Estimation of the Climate Variability Impact on Water Resources in the Nyabugogo Swamp in Rwanda

O. Munyaneza[a], E. Hakizimana[b], C. B. Sekomo[c] and V. Uwamariya[c]

[a]Department of Civil, Environmental and Geomatic Engineering, College of Science and Technology, University of Rwanda, Kigali, Rwanda, omarmunyaneza1@gmail.com
[b]Ruhango District, Department of Agriculture and Natural Resources, *P.O Box* 12,Ruhango, Rwanda
[c]University of Rwanda, Department of Chemistry, P.O. Box 3900, Kigali, Rwanda

Abstract
Climate varies on all time scales, from one year to the next, as well as from one decade, century or millennium to the next. The complex nature of climate variability is a major obstacle to the reliable identification of global changes brought by the presence and activities of humanity on this planet. The aim of this study was to investigate the recent trends and variability of annual minimum, maximum and mean temperatures, evaporation, rainfall and streamflow trend in the Nyabugogo catchment (ca. 1,647 km^2) with the goal of estimating the impact caused by this trend on water resources in the Nyabugogo swamp (220 ha). A data set of daily maximum, minimum temperature, rainfall and evaporation recorded at Kigali airport station from 1981-2013 were collected from Rwanda Meteorology Office, and the streamflow data (1981-2012) recorded at Cyamutara gauging station in Gasabo district were collected from Rwanda Natural Resources Authority (RNRA). Variations and trends of annual mean temperature time series, evaporation, rainfall and streamflow were examined. The Mann-Kendall test statistic was used to detect trend of climate variables and Pettitt tests was used to detect the abrupt change points. The Statistical Package for the Social Science (SPSS) was used to find out whether there is any correlation between them. Results show that annual mean temperature, evaporation and discharge revealed an increasing trend while rainfall trend is decreasing. The increasing temperature trends observed are possibly linked to human activities (e.g. deforestation, local urbanization). Pettitt tests revealed the abrupt change points in all climate parameters except discharge data whose analysis results are not significant due to a large number of missing data for a long period (around 50%). A strong correlation between temperature and evaporation was detected but the correlation between rainfall and discharge was found to be weak. This research provides possible major causes of such trends and correlations between climate variables and hence highlights their potential impact on water resources in the Nyabugogo swamp.

Key words: Climate variability, climate variables, correlation, trend detection, Nyabugogo swamp, Rwanda.

1. INTRODUCTION

Analyzing time series for trend detection of hydro-meteorological variables has received a great deal of attention over the past decades because of its importance for understanding and predicting future climatic change (IPCC, 2007). Some of the detected trends could be attributed to climatic (i.e. rainfall and temperature), which may lead to altered flood or low flow regimes that affect water resources and infrastructures (Uhlenbrook, 2009). Sharif and Burn (2009) demonstrated that operational decisions for water resources infrastructure and management are dependent on both the timing and magnitude of flows and, therefore, climate change impact assessment is of a paramount importance for a sustainable water resources management.

A variety of climatic and non-climatic processes influence flood processes, resulting in river floods, flash floods, urban floods, sewer floods, glacial lake outburst floods. Human encroachment into flood plains and lack of flood response plans increase the damage potential. The IPCC’s review of climate impact studies suggests large differences in the vulnerability of water resource systems to climate variables (IPCC, 2007). Potential evapotranspiration (ET) water evaporated from the surface and transpired from plants rises with air temperature. Consequently, even in areas with increased precipitation, higher ET rates may lead to reduced runoff, implying a possible reduction in renewable water supplies (IPCC, 1998).The relevance of the Sustainable Development Goals (SDG’s) impels us to consider that water resources play an important role in meeting these poverty related goals and achieving sustainable development.

Fragmented water use and bad management are the causes for conflicts among users and uses, development and environmental goals. This study aims at assisting the Government of Rwanda (GoR) to achieve its strategic goals of management of water resources in Rwanda in general but specifically in the Nyabugogo swamp by implementing the Integrated Water Resources Management (IWRM) plan for this catchment. This study estimates the impact of climate variability and change on water resources in the Nyabugogo swamp after analyzing whether there is any trend in temperature, rainfall, evaporation and streamflow and correlation between climates parameters within the Nyabugogo swamp.

2. STUDY AREA

The Nyabugogo catchment (Fig. 1) is located in the central eastern part of Rwanda. The catchment drains a total area of about 1,647 km^2. The major land use activity in the catchment is agriculture, which occupies about 897 km^2 (about 54%) of the catchment. The Nyabugogo swamp is located between 1354 m and 2,278 m above sea level and between $1^0$94’S and $30^0$04’E. The climate of the catchment is mostly of temperate and equatorial type with average temperature ranging between 16°C and 23°C, depending on the altitude of the area (Nhapi *et al.*, 2011). There are normally four seasons in Rwanda. The first is a long dry season that spans from June to September, followed by a short rainy season spanning from October to December. This season receives 30% to 40% of the annual rainfall with the highest rains falling in November. The third is a short dry season starting in December and ending in January. The fourth is a rainy season spanning from February to end of May. This season receives around 60% of annual rainfall. The Nyabugogo River which traverses the City of Kigali and crosses the swamp has a total length of 42.69 km and has many tributaries such as the Mwange River, Rusine River and Marenge River on its upstream portion. It is later fed by other rivers from the urbanised part of Kigali such as Rwanzekuma River, Ruganwa River, Mpazi River and Yanze River.

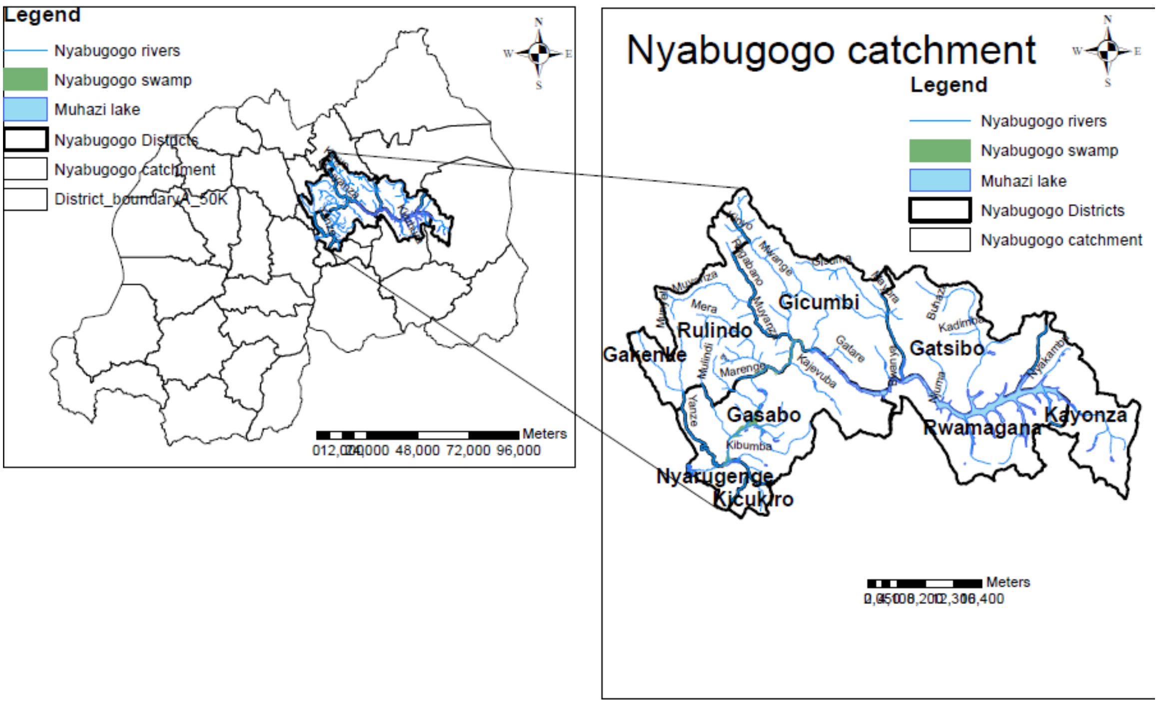

Figure 1: Location of Nyabugogo Swamp within the Nyabugogo catchment in the administrative map of Rwanda

3. MATERIALS AND METHODS

A data set of daily maximum, minimum temperature, rainfall and evaporation of Kigali airport meteorological station from 1981-2013 were collected from Rwanda Meteorology Office (RMO). The study area has no weather station which is operational. However, 1 new rainfall station and 3 gauging stations as well as 1 evaporation pan were installed in the swamp and data were collected in the period of 6 months (Feb to July 2014). New collected data were used together with historical data from Kigali Airport station (1981-2013) which is closer to the study area in order to know the variations in rainfall, temperature and evaporation patterns. In this study, the Mann Kendal (MK) non-parametric trend test has been performed using XLSTAT. Different reviews of applications of parametric and non-parametric methods have been done for the detection of trends (Chen *et al.*, 2007). Parametric tests are more powerful than non-parametric ones, but the parametric tests make an implicit assumption of normality of data that is seldom satisfied (Sharif *et al*., 2009). Hydroclimatic time series are often characterized by data that is not normally distributed, and therefore non-parametric tests are considered more robust compared with the parametric tests (Hess *et al.*, 2001). In this study we used the Mann-Kendall non-parametric test for detecting trends (Hu*et al.*, 2011). This test allows investigating long-term trends without assuming any particular distribution, and this test is also less influenced by outliers in the data sets. In addition, SPSS software was used to a non-parametric correlation between climate variables.

3.1. Trend Analysis

In this study, trend analysis has been done by using non-parametric Man- Kendall test. This is a statistical method which is being used for studying the spatial variation and temporal trends of hydroclimatic series. A non parametric test is taken into consideration over the parametric one since it can evade the problem roused by data skew (Hirsch*et al.,* 1982*)*. Man-Kendall test is preferred when various stations are tested in a single study (Hirsch *et al*., 1991). Mann-Kendall test had been formulated by Mann (1945) as non-parametric test for trend detection and the test statistic distribution had been given by Kendall (1975) for testing non-linear trend and turning point. The time series from each parameter was also subjected to the Pettitt Test (Pettitt, 1979), which is often used to detect abrupt changes in hydrological series (Shao*et al*., 2009). The test determines the timing of a change in the distribution of a time series, known as a 'change point' (Zhang *et al*., 2008). The change point divides the series into 2 sub-series. The significance of the change point is then assessed by F- and t-tests on the change in the mean and the variance. The Pettitt test was used to identify change points in the time series, at a probability threshold of p = 0.8, followed by F- and t-tests at 2.5% significance level. This procedure has been used for identifying change points in hydroclimatic data in both humid and semi-arid environments (Ashagrie*et al*., 2006; Zhang *et al*., 2008).

3.2. Autocorrelation

Trend detection in a series is largely affected by the presence of a positive or negative autocorrelation (Hamed *et al*., 1998; Serrano *et al*., 1999; Yue *et al*., 2003). With a positive autocorrelation in the series, possibility for a series of being detected as having trend is more, which may not be always true. On the other hand, this is reverse for negative autocorrelation in a series, where a trend is not detected. The coefficient of autocorrelation ρ_k of a discrete time series for lag$_k$ is projected as (Equation 1):

$$\rho_k = \frac{\sum_{t=1}^{n-k}(x_t - \bar{x}_t)(x_{t+k} - \bar{x}_{t+k})}{\left[\sum_{t=1}^{n-k}(x_t - \bar{x}_t)^2 \times \sum_{t=1}^{n-k}(x_{t+k} - \bar{x}_{t+k})^2 \times\right]^{1/2}} \quad (1)$$

Where, t_x and*Var* (x_t) are considered as the sample mean and sample variance of the first ($n - k$) terms respectively, and t $_k$ x and *Var* (x_t+k) are the sample mean and sample variance of the last ($n - k$) terms respectively. Further, the hypothesis of serial independence is tested by the lag-1 autocorrelation coefficient as H_0:ρ_1=0 against H_1:|ρ_1|>0 using Equation 2:

$$t = |\rho_1| \sqrt{\frac{n-2}{1-\rho_1^2}} \qquad (2)$$

where the t test statistic has a Student's t-distribution with $(n - 2)$ degrees of freedom (*Cunderlik et al*., 2004). If $|t| \geq t_{\alpha/2}$, then the null hypothesis about serial independence is rejected at the significance level α.

Mann-Kendall Test**:** The Mann-Kendall statistic S is given as shown by Equation 3:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(Xj - Xi) \qquad (3)$$

The application of trend test is done to a time series x_i that is ranked from i = 1, 2,..n-1 and x_j, which is ranked from j = i+1, 2,……….n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$Sgn(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases} \qquad (4)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (i)(i-1)(2i+5)}{18} \qquad (5)$$

Z here follows a standard normal distribution. A positive (negative) value of Z signifies an upward (downward) trend. A significance level α is also utilized for testing either an upward or downward monotone trend (a two-tailed test). If Z appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

$$\beta = \text{Median} \left\{ \frac{Xj - Xk}{j - k} \right\} \text{ for all } k<j \qquad (6)$$

Where β is a robust estimate of the slope

4. RESULTS AND DISCUSSIONS

4.1. Temperature Trend Analysis Results

Trends analyses of temperature have been done and results are presented in Figure 2.

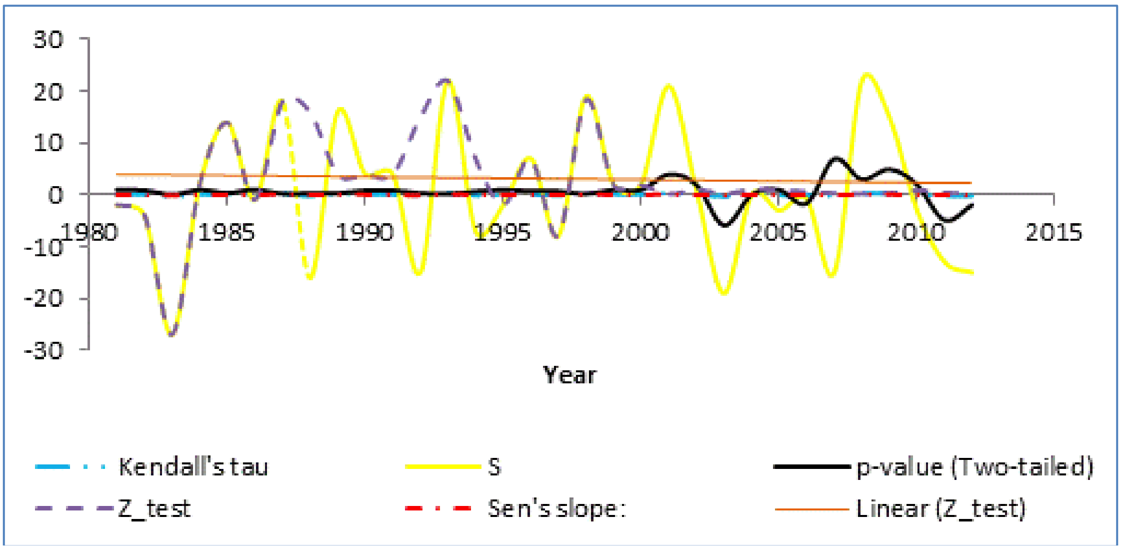

Figure 2: Trend results of temperature: The Mann-Kendall statistics M-K, S and p are respectively the Kendall's tau statistic, the Kendall score and the two-sided p-value.

Figure 1 shows the Mann-Kendall temperature trend analysis. The values above and below zero indicate respectively positive trend and negative trend. The overall linear temperature trend is also shown in Figure 2. The Kigali Airport station shows a slight decrease (1981-1983) then a significant increase in trend in the period 1984-1999. These results are in line with the findings of Rwanyiziri *et al*. (2013) who found that most of the part of the period 1991-2012 corresponds to a significant increase in temperature trends.

Trends were not significant at the 5% significance level and we have detected trends at the 10% significance level (Burn *et al.*, 2011). The observed warming was supported by Collins (2011) who demonstrated that significant increasing temperature trends were found on average all over the African continent. Pettitt tests revealed that abrupt change points were observed in the years 1985, 1987, 1989, 1993, 1998 and 2001. This change point may be related to the period of intensive human activities in Rwanda such as agriculture development and urbanization. The increasing temperature trends observed are possibly linked to human activities (deforestation local urbanization) (MINITERE, 2006; REMA, 2009; Munyaneza*et al.*, 2011; Safari, 2012), and can possibly be attributed to natural variability or climate change (Safari, 2012).

4.2. Trend Analysis Results of Rainfall

Trends analyses of rainfall have been done and results are presented in Figure 3.

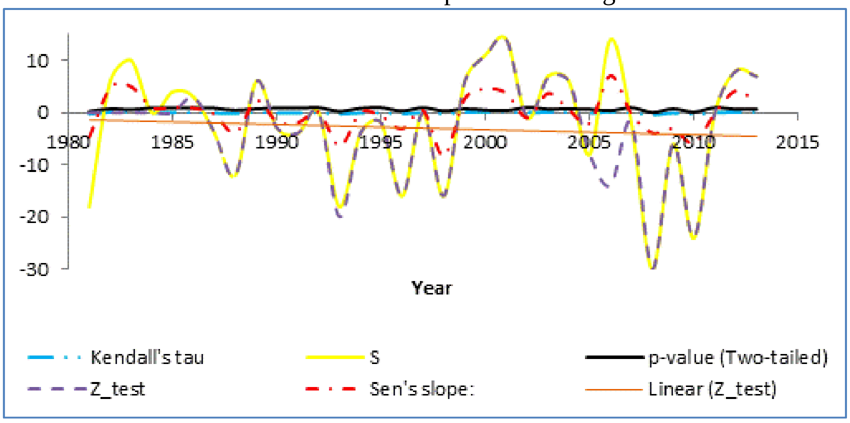

Figure 3: Trend results of rainfall: The Mann-Kendall statistics M-K, S and p are respectively the Kendall's tau statistic, the Kendall score and the two-sided p-value.

Figure3 shows that there is a significant decrease in rainfall. Similar results were obtained by Rwanyiziri *et al*. (2013) who reported that that since 1992 the total annual rainfall has significantly changed and more

unpredictable patterns of precipitation increased. The values above and below zero indicate respectively positive trend and negative trend.
The highest rainfall was observed in the year 1989, 1998, 2001, 2010 and the lowest in 1992, 2000 and 2008. In other years the amount is fluctuated. However, between 1980 and 1992 the amount of rainfall is generally decreasing and between 1992 and 2003 there is extremely high variability. From the year 1999-2001, 2004-2004 as well as 2011 to 2013, the trend shows that the rainfall is increasing. Although the overall trend shows a declining trend, there is tendency towards increased precipitation seen from 2011 onwards. Nevertheless, Nyabugogo swamp has been prone to heavy floods and the former may be explained by increase in urbanization which results in increase of impermeable (Munyaneza *et al*., 2012). In fact, with impermeable surface there is a reduction in water infiltration thus causing heavy runoff. Pettitt tests for rainfall revealed that abrupt change points was observed in the years 1981, 1998, 2008 and 2010.

4.3. Trend Analysis Results of Evaporation

Trends analyses of rainfall have been done and results are presented in Figure 3.

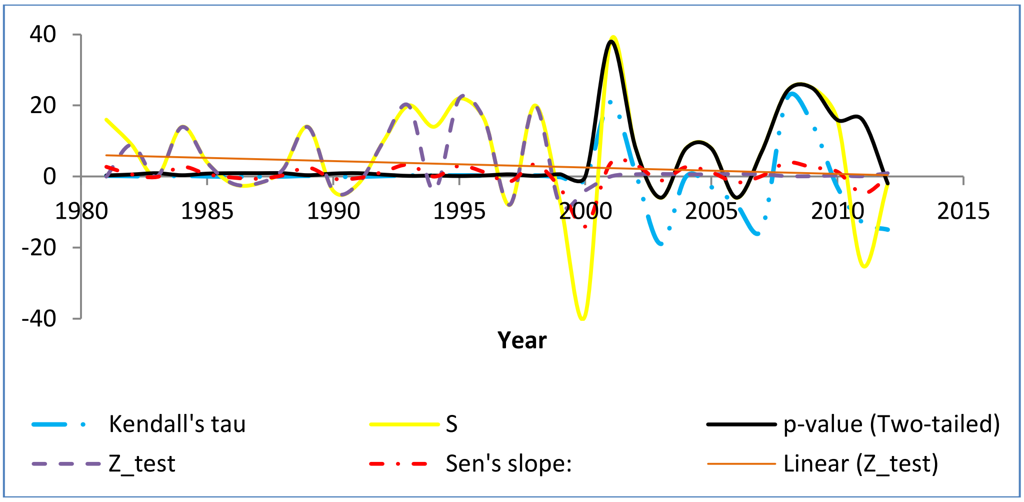

Figure4: Trend results of evaporation: The Mann-Kendall statistics M-K, S and p are respectively the Kendall's tau statistic, the Kendall score and the two-sided p-value.

Figure 4 shows that there is a significant trend in evaporation in the Nyabugogo catchment. This is also supported by the trend observed in temperature trend results (Figure 2) in this catchment. In fact, the increasing temperature results are an increase in potential evaporation largely because water holding capacity of the air is increased (Chattopadhyary*et al*., 2007). In addition, it may be explained by the fact that the cover, type, and properties of vegetation play a very important role in evaporation. Interception of precipitation is very much influenced by vegetation type (as indexed by the canopy storage capacity), and different vegetation types have different rates of transpiration. Moreover, different vegetation types produce different amounts of turbulence above the canopy; the greater the turbulence, the greater the evaporation. The values above and below zero indicate respectively positive trend and negative trend. Pettitt tests for evaporation revealed that abrupt change points were observed in the years 1982, 1984, 1991, 1995, 1998 and 2001.The abrupt change points of evaporation coincide with that observed for temperature in some years which is obvious when temperature increases the potential evaporation also increases (Chattopadhyary *et al*., 2007).

4.4. Discharge Trend Analysis

The trend analysis of the mean annual discharge of the Nyabugogo River was performed using Mann-Kendall test statistic. Due to the large data gap discharge data sets (Munyaneza *et al*., 2012), it was difficult to analyze and draw a conclusion. In fact, long records of runoff are essential to determining whether runoff of a river is changing over time (Peter, 2000). The reasons are mainly due to: i) gauge datum shifts and gradual shifts of zero stage control levels, ii) Poor river bed stability, iii) Instable controls, and iv) Insufficient number of discharge measurements.

The general conclusion which can be drawn after the analysis is that there is no continuous time series of daily water levels and/or discharge data available in Rwanda for the selected time period. The percentage value of missing streamflow data is greater than 50% (from 1984 to 1994 and from 2001 to 2009), thus we cannot rely on the results of such a poor data. However, we should not ignore that there might be a significant increase in discharge of Nyabugogo river especially basing on escalating human population which translate into the increase in human activities, urbanization, soil erosion and increasing industrialization within Nyabugogo catchment or natural climate variability (Mutabazi *et al*., 2004, Munyaneza *et al.*, 2012; Safari, 2012).

4.5. Correlation Between Climate Variables

A series of non-parametric tests were carried out on the temperature, rainfall, evaporation and discharge. The Statistical Package for the Social Science (SPSS) was used to find out whether there is any correlation between them. For datasets which are not drawn from a population with specific statistical conditions, such as normal distribution, nonparametric tests are appropriate (McCuen, 2003). This is the case for the study data, which is not unusual for hydroclimatic data (Tilahun, 2006). The Kendall's tau_b and Spearman rank test were used to determine the correlation coefficient which helps us to know the magnitude of the correlation between climatic variables especially with the focus on the Nyabugogo swamp.

The 1st trend analysis test, the Spearman rank test, is a simple measure of correlation between 2 data series and is a special case of the Pearson product-moment coefficient (Myers *et al.*, 2003). It has often been used for temporal analysis of climatic variables (*Yu et al.*, 1993; González-Hidalgo *et al.*, 2001).

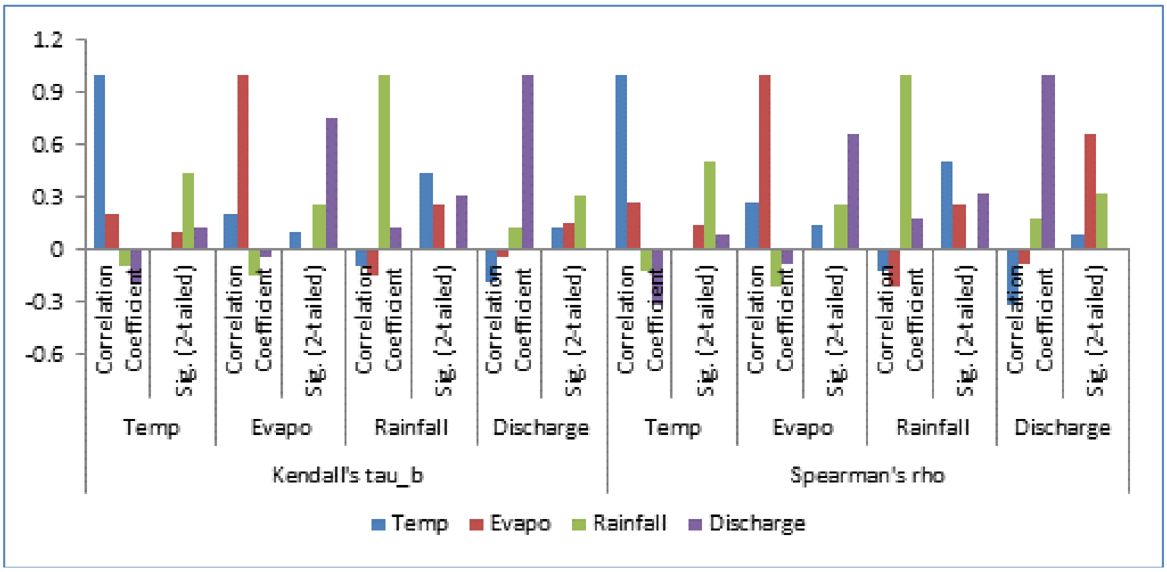

Figure5: Non-parametric correlation results between temperature, rainfall, evaporation and streamflow

Figure 5 show that streamflow was slightly correlated with the total rainfall. The observed slight relation between rainfall and streamflow is probably due to missing data and negatively correlated with the mean temperature (Munyaneza *et al*., 2012) which is in line with the fact that temperature can be seen as a proxy for available energy in the system and, thus, for the atmospheric evaporation demand. The observed positive relationship between rainfall and streamflow is also supported by Mutabazi *et al.* (2004). However, the observed similarity in streamflow and rainfall variation implies that changes in streamflow should be linked with corresponding changes in the rainfall environment. Analysis of annual mean temperature and evaporation revealed an increasing trend while rainfall trend is decreasing (Munyaneza *et al.*, 2011; Safari, 2012; Rwanyiziri *et al*., 2013).

The results of a non-parametric correlation (Fig.5); the Kendall's tau between temperature and rainfall is higher than other parameters whereby the correlation is very week. The significance test (2-tailed) was performed at 10% and the higher significance was found to be between temperature and rainfall (0.435). In fact, precipitation and temperature are physically related through the dependence of atmospheric moisture on temperature (Buishand, 1999). This higher significance between temperature and rainfall is obvious for if temperature rises there is a higher evaporation which increase water holding capacity of the atmosphere thus precipitation take place. This supports the idea that "higher temperatures and precipitation may go hand-in-hand, although in more maritime environments (Kevin, 2005); however in the maritime environment, the passage of a cold front may be followed by showers evokes the combination of cold and wet.

The correlation between climate variables was performed using Kendall's tau and it was found that temperature was positively correlated with evaporation and vice versa. However, temperature was found to be negatively correlated with rainfall and discharge. So far, rainfall and discharge were found to be positively correlated (Munyaneza, 2014), whereas the correlation between rainfall and temperature and evaporation was found to be negative. The same analysis was performed using Spearman's rho and the correlation between temperature, evaporation, rainfall and discharge was found but slightly higher than that obtained with Kendall's tau (Fig. 5).

4.6. Effects of Climate Variability and Change in the Nyabugogo Swamp

Based on the results of our research, we can highlight a number or potential effects of climate variability and change likely to take place in Nyabugogo swamp:

I. Rainfall variability is related to overall impacts on hydrological flow, water storage and availability in the Nyabugogo swamp.

II. During the period of heavy rains, surface runoff can lead to infrastructure destruction (Fig. 6, Photo 2 &3) and human lives loss.

III. The reduction of rainfall within the catchment affects irrigated agricultural areas alongside the rivers and water reservoir thus reduction in crop performance.

IV. The decrease of rainfall as a unique source of water may result in river water lowering and thus loss of biodiversity.

V. The potential effects of climate variability and change on water resources are well recognized globally and have been identified as a major issue facing the availability of groundwater resources (Alley *et al*., 1999).

VI. Increasing temperature generally results in an increase in potential evaporation, largely because the water-holding capacity of air is increased. Changes in other meteorological controls may exaggerate or offset the rise in temperature, and it is possible that increased water vapor content and lower net radiation could lead to lower evaporative demands.

VII. The climate variability and change significantly alter water quality by changing temperatures, flows, runoff rates and timing, and the ability of watersheds to assimilate wastes and pollutants. Higher flows of water could reduce pollutant concentrations or increase erosion of land surfaces and stream channels, leading to higher sediment like the ones observed in Nyabugogo wetland (Fig. 6, Photo 4) after a storm event chemical and nutrient loads in rivers. Increased periods of inundation for wetlands would result in increased rates of methane production (Meyer *et al*., 1992) and other anaerobic processes such as mercury methylation (Rudd, 1995). Lower flows could reduce dissolved oxygen concentrations, reduce the dilution of pollutants, and increase zones with high temperatures.

VIII. Changes in precipitation will also play a crucial role by affecting water quantity, flow rates, and flow timing. Decreased flows can exacerbate temperature; increase the concentration of pollutants, increase flushing times, and increase salinity in arid regions (Schindler 1997, Mulholland *et al*. 1997).

IX. Increases in water flows can dilute point-source pollutants, increase loadings from non-point source pollutants, decrease chemical reactions in streams and lakes, reduce the flushing time for contaminants, and increase export of pollutants to coastal wetlands and deltas (Jacoby 1990, Mulholland et al. 1997, Schindler 1997).

X. Increased net evaporation may increase salinity in Nyabugogo wetland water resources as also confirmed by Peter *et al.* (2000).

Figure 6:Photo1 shows the floodplain in Nyabugogo after a heavy storm event; Photos 2&3 show destroyed road at Nyabugogo after heavy rainfall; Photo 4 shows heavy loads deposited by Mpaziriver in its riverbed during the floods season.

4.7. Results on the impact of climate variability and change on water resources in the Nyabugogo swamp

The results of the analysis of temperature have proved a positive trend. The increase of temperature in the swamp have a direct impact on water evaporation by direct radiation, a reduction of the function of sediments retention and flood control, a gradual erosion of biodiversity within the swamp (Bates *et al*., 2008).The analysis of rainfall within the Nyabugogo catchment highlighted a decrease in the rainfall amount; with decreasing amounts of rainfall, the hydrological regime of wetlands is being threatened. Some of these threats, in the case of water, have affected both the quantity and quality of water available. The impact of rainfall reduction observed within the Nyabugogo swamp was also observed by Kabalisa (2006) who concluded that Rwanda's agriculture is rain-fed and is therefore exposed to vagaries of climate fluctuation. Many areas which use poor farming methods without integrating soil and water resources conservation tend to have weak agricultural productivity. In such instances, soil moisture becomes the limiting factor for crop growth (Kabalisa, 2006). The reduction of rainfall in the Nyabugogo swamp will have a negative impact on availability and sustainability of surface and ground water resources (*Dragoni et al*., 2008). The potential effects of climate variability and change on water resources are well recognized globally and have been identified as a major issue facing the availability of groundwater resources in the United States (Alley *et al*., 1999).

Climate variability and change can affect the quantity and quality of various components in the global hydrologic cycle (Loáiciga*et al*., 1996; Sherif*et al*., 1999; Milly*et al*., 2005). Such changes to the surface components of the global hydrologic cycle will likely influence the subsurface hydrologic cycle within the soil, unsaturated zone, and saturated zone, and may affect recharge, discharge, and groundwater storage of many aquifers worldwide (Timothy, 2009). However, understanding the potential effects of climate variability and change on groundwater is more complex than with surface water (Holman, 2006). Groundwater-residence times can range from days to tens of thousands of years or more, which delays and disperses the effects of climate and challenges efforts to detect responses in the groundwater to climate variability and change (Chen *et al*., 2004). Furthermore, human activities, such as groundwater pumping and resulting loss of storage and capture of natural discharge, are often on the same time scale as some climate variability and change, which makes it difficult to distinguish between human and climatic stresses on groundwater (Hanson *et al*., 2004).

The climate variability and change significantly alter water quality by changing temperatures, flows, runoff rates and timing, and the ability of watersheds to assimilate wastes and pollutants. Higher flows of water could reduce pollutant concentrations or increase erosion of land surfaces and stream channels, leading to higher sediment like the ones observed in Nyabugogo wetland after a storm event resulting in chemical and nutrient loads in rivers. Increased periods of inundation for wetlands would result in increased rates of methane production (Meyer *et al.*, 1992) and other anaerobic processes such as mercury methylation (Rudd, 1995). Lower flows could reduce dissolved oxygen concentrations, reduce the dilution of pollutants, and increase zones with high temperatures.

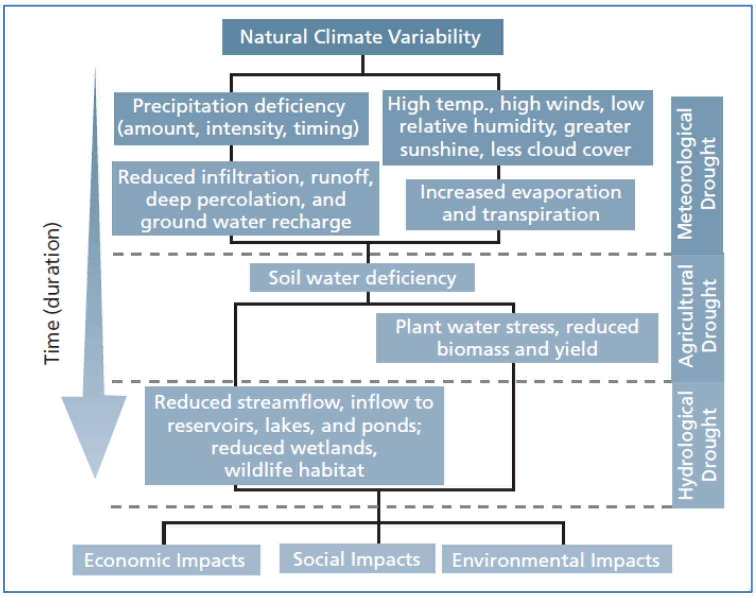

Figure 7: Summary of climate variability impact on water resources in the Nyabugogo swamp

Figure 7 summarizes different scenario likely to happen to the hydrological system in the Nyabugogo swamp. An urgent action is required to cope with the negative impact of the climate variability whether natural or anthropogenic it can be. A decrease in amount and intensity along a time scale will result into reduced infiltration, percolation which contributes to ground water recharge as an important source of the water resources. In addition, high evaporation and transpiration resulting from higher temperature with low relative humidity and high wind speed, high sunshine with less cloud will cause water deficiency within a watershed. So far, the crop will be stressed in an environment with less soil moisture which in turn results into low crop productivity. A synergy among different stakeholders involved in water resources management should rise and shine to avoid the socio-economic potential and environmental impact deriving from the mismanagement of climate variability and change.

5. CONCLUSIONS

Observed rainfall showed a significant rainfall decrease and this trend is in accordance with the second national communication related to climate change (REMA, 2010). The results of the current research highlighted that temperature and evaporation trend analysis is significant. However, we should not ignore that there might be a significant increase in discharge of Nyabugogo river, especially basing on escalating human population which translate into the increase in human activities, urbanization, soil erosion and increasing industrialization within Nyabugogo catchment where Nyabugogo swamp is located or natural climate variability. The research highlights the potential impact of climate variability and change. It should be noted that no single approach will solve the problems we have described. Based on this research findings, the conclusion that can be drawn is a holistic approach which is needed to address the challenges related to climate variability and change. Therefore, there is a need of application of integrated methods for a good sustainable water resources management in the Nyabugogo catchment. Information about how storm frequency and intensity has changed and how will change is vitally important for determining impacts on water and water systems. Yet such information is not reliably available. More research on how the severity of storms and other extreme hydrologic events might change is recommended. Then, a regular data record should be given a careful attention for future research by installing enough equipment with continuous data collection in the catchment. Finally, more detailed assessment of trends in river flows and floods, using data reaching to the present, is needed to determine if changes in climate are yet producing changes in runoff, as is a better understanding of the implications of changes in larger atmospheric conditions for runoff.

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LIST OF SYMBOLS

DEM	Digital Elevation Model
GIS	Geographic Information Systems
IHP	International Hydrological Programme
IPCC	Intergovernmental Panel on Climate Change
RNCU	Rwanda National Commission for UNESCO
RNRA	Rwanda Natural Resources Authority
SDGs	Sustainable Development Goals
SFAR	Student Funding Agency of Rwanda
SPSS	Statistical Package for the Social Science
UNESCO	United Nations Educational, Scientific and Cultural Organization
UR	University of Rwanda