Assessment of Temperature Changes in Upper Akagera Basin: Case of Rwanda

C. Museruka [1], C. Ndayisaba [2], A. Mutabazi [3], and F. Nsabukunze [4]

[1]Institute of Agriculture Technology and Education of Kibungo (INATEK)
[2,4]Institute of Scientific and Technological Research (IRST), Butare
[3] Rwanda Environmental Management Authority (REMA), Kigali

Abstract

Apart from rainfall records, temperature is a key and available database for input to climate change models in close link with water resources management and study of teleconnected impacts of El Nino/La Nina events. Through this paper, we focused on local scale warming in selected areas of upper Akagera basin with Rwanda as a case study. With statistical analysis, variability of frequency for warmer days (i.e.: $T \geq 30°C$) was found to be high at Kigali station: 80days in 2006 against 5 in 1971; and annual mean temperature has been increasing gradually within such a period of 35 years with a rate of 0.036°C/year. Therefore, local warming is about seven times more important that the average global warming which is about 0.005 ^{o}C every year since the early 1850s. Results from analysis of existing water levels were found to be relatively correlated to temperature changes: 23.7 % for Akagera at Kigali/Kanzenze (eastern Rwanda) and 25.3 % for Akanyaru river at Rwabusoro (southern east of Rwanda). Impacts of increase in temperature are negatively affecting water resources so that rivers like Akanyaru and Nyabarongo forming the upper Akagera are experiencing decrease in water level at a rate of 10 cm/^{o}C/year. Given that any small change can result in significant catastrophic consequences such as perturbation in agriculture crops and tendency to converting arable lands into semi-arid ones; wider investigation on local warming phenomenon is recommended.

***Key words*: **Temperature increase, water levels, Akagera Basin, droughts, El Nino, local warming.

1. INTRODUCTION

Climatic and geophysical extreme events such as tsunami, earthquakes, floods and droughts are becoming more and more huge challenges both at local and global scales. Those linked to the teleconnected ENSO (El Nino southern oscillation) and SST (Ocean Pacific sea surface temperature) variations are frequently occurring and affecting all regions at global scale (REMA, 2009; Jeffrey Sachs, 2008).

Without any doubt, global warming is a reality and was identified as a main cause of extreme events. In fact the GHG (greenhouse gases) emission in atmosphere resulted in a regular increase of the Earth surface temperature with an average rate of 0.05°C every 10 years since the 1850s, at the early industrial era (Jeffrey Sachs, 2008). The cause of global warming is mainly due to the rapid growth of carbon dioxide (CO_2) emissions in earth atmosphere. In fact and more recently, data confirmed that the use of fossil fuels is the major contributor to anthropogenic GHG emission so that CO_2 concentrations had increased to over 390ppm (part per million), by the end of 2010, i.e. 39% above preindustrial levels (IPCC, 2011). Such a situation is alarming as far as the acceptable limit is 450 ppm (Jeffrey Sachs, 2008).

At local scale, impacts of climate change phenomenon were also identified even for ancient civilizations and societies; climatologists and paleoecologists recognized several signals of ancient climate and environmental changes that contributed to the Maya collapse, especially deforestation, erosion and droughts probably repeatedly (Diamond, 2006).

Nowadays, climate extreme events and associated negative impacts remain a reality. For instance and at local scale in Upper Akagera Basin, during the period 1997 -1998 the ENSO event caused important flooding among others along Nyabarongo river while the ENSO event which occurred during 2000-2001 was associated to devastating drought mainly in Bugesera , a region common to the North of Burundi and Southern East of Rwanda (IPCC, 2007). As during the last decades both rainfall and temperature are significantly changing in Rwanda (our case study). Establishment of amplitudes and frequencies of such changes and investigation on particular impacts of temperature increase on water resources availability and variability are essential for any sustainable economic planning and poverty alleviation strategy.

In case of a continuous increase in temperature, what will be the influence on hydrological behavior for mainly the most sensible areas like Bugesera? Which types of impacts associated to combination of external factors (ENSO and SST) and local forcing, while the SST fluctuations are almost regular with a cycle of 5 to 7 years and resulting in flooding followed by droughts? Furthermore average temperature at local scale in Rwanda is characterized by a regular increase; this is the case especially for the maximum temperature. This was observed mainly at Karama (meteorological station) and at Mfune (Akagera hydrological station) both located in southern east of Rwanda, areas more vulnerable due to their highest temperatures in the country: maximum of 34°C in 2005 against 31°C in 1962. Instead, for the North at Rwerere (altitude: 2312 m) maximum temperature changed from 23.6°C in 1962 to 24°C in 2005.

With reference to above interrogations and concerns, and in order to understand the way the local warming is affecting our water resources, specific objectives of this paper are especially oriented to identification of local warming phenomenon in upper Akagera. Apart from this introductive background, the second section deals with a brief descriptive presentation of the study area and is followed by a section summarizing the methods and a list of datasets involved in this research. The fourth section conducts an analysis of research results from statistical regression and correlation between temperature and water levels of selected rivers.

2. DESCRIPTION OF STUDY AREA

Rwanda is located between latitudes 1°04'and 2°51' south and longitudes 28°45' and 31°15' east. Its surface area is 26,338 km^2 with a population density among the highest in Africa with 321 people per km^2 in 2002 (REMA, 2009).

2.1. Topography

Rwanda is a territory covering land compartments varying from 900 m to 4,500 m of altitude. The country is essentially mountainous with over 70% of the cultivated land surface presenting slopes superior to 10%. Rwanda relief can be divided into four following categories: the Congo-Nile Ridge, the central plateau, the east and the south west. The Congo-Nile Ridge which is a range of mountains along the left branch of African Rift zone, with an altitude ranging between 2500 and 4500 m. Overhanging Lake Kivu, it divides Rwanda's waters in two parts: those which flow into the Congo basin in the west; and, those which flow into the Nile in the east. The Congo-Nile Ridge is dominated in the north-west by the volcanoes range, which consists of five massifs, the highest is Karisimbi with an altitude of 4507 m. The Central Plateau with an altitude decreasing from 2000 m to 1500 m from west towards east is made of hills with tops, separated by deep valleys, often filled up with alluvial deposits due to important erosion and runoff flow. The lowlands of the East are dominated by a depression of the relief, generally decreasing from 1500 m to 1100 m of altitude. The fourth category is regarding the southern west in the plain of Bugarama, a part of a tectonic depression of the African Rift; the lowest altitude is 900 m along Rusizi River, the outlet of Lake Kivu towards lakeTanganyika (REMA, 2009) . The depths of water in the main lakes vary between 8 m and 478 m; this highest depth is recorded in Lake Kivu, an international water reservoir shared between D.R. Congo and Western Rwanda. The figure 1 below shows Rwanda topographic features.

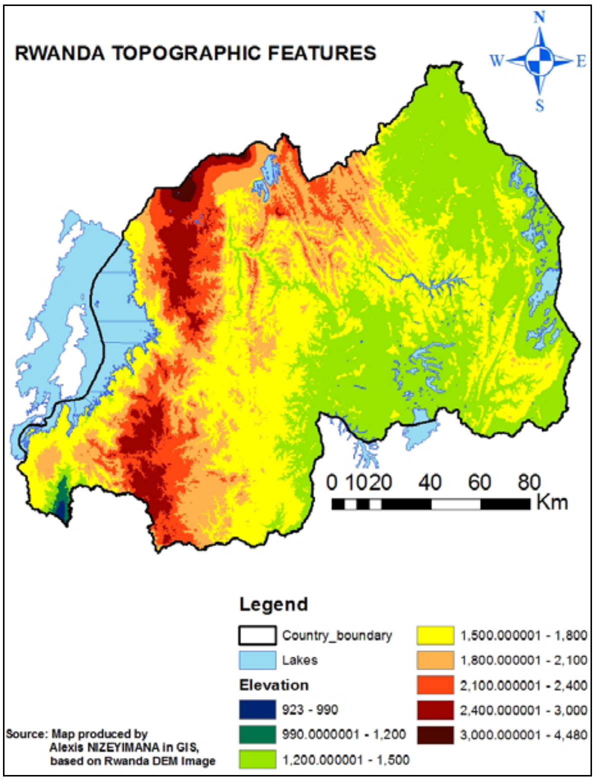

Figure 1: Rwanda topographic features (Source: Produced by Alexis NZEYIMANA in GIS based on Rwanda DEM Image)

2.2. Hydrography and Climate distribution

As presented below in figure 2, the study area within upper Akagera basin is crossed by three main rivers Nyabarongo, Akanyaru and Akagera. In fact, a large portion (67 %) of Rwanda land area is located in the Nile Basin and drains 90 % of Rwanda national water resources towards Lake Victoria via the Akagera River. This makes the Akagera River the major source of the White Nile (NBCBN, 2010).

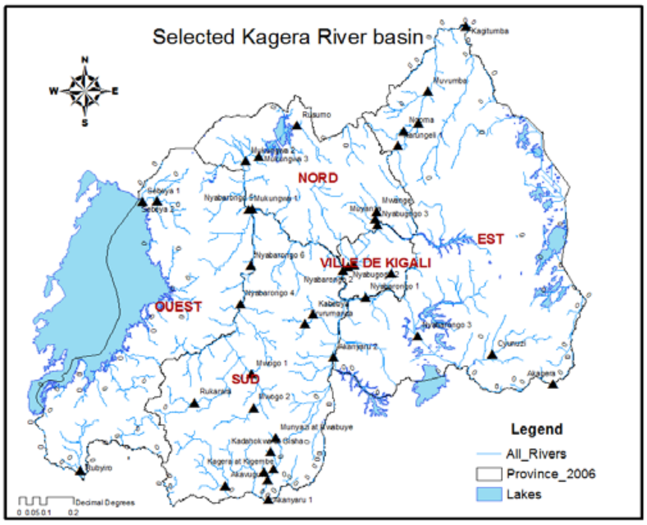

Figure 2: Upper Akagera Basin in Rwanda (source: Rwanda Meteorological Service)

For Rwanda rivers, main operational hydrological stations i.e. presenting a sufficient number of records for statistical analysis are as follows region per region: in East ("Est"), there are Nyabarongo-3 (Mfune), Nyabarongo-1 (Kanzenze near kigali), Nyabarongo-2 (Kigali) and Akanyaru-2 (Rwabusoro); in Central plateau there is Nyabarongo-4 (Mwaka) while in the South ("Sud"), there is Akanyaru-1(Road Butare-Ngozi). Other remaining stations mentioned above in figure 2 will not be considered in our study because of a lot data is missing. Regarding the case of Akagera hydrological station at Rusumo falls, it is in fact an international flow drained not only from Rwanda but also from Burundi and Tanzania.

Below in figure 3, spatial distributions of both rainfall and temperature are presented. Average rainfall is ranging from 800 mm per year in the East to 1500 mm per year in highland areas of North and West. Distribution of average temperature is correlated to that of rainfall: where rainfall is low, temperature is high. Thus, in the East, the temperature is the highest (average of 21°C). Instead, the lowest average temperature (16°C) is recorded in the Northwestern highlands.

The climate change in Rwanda is affecting temperature and rainfall patterns leading to increased natural disasters related to extreme events (floods and droughts). Eastern and South-Eastern regions are more affected by prolonged droughts while the northern and western regions experience abundant rainfall that usually causes erosion, flooding, and landslides (Twagiramungu, 2006). Among other issues, this change was associated to a significant decrease in number of rainy days: average annual total of 146 during the period 1917-1990 against 131 rainy days over the period 1991-2010 (after our analysis of data from Rwanda Meteorological Service/not yet published).

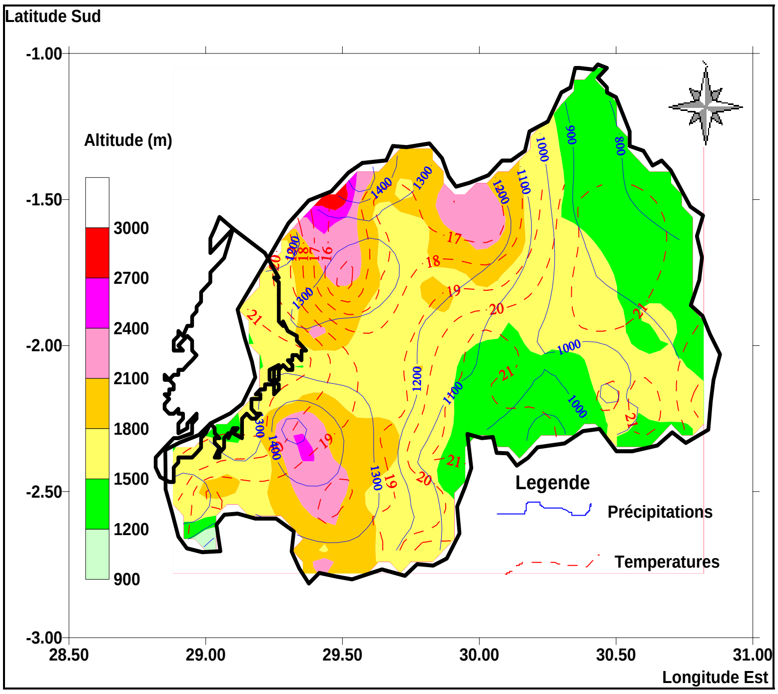

Figure 3: Rainfall and Temperature [Source: Data (period 1971-2009), Rwanda Meteorological Service]

2.3. Local Warming

Below in figures 4, 5 we present literature data and documentation on temperature variations and tendency to a regular increase.

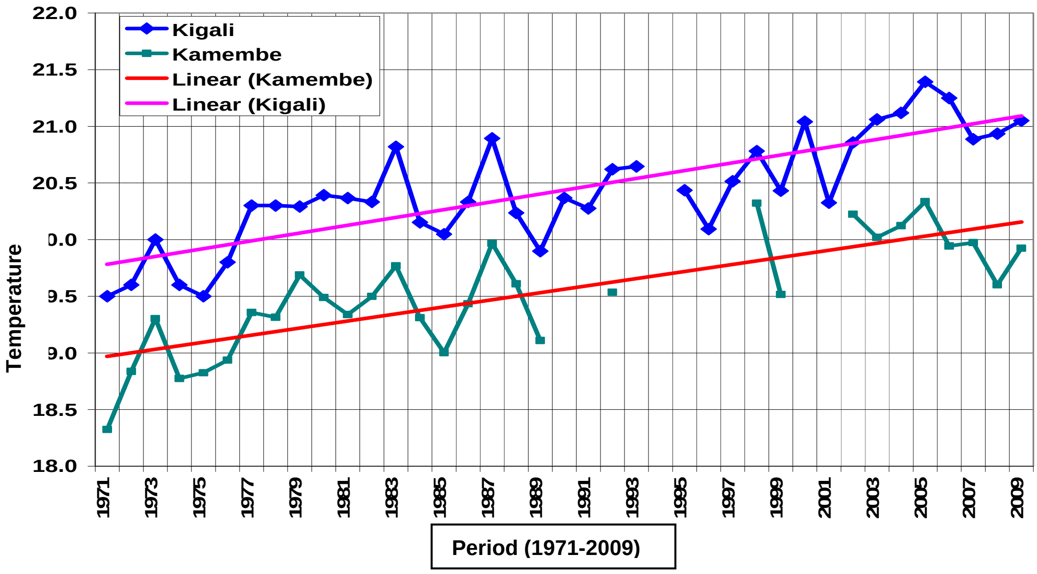

Figure 4: Temperature trends at Kigali and Kamembe stations (Source: REMA, 2009)

According to above trends plotted in the figure 4, the tendency of average temperature to increase was identified at Kigali and Kamembe meteorological synoptic stations for data records covering the period 1971-2009. The lowest average temperature was 19.5^{o}C and 18.3^{o}C respectively for Kigali and Kamembe against highest values of 21.4^{o}C and 19.7^{o}C. The year 2005 was the hottest within this period of 1971-2009.

Impacts of such an identified increase in temperature in Rwanda are among others associated to the tendency to convert arable lands into arid zones. Below, in the picture 1, an example of ecosystem affected by drought is presented.

Picture 1: Cattle graze in the forest in Akagera National Park, especially during periods of drought (REMA, 2009)

More recently severe droughts were recorded in 2005, 2006 and 2008; with reference to figure-4, 2005 was the hottest year. In addition, important changes in climate were recorded: floods associated to the 1997-1998 ENSO events followed by prolonged droughts in 1999-2001.

More threatened areas in Rwanda as a part of the upper Akagera river basin are mainly the East and the South, two regions experiencing impacts of regular increase in the maximum of temperature often exceeding 30^{o}C. This is occurring especially during the period of January-February and that of July-August-September within which the solar declination is more matching latitudes in Rwanda (C. Museruka *et al.*; 2007; J.A.Duffie *et al.*; 1980).

3. METHODS AND DATASETS

In addition to the descriptive presentation of the area of study presented above, we provide below a summary on methodology and data. Data on temperature were collected from Rwanda Meteorological Service (department of the Ministry of Infrastructure) and ISAR (Institut des Sciences Agronomiques du Rwanda, an institute managed by the Ministry of Agriculture), while data on water levels were provided by ministerial department in charge of water resources management. Selected stations for temperature datasets were Kigali, Byumba in the North, Byimana in the central plateau, Ruhengeri in the North and Gikongoro in the South. Regarding data on water levels, we considered hydrological stations selected on Akanyaru, Nyabarongo and Akagera rivers.

Both for temperature and water levels, time series analysis were done and statistical regressions were established for each selected station. Therefore, the rates of changes were computed. Finally, correlations between temperature and water levels were established in order to identify impacts of temperature change on water resources in upper Akagera basin with Rwanda as a case study.

4. RESULTS, ANALYSIS AND DISCUSSION

4.1. Temperature Changes in Rwanda

The temperature records analyzed through time series and regression options (linear, logarithmic and polynomial) for meteorological stations located in Northern, Central and Eastern areas of Rwanda confirmed a tendency of changes as presented below in figures 5, 6, 7, 8 and 9. The amplitude and the sign of changes are depending on the region: a tendency to a decrease in temperature was observed in the North (Byumba, figure 5, period 1981-1991) and in the central plateau (Byimana, figure 6, period 1960-1992); instead, the North-west (Ruhengeri, figure 7, period1977-2003) confirmed a tendency of stability in temperature; while a tendency to an increase was identified in the South (Gikongoro, figure 8, period 1990-2003) and in the East (Kigali, figure 9, period 1971-2003). Above data on temperature and below results in the following figures refer only to the maximum temperatures contrary to the average temperatures regarding the figure-3 within section 2.

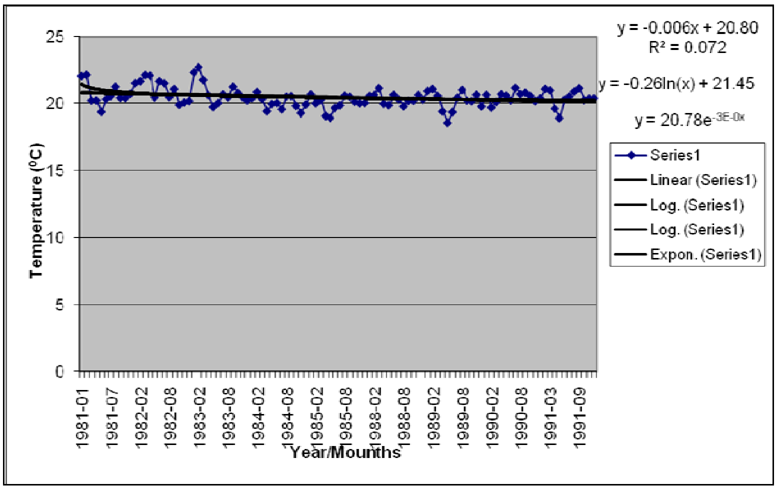

Figure 5: Temperature changes at Byumba station (North)

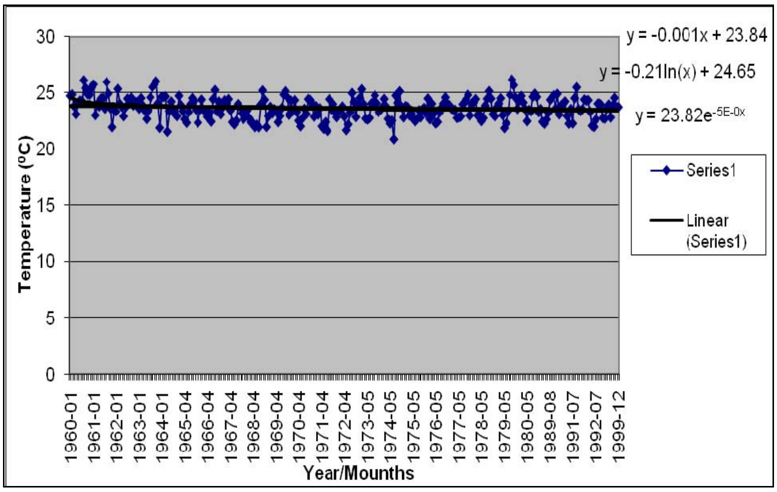

Figure 6: Temperature changes at Byimana station (in Central plateau)

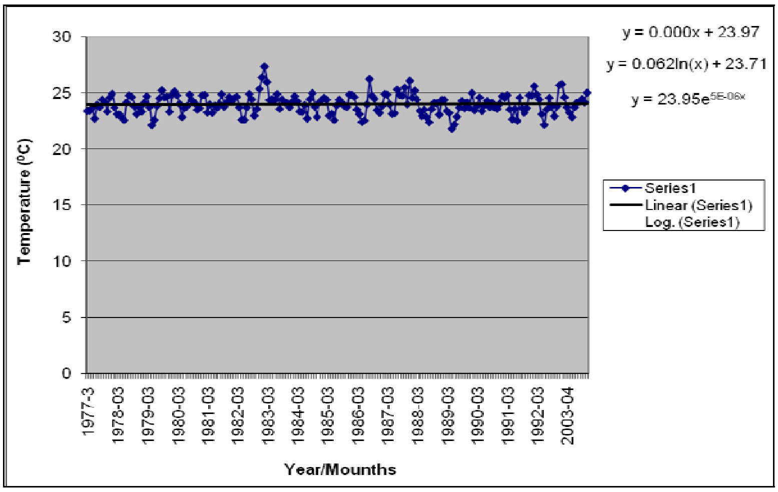

Figure 7: Temperature behavior at Ruhengeri station (in Northern West: high lands region)

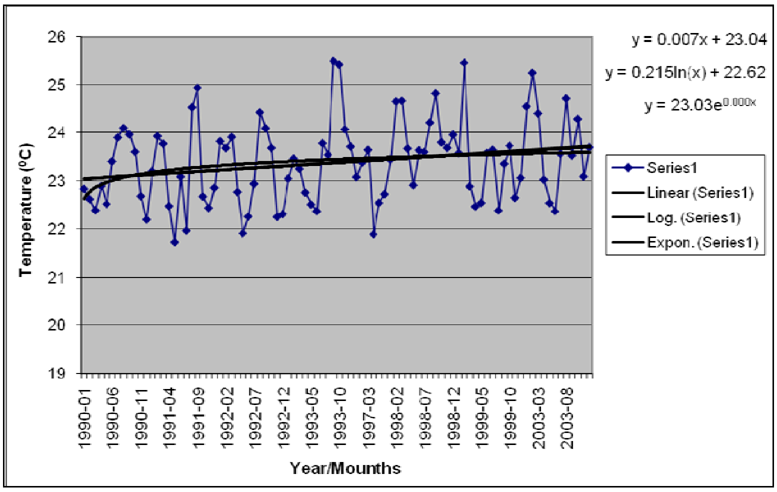

Figure 8: Increase in Temperature at Gikongoro station (in Southern areas)

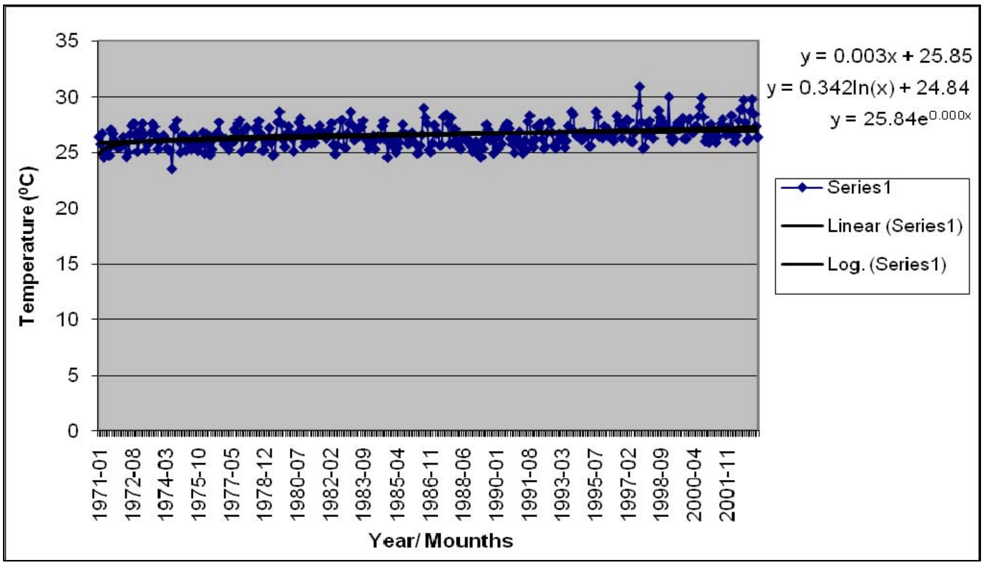

Figure 9: Increase in Temperature at Kigali station

For all above figures, graphs are representing in coordinates as follows: each point on the X axis represents the N^{th} days within the period of study, while Y axis stands for the temperature in ^oC. The rate of increase for the maximum temperature is thus 0.036°C/ year since 1971 at Kigali station. Such indicators to local warming in Rwanda is in good agreement with historical observations associated to prolonged droughts especially affecting Eastern and Southern areas like Bugesera and Mayaga, regions common to Burundi and Rwanda. With reference to above results, it is clear that where rainfall is low, the rate of change in temperature is positive while where rainfall is higher, change in temperature is negative or nil. Note also that high lands are characterized by higher amount of rainfall.

4.2. Changes in Water Level

Below we present the results of regression analysis of daily values and associated rate of change in water level at selected hydrological stations. In below table-1 each value of X^{th} stands for the N^{th} day within period of study, while the parameter Y represents the recorded water level and is expressed in meter.

Table 1: Changes in water levels in selected river at hydrological station

River	Station (refer to fig.2)	Lat (South)	Long (East)	District	Linear Regression	Rate of change (mm/yr)	Period of study
Akanyaru ($1425km^2$)	Akanyaru-1 (Butare-Ngozi Road)	2°48	29°58	Gisagara (South)	$y=-1*10^{-5}x+1$	-3	1971-2000
Akanyaru ($2360km^2$)	Akanyaru-2 (Rwabusoro)	2°16	29°58	Bugesera (South-East)	$y=-6*10^{-5}x+3.62$	-18	1974-2000
Nyabarongo ($2570km^2$)	Nyabarongo-4 (Mwaka)	2°05	29°37	Muhanga (central plateau)	$y=6*10^{-5}x+1.5$	+23.1	1971-1998
Nyabarongo ($8900km^2$)	Nyabarongo-2 (Kigali)	1°57	30°	Kigali (East)	$y=3*10^{-5}x+1.8$	+12.6	1961-2000
Akagera ($14600km^2$)	Nyabarongo-1 (Kanzenze)	2°03	30°05	Bugesera (East)	$y=-6*10^{-5}x+4.8$	-16.8	1971-2000
Akagera ($15720km^2$)	Nyabarongo-3 (Mfune)	2^{o}12	30°16	Bugesera (East)	$y=-2*10^{-5}x+3$	-4.2	1971-2000

Through our study, and as indicated above in table-1, we focused on hydrological stations regarding the three rivers of Akanyaru, Nyabarongo and Akagera where, the rates of change are negative, i.e. decrease in water levels. This means that water flows are drained from the sub-basins of South and East where temperature is characterized by an increase. This is regarding stations of Akanyaru and Akagera rivers. Instead, the two stations of Nyabarongo river (Nyabarongo-2/Mwaka and Nyabarongo-4/Kigali) are characterized by an increase in water level with a rate ranging between 12.6 and 23.1 mm / yr. In fact, the main Nyabarongowater flows are drained from the North, the West and the Central plateau where the rate of change in temperature is either negative (Byimana, Byumba) or (Ruhengeri) as identified in section 4.1. Note that we have to emphasize that even though once Nyabarongo and Akanyaru form Akagera at Kanzenze station, water level continues to decrease. In fact from Kanzenze to Mfune station (Nyabarongo-4 in figure 2), The Akagera river flows across the South-East area of Rwanda, a region particularly hot. Below in the figures 10 and 11, we illustrated such changes in water levels.

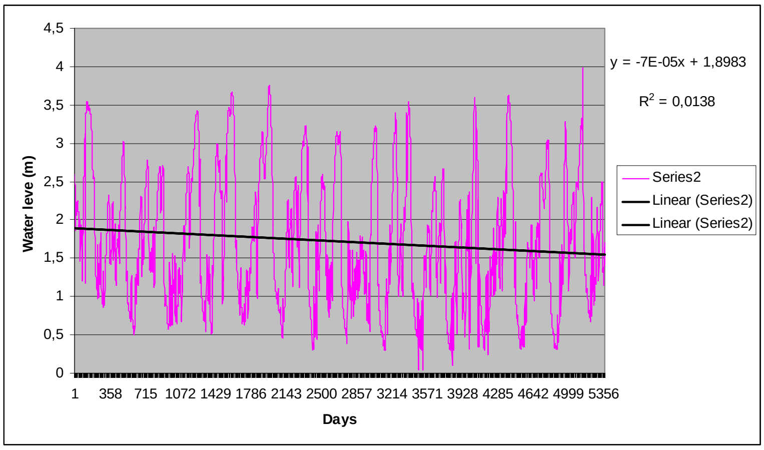

Figure 10: Changes in Water level for Akanyaru at Rwabusoro

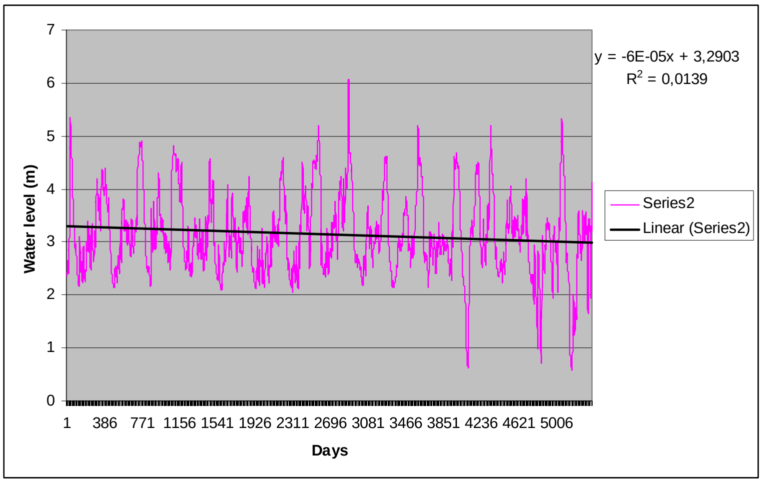

Figure 11: Changes in Water level for Akagera at Kanzenze

Apart from the station of Mfune in the East for Akagera River where the decrease in water level is relatively small; the case of Akanyaru at Rwabusoro and of Akagera at Kanzenze are crucial: in fact the decrease is significant (18 and 16.8 mm /yr respectively).

4.3. Correlation between Temperature and Water levels

Above results proved that water levels for rivers located in South-Eastern regions of Rwanda are characterized by a decrease. We therefore present as below in figures 12 and 13 the correlation between such trends of temperature (T) and water level (H) over the period 1974-1988, where data of both T and H are available, for the two above mentioned crucial stations. Note that X axis represents T in ^{o}C while Y axis stands for H in meter. The noisy character of the below graphs is due to the use of a high number of daily values.

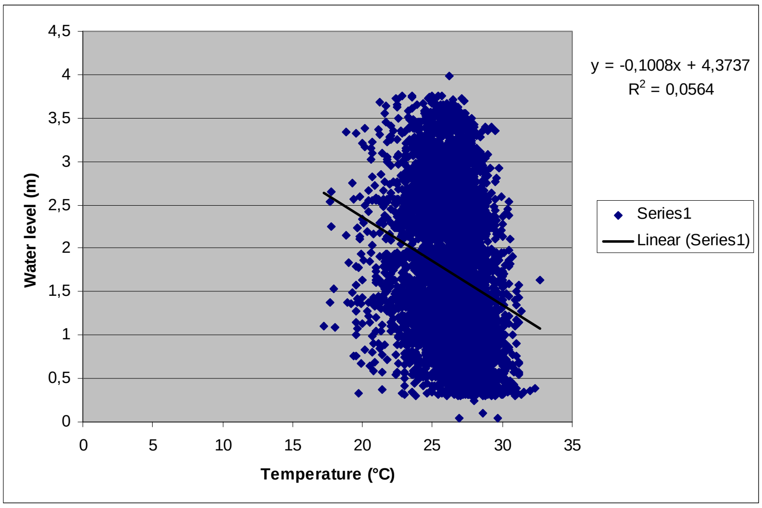

Figure 12: Correlation between T and H of Akanyaru at Rwabusoro

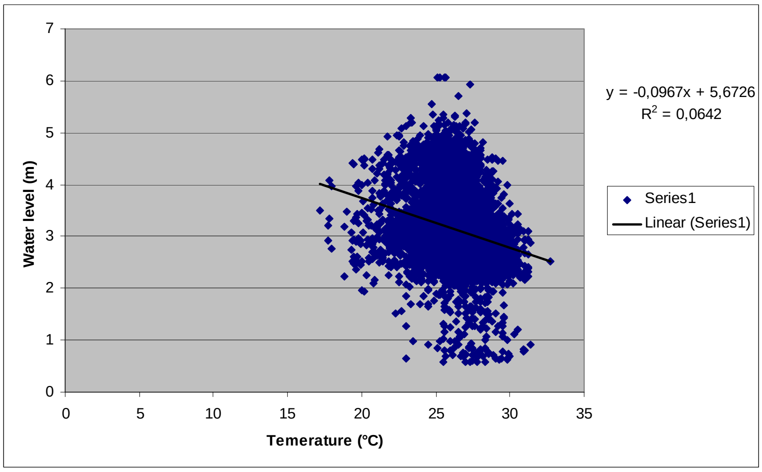

Figure 13: Correlation between T and H of Akagera at Kanzenze

Regarding the Akanyaru river, the rate of decrease of H is governed by a linear regression expressed as follows: **H = -0.1008T +4.374** where H is in [m] and T in [^{0}C]. Regarding the Akagera river at Kanzenze the correlation equation is **H= -0.096T+5.672, t**herefore water level decreases with a rate of 100.8mm /^{0}C for Akanyaru at Rwabusoro and 96mm /^{0}C for Akagera at Kanzenze.

5. CONCLUSION

Through a statistical analysis of temperature changes at selected stations in part of upper Akagera river basin in Rwanda we proved that temperature is regularly increasing with an alarming rate relatively high and requiring more particular attention. While global warming is linked to an increase of about 0.05 °C every decade since the early 1850s, local warming in Eastern and Southern areas of Rwanda is about 0.36 °C per decade i.e about 7 times more important if compared to global warming. Impacts of such an increase are negative among others for water resources and ecosystems so that some rivers like Akanyaru and Nyabarongo forming the upper Akagera river are experiencing a decrease of water levels at an average rate of about 10 cm per a 1°C increase of temperature.

6. AKNOWLEDGEMENTS

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AUTHORS' BIOGRAPHY

Dr. Casimir Museruka was awarded a PhD in physics in Dakar in 1995 and, at Abidjan, a DEA (MSc) in geophysics, in solar energy and BSc in applied physics. But also he got a basic diploma A1 in civil engineering in 1980, a diploma in energy management in 1999 in the Netherlands. The ICTP (international centre for theoretical physics) awarded him a scientific position of a Regular Associate since 2003. Through the ministry in charge of water resources, Museruka contributed in introducing the NBCBN in Rwanda.

Mr. Cyprien Ndayisaba is working for the Institute of Scientific and Technological Research (IRST) in the domain of environment since June 2006 and he headed Nyange Research Station from June 2009 until October 2011. He obtained a Postgraduate Diploma in Environmental Management and Natural Resources Conservation at the University of Burundi in 2008 and a BSc in Chemistry at the National University of Rwanda in 2005. Now, Mr. Cyprien Ndayisaba is undertaking his Master of

Environmental Science and Technology at UNESCO-IHE, Institute of Water Education in The Netherlands. He joined NBCBN since 2009 as a member of NBCBN Rwanda Node.

Mr. Alphonse Mutabazi is working as Climate Change Specialist at Rwanda Environmental Management Authority (REMA). He is an Engineer Meteorologist with an MSc in Engineering since 1994 from Russian State Hydro-meteorological Institute, Saint Petersburg, Russia. He joined NBCBN in 2011.

Mr. Felicien Nsabukunze is working as a Researcher at the Institute of Scientific and Technological Research (IRST) in domain of Renewable Energy since November 2010. He has a BSc in applied Physics at Kigali Institute of sciences and Technology (KIST) in 2009 and he joined NBCBN in 2011 as a member of NBCBN Rwanda Hydropower Cluster.