.*, 2011).

Hydropower has generated the bulk of electricity in Rwanda since 1960s. Its overall potential is estimated at about 400 MW but the current installed hydro capacity is 98.5 MW (MININFRA, 2015).

Rwanda is also focusing on hydro and other renewable energy sources partly because of environmental and climate change concerns (MINIRENA, 2011:25).

The Government of Rwanda (GoR) has now set a national target to increase electricity access to 70% by 2017. It has also prepared an expansion plan aimed at increasing the electricity generation capacity from about 100 MW in 2012 to 1,160 MW by 2017 (AfDB, 2013).

Dams and reservoirs can be used to supply drinking water, generate hydroelectric power, increase the water supply for irrigation, provide recreational opportunity, and improve certain aspects of the environment (WWF, 2013).

According to Tamar and Ostrovsky (2011) reported that water levels of lakes fluctuate naturally in response to climatic and hydrological forcing. Human over-

exploitation of water resources leads to increased annual and inter-annual fluctuations of water levels.

However, natural water level fluctuations (WLF) in freshwater stratified lakes of the temperate and subtropical regions are typically up to 1.5 m annually and up to 3 m multi-annually (Tamar and Ostrovsky, 2011).

Though, in Brazil, Israel and Uganda, adverse environmental impacts such as the decrease in Lake water level have been identified during and after many reservoir constructions (Rosenberg, 1995; Tamar and Ostrovsky, 2011 and Muwumuza, 2014).

According to the National Aeronautics and Space Administration (NASA) (2005) Nalubaale Dam regulates the flow of water out of Lake Victoria and into the Nile River. Increased discharges of water from the dam for power production may be causing the water level of Lake Victoria to drop.

When the hydropower is in activity of producing the electricity, the lower water levels are usually experienced in the afternoon and the higher levels are experienced in the morning and night time at Bujagali Dam in Uganda (Muwumuza, 2014).

By 2004, water levels in Lakes Burera and Ruhondo had fallen to 50 percent of their

average depth due to the disturbance of Rugezi Wetlands by cultivation and cattle grazing activities (UNEP, 2006).

The GoR has developed and implemented different principles, policies and laws in order to protect and rehabilitate these destructed ecosystems (Hove *et al.*, 2011). The subsequent passage of the Environment Law on 1 May 2005 further strengthened the legal authority of the government to control activities within the Rugezi Wetlands and along the shores of Lakes Burera and Ruhondo. Specifically, this law enabled the government to restrict agricultural and pastoral activities to 10 meters away from the banks of streams and rivers and 50 meters away from the banks of lakes. In 2008 the Government also declared the Rugezi Wetlands a protected area (Hove *et al.*, 2011).

Rugezi Marsh serves as a link between land and water resources and it is the most important water tower of Burera and Ruhondo lakes. The runoff from it contributes to 50% of inflow in the Lake Burera (RRAM, 1988; Hategekimana and Twarabamenye, 2007).

Besides, these natural fluctuations are an inherent feature of lake ecosystems, essential for the survival and well-being of

many species that have evolved to suit their life cycle to those fluctuations, and needed for a range of ecosystem services (Gasith and Gafny, 1990; Wantzen *et al.*, 2008b).

Human exploitation of water resources leads to increased annual and inter-annual fluctuations of water levels, at times far beyond natural amplitudes. A range of natural features of the water level regime are often impacted, not only the amplitude of fluctuation but also the timing of the minimum and maximum water levels and the rates of water level increase and decline (Tamar and Ostrovsky, 2011, Wantzen *et al.*, 2008a).

The aim of this research was to assess the effect of water variation on hydropower plant functionality in Rwanda particularly in Ntaruka Hydropower Plant (NHPP) station and Burera Lake in order to propose the best management practice for energy production systems in hydropower plants that help to recover the lake water level.

This study will provide to policy makers and energy sector; the information needed for the improvement of hydropower energy system in Rwandan lakes. Likewise, the evaluation of all the activities within the catchment of the Lake that are water demanding through field visit; the assessment of the Lake Burera inlet, outlet

and the NHPP outlet through field visit; the collection of hydro-meteorological, energy production records data at NHPP and Burera Lake and the elaboration of technical analysis in order to achieve our objective.

## **2.MATERIALS AND METHODS**

### **a. *Materials***

The Global Positioning System (GPS) and tape measure were used to measure the current lake water level, camera for taking pictures and the data reports from 2005 to 2015 on Burera Lake water level and energy production were provided by NHPP technicians' team.

### **b. *Methods***

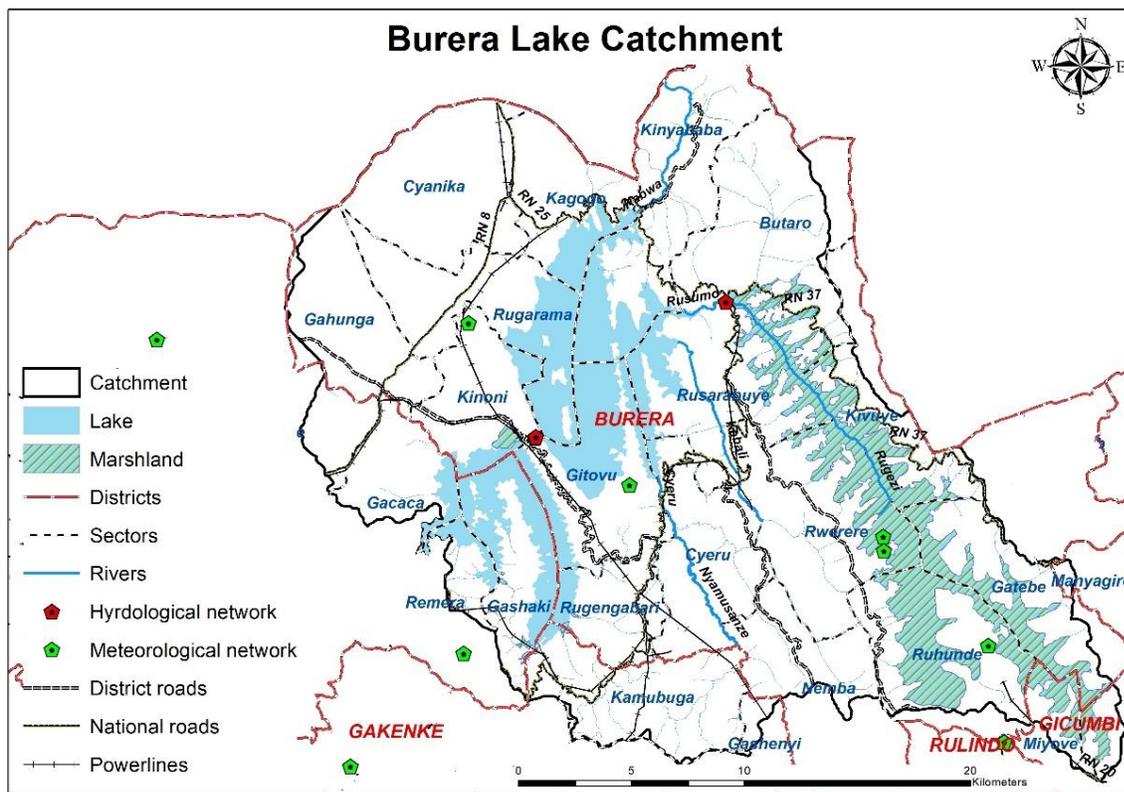
The methodology was divided into qualitative and quantitative methods so as to ensure good results were acquired. The direct measurement of Lake water level has been done where the average water level and energy were calculated from 2005 to 2015. The evaluations and observations were done through the field visit inspections at NHPP inlet (Burera Lake) and outlet point, Cyeru, Kabwa and Rusumo River near Rugezi Wetland in order to collect data and observe their status and contribution to Burera Lake water.

Later, the collected data were analyzed using Microsoft Excel 2013 so as to show numerically the environmental impacts of the NHPP on Hydropower production.

**c. Situational and physical characterization of the study area**

Burera Lake has approximately 47 square kilometers and a catchment area of 580 square kilometers. It is located at -1°26'49.33'' of Latitude and 29°44'28.91'' of Longitude (Lenzer, 2009). Burera Lake is curved by heavily eroded hills composed by

older metamorphic rocks (Hategekimana and Twarabamenye, 2007). Its catchment is located in the Northern Province, the Burera District. The Lake has 3 major tributaries, the first one being the Rusumo fall which the outlet of the Rugezi wetland lying within the Districts of Burera and Gicumbi and the other two being the rivers Cyeru and Kabwa (Fig.1). The existing bathymetric survey of the Lake indicates an approximate depth of 169 meters with a number of underground caves.



**Figure 1: Burera Lake and its catchment area map (Source: Hirwa H., 2016).**

**d. NHPP description**

The NHPP is located in the middle of the Lake Burera and the Lake Ruhondo. The

outflow of the first lake to the second is controlled by the hydropower plant tailrace outflow. This hydropower is the first ever built in Rwanda and its study was done, under the tutorship of the Belgian Kingdom, by the consortium made of the companies SOFINA S.A. form Bruxelles and ACEC de Charloi + ESCHEsrWISS of Switzerland.

The system was conceived to benefit from the extraordinary hydraulic potential of the River Ntaruka linking the Lakes Burera and Ruhondo with only a length of 440 meters and a potential head of 102 meters. The plant was designed for a monthly production of 11.25 Mw and an annual demand of 22 Gwh using three electrical tribunes. Water from the Rugezi Wetlands flows downstream first into Lake Burera supplying nearly half of its inflow and then into Lake Ruhondo before entering the Mukungwa River (Hove *et al.*, 2011&UNEP, 2006). The potential for an electricity supply crisis had been looming for a number of years due to the continued over-exploitation of the country's hydropower resources and degradation of the Rugezi-Bulera-Ruhondo watershed (Hove *et al.*, 2011). Collectively these processes of drainage, siltation and greater evapotranspiration contributed to a decline in the wetlands' water table (CITT,

2006; Hategekimana and Twarabamenye, 2007).

However, the records indicate that the Ntaruka hydropower plant had known technical shut down due to low water level reduction in the Lake Burera in the period of 1985, 1987, 1992 and 2007; since the energy demand was higher than water needed; over 12 cubic meters per second (Hove *et al.*, 2011).

### 3. OBSERVATIONS AND RESULTS

#### 3.1 Hydro-meteorological data

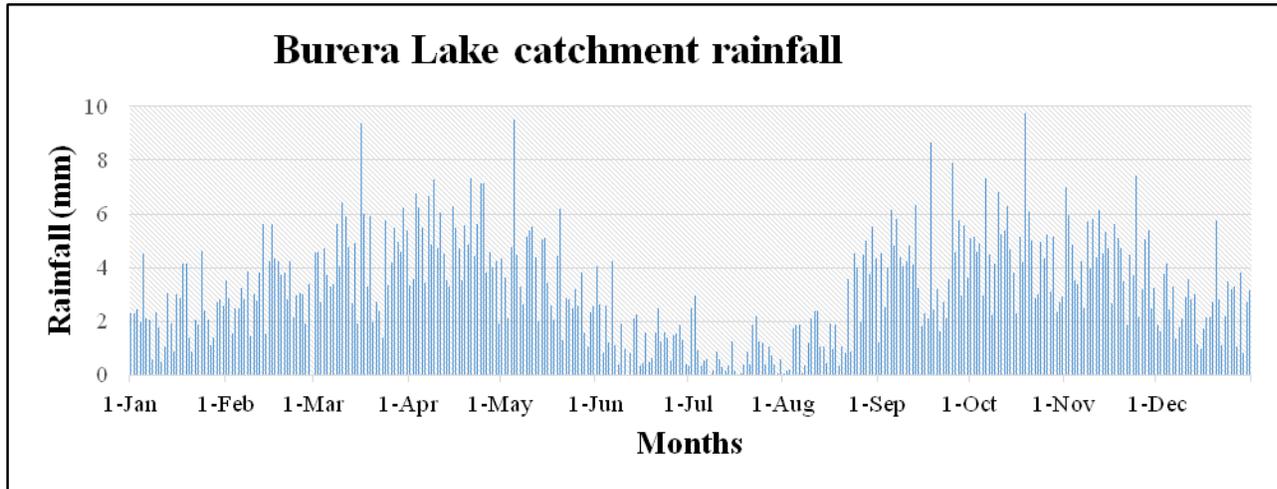
The main hydrological processes are illustrated as these were used to have an idea of the hydrological behavior of the catchment. These are rainfall, evaporation and runoff. Typical catchments like the one of the Lake Burera, containing a protected area, easily reflect the impacts of climate change and other natural modifications. In order to allow the assessment of the Lake Burera catchment hydrological behavior using the existing data was calculated.

#### 3.2 Rainfall measurement

The representative rainfall year of the Lake Burera catchment is illustrated in fig. 2. The highest rainfall measurements was observed in March, May, September, October and November of 9.38mm, 9.50mm, 8.65mm,

9.77mm, and 7.41mm respectively. It can clearly be seen 2 separate rainy seasons with daily peaks varying around 10 millimeters of rainfall. The figure 2 below represents all the daily water income that usually falls in

the catchment of the Lake Burera. The graph indicates an average medium rainfall income in the catchment since the annual rainfall over the catchment is approximately 1163 millimeters.

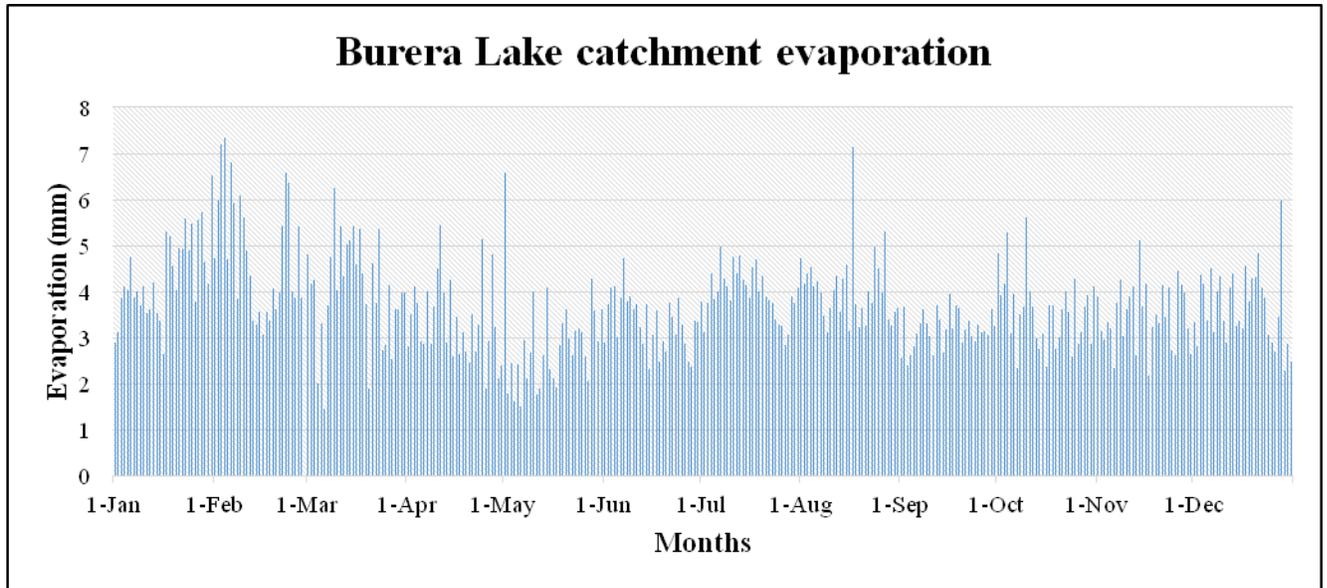


**Figure 2. Annual hydrological rainfall of Burera Lake Catchment**

### **3.3 Evaporation**

The representative evaporation year of the Lake Burera catchment is illustrated in figure 3. The catchment is seen to have high evaporation which is very much linked to the high water content in the catchment from

the Rugezi wetland and lake itself. The high evaporation rate were observed in February, March, May, August, October, November and December. An annual evaporation of 1356.47 millimeters is observed.

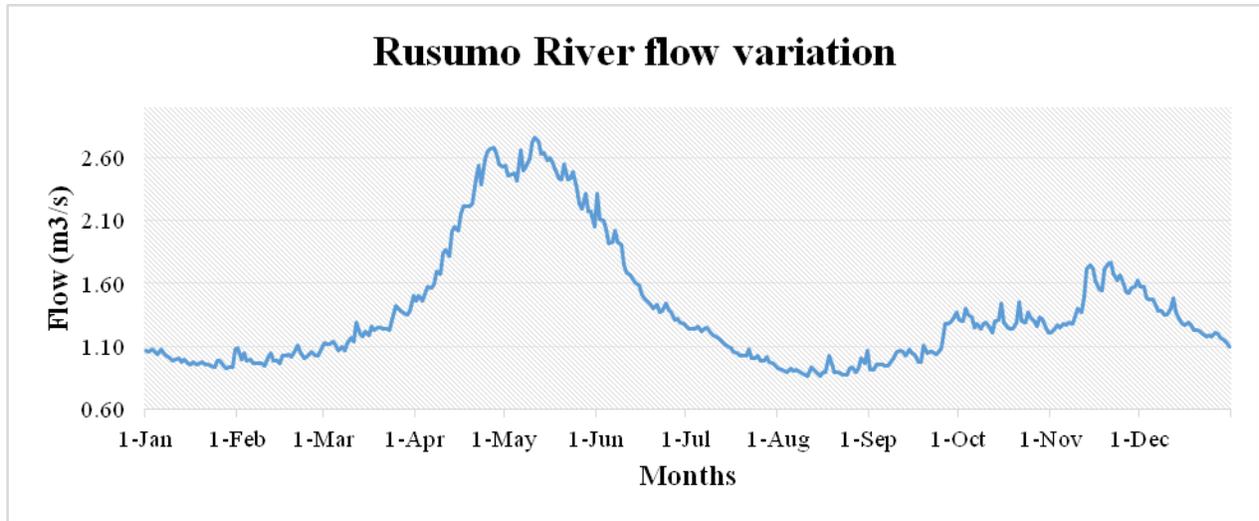


**Figure 3. Annual hydrological evaporation of the Burera Lake catchment.**

### **3.4 Rusumo River flow**

The flow of Rusumo River represented in an average hydrologic year, refers to figure 4. From January to March, Rusumo stream flow varies from 0.99 to 1.36m<sup>3</sup>/s whereas from July to December; the flow varies from 1.24 to 1.48m<sup>3</sup>/s. The highest flow was observed in April and May of 2.52m<sup>3</sup>/s and

2.58m<sup>3</sup>/s respectively and indicates a variation of flow between 2.76 and 0.8 cubic meters per second. Figure 4 is specific for the Rusumo River indicating the contribution of the Rugezi wetland in the catchment of the Lake Burera. There is also contribution from the Cyeru and Kabwa Rivers in the same catchment resulting in the whole lake surface fluctuation.

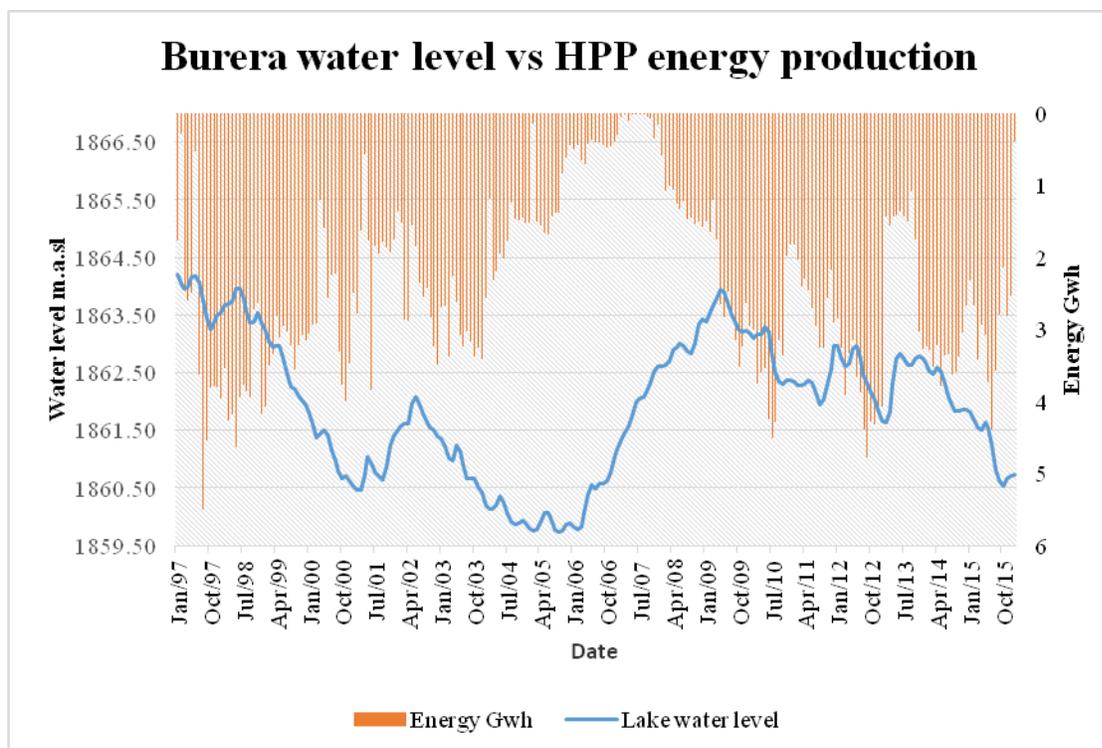


**Figure 4. Annual hydrological flow variation of Rusumo River.**

**3.5 Relationship between Burera water level and electricity production by NHPP**

By comparing Burera Lake water level and electricity production (figure 5), the lowest energy produced was 0.856GWh which linked to 1861.92m whereas the highest was 45.90GWh which linked to 1862.53m. However, the level of water of 1857.04m has been registered in October 2015. On the other hand, in 2005 the plant produced

14.12GWh which is linked to 1859.84m while in 2000 it produced 29.42GWh which corresponded to 1863.5m (high level of water). In addition, from January, 2014 to December, 2015; the lake shrank in 2.27m of its depth.



#### 4. DISCUSSIONS

The hydro-meteorological features of East-African Lakes such as Lake Kivu, Victoria, Burera and Ruhondo Basin are in accordance with the regional climate (Fig. 2 and 3) where the altitude-moderated equatorial climate is bimodal with rainy months (September to May) interrupted by dry months (June to August) because of the twice-annual passage of the Intertropical Convergence Zone (Verschuren *et al.*, 2009 and Muvundja *et al.*, 2014).

Also, the variations of water level of natural (unregulated) lakes are an indicator of changes in the hydrological budget of the

lake catchment. Such changes may be caused by climatic variations (precipitation, evapotranspiration and other meteorological components) or by changes in the runoff characteristics (such as land-use changes) in the catchment (Vuglinskiy *et al.*, 2009). Depending on the ratio of the catchment area per lake surface area, lake levels change within time scales ranging from hours to years (Mason *et al.*, 1994). Similarly, the catchment of Burera Lake is seen to have high evaporation and annual precipitation of 1356.47mm and 1163mm respectively which are very much linked to the high water content in the catchment from the Rugezi wetland and lake itself.

As Hove *et al.* (2011) reported that Ntaruka's reduced electricity generation was attributed to a significant drop in the depth of Lake Burera in 2004, which acts as the station's reservoir (Fig.5).

Furthermore, from October 2015 to December 2015, the lake water level started to decrease at high extent of 1.54m because the energy overproduction where the intake in Burera lake by principal affluent streams is  $4.83\text{m}^3/\text{s}$  whereas the outlet is  $12.01\text{m}^3/\text{s}$  when the plant is functioning at maximum capacity or at over-production of electricity depend upon the high demand of consumers. Actually, Ntaruka was designed with the capacity of 11.25 MW (UNPEI, 2011)

## 5. CONCLUSIONS

This study has shown the adverse environmental and water availability effects that caused mal-function of hydropower energy production. NTARUKA HPP dam was constructed to retain water that could facilitate the production of hydroelectricity which could be added to the national network. This was a good thing but there were different aspects that affected the environment of the area that have been discussed in this paper. One of the contentious issues was the decrease of Burera water level. The water levels

fluctuate within 2.14 meters lower than the normal level after energy overproduction. Economically, there have been more positives than negatives in terms of energy availability but more effort is needed to supplement hydropower energy for national development.

After all, we recommend NTARUKA HPP to produce energy at the critical point of 1.4GWh which approximately corresponds to 1861.00m of altitude so as to allow recuperation of lake and reduce high lake water evaporation. Furthermore, Rwanda has to board on a striving and broadminded effort to diversify its energy supply through development of its methane gas in Kivu Lake, geothermal in Kalisimbi, presented peat in marshlands, solar everywhere in the country particularly in Eastern and Southern province and biogas resources for all.

Not only the land-use management practices that minimize soil erosion and protect sensitive ecosystems, it is recommended to reduce vulnerability to future climate shocks and stresses and also integrated watershed management which can support adaptation to climate change, particularly with respect to the maintenance of hydropower potentiality.

## 6. ACKNOWLEDGMENTS

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