Assessing the Impact of Climate Change of the Water Resources of the NDURUMU Nile Sub-Basin

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Abstract
This research was initiated with the objective of estimating the level of impact of climate change on the watershed's water availability. Climate change scenarios of precipitation and temperature were developed from the year 1975 until 2050 in the Ndurumu river basin. A linear hydrological model was used in this study to assess the non-climatic and climatic baselines impact of climate change on the water resources of Ndurumu river basin. The outputs from the projections of MAGICC/SCENGEN without climate change and with climate change (developed by the team of researchers of climatology) were used to produce the future scenarios. From these outputs with climate change, a tendency to the increase in precipitation for the farming season A (SONDJ) and a tendency to a decrease for this same parameter for the farming season B (FMAM) were assured. Also the behavior of the water resources, according to the projected changes of the principal climatic parameters (i.e. the temperature and precipitation) led to an increase of average annual flows by the year 2050 to about 7% more than now. This would most probably induce more climatic impacts as well as non- climatic impacts on these resources.

The results of the research will help in elaborating the possible measures in ahead of time.
Moreover, this will allow the consideration of the possible future risks in all phases of water resource development projects.

***Key words*:** Water Resources Management, climate change, hydrological models, scenarios

1. INTRODUCTION

The Burundi's freshwater resources are under increasing pressure. Growth in population, increased economic activity and improved standards of living lead to increased competition for water and conflicts over the limited freshwater resource. A combination of social inequity, economic marginalization and lack of poverty alleviation programmes also force people living in extreme poverty to overexploit soil and forestry resources, which often results in negative impacts on water resources. Lack of pollution control measures further degrades water resources. According to the precise definitions given by Houghton et al. (2001), climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period. Hence, assessing the impact of water resources to Climate Change at a watershed level is crucial. This gives an opportunity to develop appropriate adaptation options that must be taken ahead of time.
The objectives of this study were to:

- establish scenarios with and without climate changes to selected parameters of the watershed for the period 1975-2050
- assess the possible impacts of the climate change on water resource availability of the watershed for the period 1975-2050;
- list possible mitigation measures

2. DEFINITION OF THE FIELD OF THE STUDY

2.1. Identification of the Target Unit

The Information on groundwater is not well known and is little exploited in Burundi. Therefore, in this study, the surface water is the target unit as it dominates the life in Burundi. Worldwide, it is drained by hairy rather dense river, FIG. 1 .The water resources of Burundi are considered to be sufficient to meet the needs of the country.

Nevertheless, water is a limited and vulnerable source. This consideration is explained by the fact that the exploitation of the quantities of the available water, at an affordable price by the recipients, is limited by a variety of factors in particular including the unfavorable climatic conditions in certain areas, the unequal space-time distribution of the rainfall, the competition for the exploitation of the resource, the lack of policy of its conservation and the need for sharing the available water resources within the riparian Nile basin countries.

2.2. Study Area Definition

The study relates to Bugesera region (North-Eastern of Burundi) at Ndurumu river basin. This basin was selected as it was strongly affected, by a water stress, during the last ten years. Also, this area undergoes environmental pollution (deforestation) more marked than elsewhere of the Nile basin part of Burundi.
Map (Figure 1) shows the localization of this river basin being the subject of this study.

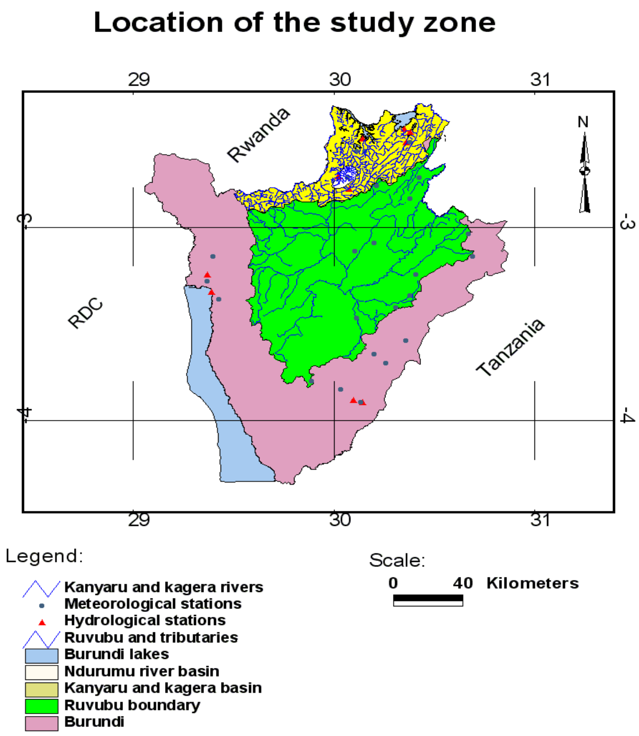

Figure 1: Location of the study zone map

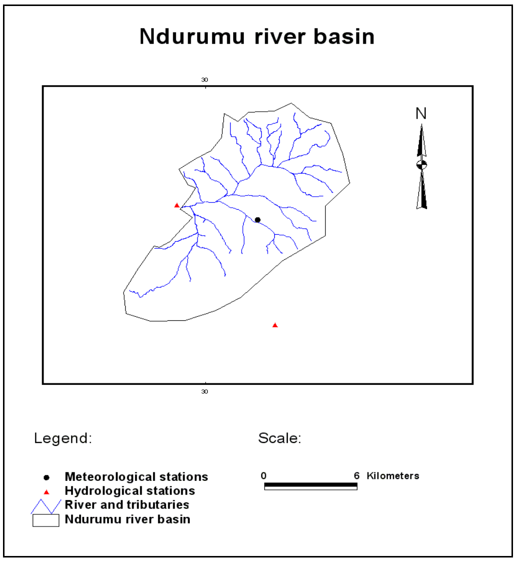

Figure 2: Ndurumu river basin

3. METHODOLOGY AND DATA ANALYSIS

Temporal Horizon

The impact of climate change on water resources of Ndurumu Nile sub-basin was predicted to the horizon 2050. The baseline period of the data was selected as going from 1975 to 2005 which is the year of the baseline situation. The estimate of the various parameters held in consideration was made on a 10 years time interval that is to say at horizons 2010, 2020,2030,2040,2050.

3.1. Source and Availability of the Data

All hydro meteorological and cartographic data, used in this study, were obtained from IGEBU (IGEBU, 1988).

For rainfall series, the climatologic station of Kirundo at Ndurumu river basin was considered as e reference. For flow series, the hydrological station of Ndurumu at Marangara was considered as a reference. The Period of observation of precipitations was from 1975 to 2005 for the station. The Period of observation of the flows was from 1981 to 1990 for Ndurumu at Marangara.

3.2. Hydrological Reference Data

As for the hydrological data, table (1) and (2) are given. They indicate the characteristics of the river basin and the historical data measured at Kirundo and at Marangara stations respectively.

Table 1 Characteristics of the river basin in the study area

River Basin	Area (Km^2)	Climatological station of reference	Annual Average Flow (m^3/s)	Annual Average rainfall (mm)	Temperature
Ndurumu	245	Kirundo	1.07	1051.5	21.4

Table 2 Historical data measured at Kirundo and at Marangara

Year	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**
RR(mm)	1200.9	1135.5	1001.1	887.3	1292.3	1217.2	1114.5	1179.4	981.1	1175.9
Q(m^3/s)	1.14	1.11	1.04	0.99	1.18	1.15	1.10	1.13	1.10	1.03
Q(mm)	146.5	142.6	134.5	127.7	152.0	147.5	141.3	145.2	133.3	145.0

IGEBU (1980-1990)

From table (2), clear was the shortage of water (1984) and the increase of precipitation (1985) during the period of observation.

3.3. Data Analysis and Their Reliability

(NINDAMUTSA A., 2007): The missing data were synthesized and extrapolated. Moreover their consistencies were examined. On the other hand, linear modeling was achieved.

3.4. Selection of the Methods

The methodology, in this study of assessing the impacts of climate change on water resources associated the following methods: the analogy, field investigations, modeling and the judgment of expert. The analogy referenced to the historical situations of the water resources of the country which occurred in the past and which will be able to be repeated in the future (drought and floods). The judgment of expert is particularly a question of synthesizing complex relations which go beyond the formal methods. Burundi has a very great ecoclimatic diversity which complicates more the study of vulnerability and adaptation to the climate change.

The investigations on the field were carried out in the zone of study (Bugesera) to really realize of the effects of the climate change on water resources in this area. These surveys were carried out near the populations and of the local managers (chiefs) at various levels.
Modeling with two levels:

- MAGICC/SCENGEN was used for simulating the climate change and generating the future scenarios.
- Linear Perturbation model (LPM) was exploited in the comparison of the rainfall of reference for the basin of study and the flow measured to the outlet.
- This model was further used for the establishment of the situation of the water resources in the absence and in the presence of the climate change to the horizon 2050.

4. TEST OF THE METHOD AND DEVELOPMENT OF THE HYDROLOGICAL BASELINE

The treated time series of daily data of average precipitations and flows were calibrated. The correlation between the flows to the outlet and average precipitations at the upstream of the catchment area of Ndurumu was established using the Linear Perturbation Model (LPM). Figure 4 shows the degree of performance of the model during the transformation of the rains fallen at the upstream of the catchment area at Kirundo station into flows at the outlet of Ndurumu at Marangara station .On the other hand , figure 5 shows the correlation between the measured flows and the simulated flows.

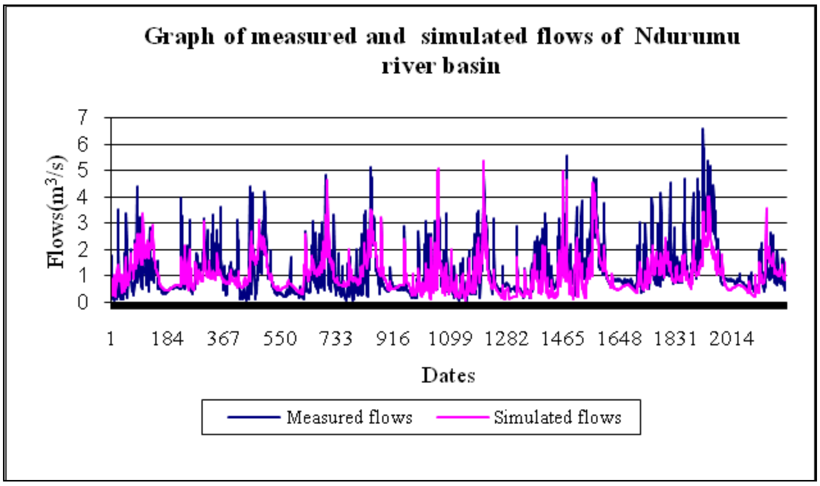

Figure 3: Measured and simulated flows of Ndurumu river basin

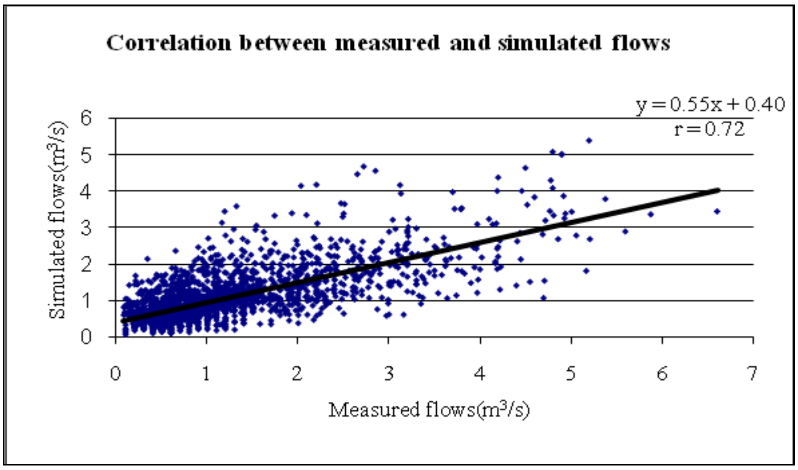

Figure 4: Correlation between measured and simulated flows

For Ndurumu: $Y = 0.55X+0.40$ $r = 0.72$

Where:

Y: Simulated flow at Marangara [m3/s]

X: Measured flow at Marangara [m3/s]

r: Correlation coefficient [-]

The correlation between the simulated flows and the flows measured at the outlet of the basin of Ndurumu is acceptable from the engineering point of view. It shows that the used Linear Perturbation Model (LPM) performed well. This evaluated the reliability of the data and the performance of the used model (LPM).

4.1. Development of the Data

The development of the data was achieved based on the good correlation between the flows simulated to the outlet and rainfall observed at the upstream of the catchment in order to establish a linear standard mathematical relation.

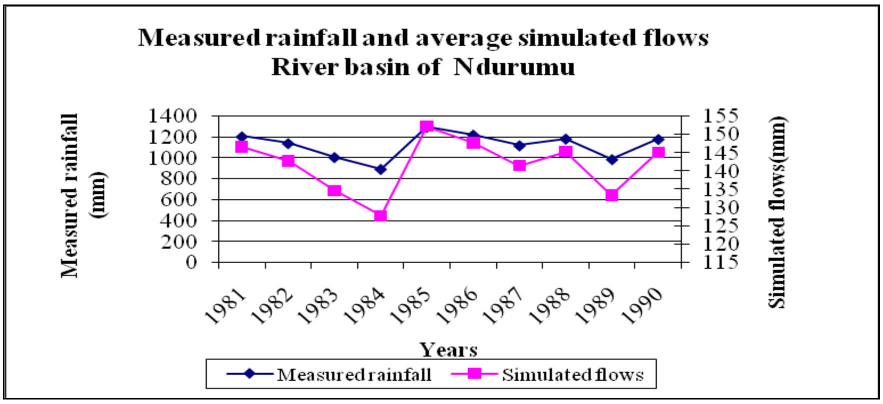

Figure 5: Measured rainfall and average simulated flows

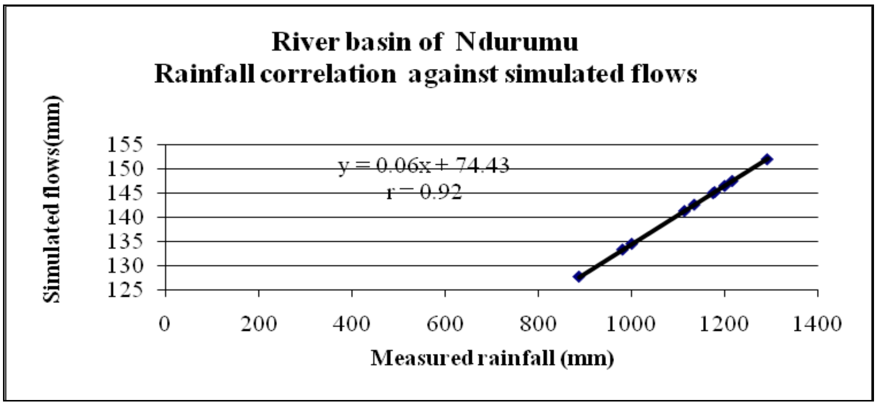

Figure 6: Rainfall correlations against simulated flows

For Ndurumu: Y= 0.06X+74.43 r= 0.92

Where:

Y: Annual average flow simulated at Marangara [mm]
X: Annual observed rainfall at Kirundo [mm]
r: Correlation coefficient [-]

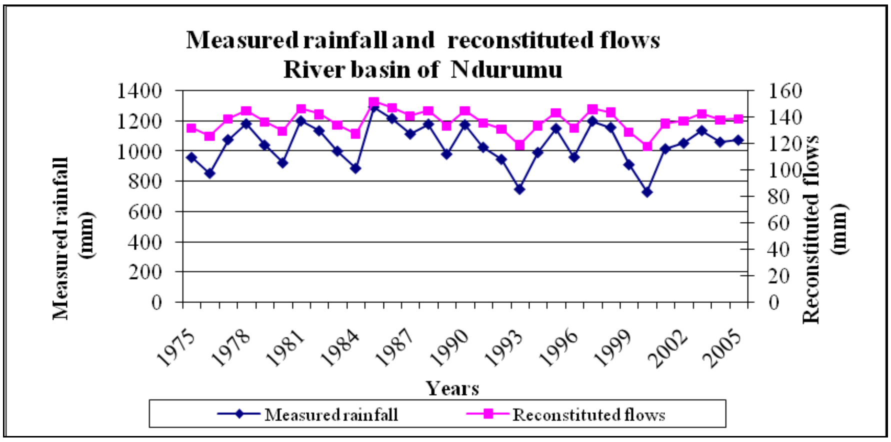

Figure 7: Measured rainfall and reconstituted flows

This equation helped in reconstituting the series of flows for all the reference period 1975-2005.

4.2. Presentation of the Hydrological Baseline Situation Without Climate Change

The projection of the rainfall series for the period of reference to the temporal horizons until year 2050 was developed based on the average results of all MAGICC/SCENGEN used models. Having these projected rainfall series that presented relations between rainfall-runoff, the series of the average flows was reconstituted for all the considered period (1975-2050), figure 7.

Table 3 Annual average flows (mm) and (m3/s)

Temporal horizon **River basin**	**2010**	**2020**	**2030**	**2040**	**2050**
Ndurumu (mm)	141.6	143.4	131.4	142.7	144.4
Ndurumu (m^3/s)	1.10	1.11	1.02	1.11	1.12

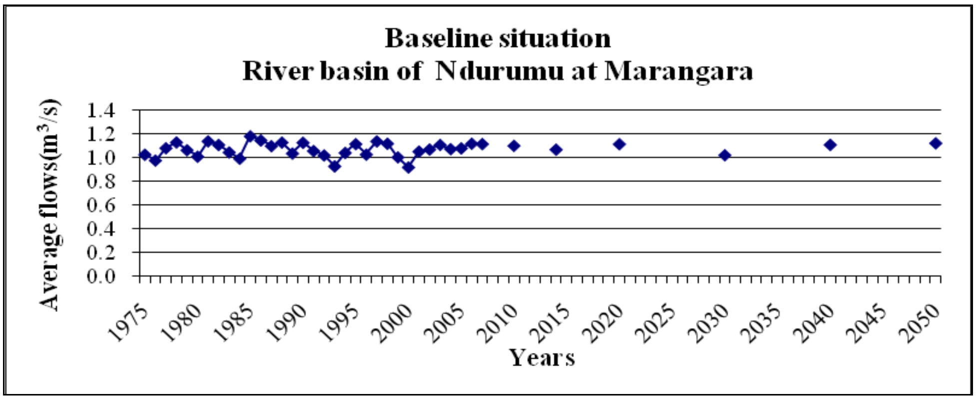

Figure 8: Baseline situation

The established baseline situation indicated that the flows of Ndurumu remained almost constant with a little increase in the flows in 2050 compared to the annual average flows of the reference period (1975-2005). For this river, the annual average flow ranged between 1.07m3/s and 1.12 m3/s for Ndurumu for the reference period (1975-2005) and projected in 2050. This corresponds to a rise of 0.05 m3/s which is equivalent to 4.7%. These effects were not taken into account the climate change during the considered period. This means that these effects are caused by other phenomena which are not originating to climate change.

5. ESTABLISHMENT OF SCENARIOS

5.1. Without Climate Change

The described hydrological baseline situation presented the evolution of the water resources of the Ndurumu river basin in Marangara during the period 1975 – 2050.This case is regarded as a scenario where the climatic parameters (i.e. the rainfall and the temperature of the air) did not change by time.

5.2. With Climate Change

The climatic study to the rainfall and temperature changes revealed that the climate changes below the entire study zone and occur on 3 levels of scenarios: High, Medium and Low. For rainfall, the annual values of the scenarios High, Medium and Low are identical everywhere, while for the temperature, the scenarios Medium and Low indicated the same values for all the projected period (2010-2050) whereas for the same period, the High scenario gave values slightly lower than the scenarios Medium and Low. Table 4 and 5 presented below the results of projection of scenarios with climate changes of rainfall and temperature respectively.

Table 4 Rainfall in %

Scenarios Horizon	High	Medium	Low
2010	1.0	1.0	1.0
2020	1.5	1.5	1.5
2030	2.3	2.3	2.3
2040	3.2	3.2	3.2
2050	4.1	4.1	4.1

Source: Results of projection of scenarios with climate changes

Table 5 Temperature in C°

Scenarios Horizon	High	Medium	Low
2010	0.3	0.4	0.4
2020	0.5	0.6	0.6
2030	0.7	0.8	0.8
2040	0.9	1.2	1.2
2050	1.0	1.6	1.6

Source: Results of projection of scenarios with climate changes

The following step was to determine the evolution of the water resources in situation of the climate changes expressed in flows of the studied river basin. The procedure used the correlation established between the simulated annual average flows and annual rainfall in the studied catchment area. The established linear regression equation before by the LPM enabled the research team to reconstitute the annual average flows from the rainfall calculated with climate changes for various levels of scenarios (Table 6).

Table 6 River basin of Ndurumu at Marangara

Years	High Scenario		Medium Scenario		Low Scenario	
	RR (mm)	Q (m^3/s)	RR (mm)	Q (m^3/s)	RR (mm)	Q (m^3/s)
2010	1131.3	1.11	1131.3	1.11	1131.3	1.11
2020	1167.4	1.12	1167.4	1.12	1167.4	1.12
2030	972.0	1.02	972.0	1.02	972	1.02
2040	1174.6	1.13	1174.6	1.13	1174.6	1.13
2050	1214	1.14	1214	1.14	1214	1.14

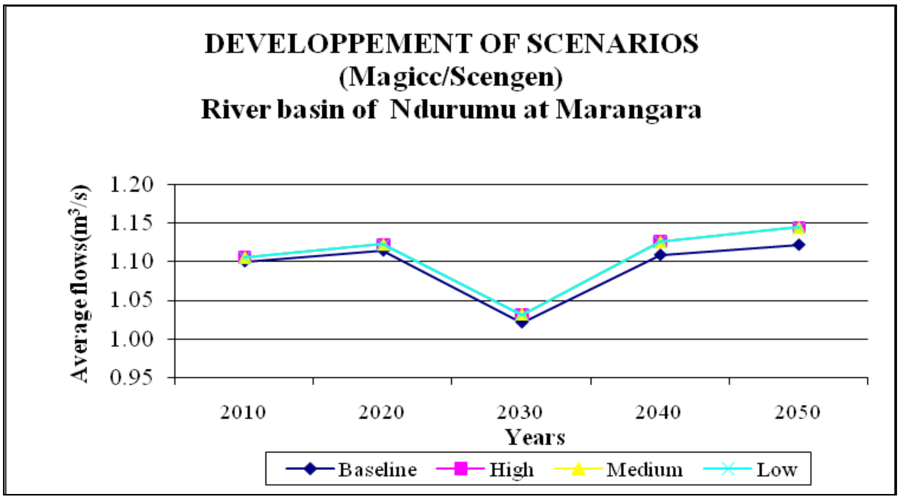

Figure 9: Graph showing the development of scenarios of the average flows at Marangara

The developed scenarios (Figure 9) at various levels of sensitivity of the climate changes indicated a slight increase in precipitations and temperature accompanied by a considerable increase in the flows of the rivers in the study area. Thus, all the scenarios (high, medium and low) with climate change showed clearly that the annual average flows of Ndurumu at Marangara ranged between 1.07 m3/s and 1.14 m3/s during the period 1975-2005 (reference period) by 2050. This corresponds to an increase of 6.5%. However, we notice a major reduction in the water resources for the period 2020-2030 for Ndurumu, to consider the increase between 2030 and 2040.

6. THE IMPACTS ASSESSMENT

The impacts are defined as the cumulative effects of the future climate changes on an exposure unit, by supposing that there will be no concomitant changes on the environmental conditions, technological, social and economic current (Amadou THIERNO GAYE, 2007). Water, being essential in the evolution of humanity, (living organisms and the natural habitat), any climate changes (intervening on precipitations and temperatures) influences it. According to the projections MAGICC/SCENGEN developed by the team of climatology within the global framework of the preparation of the SCNCC, it was noted that an increase tendency of rainfall for the farming season A (SONDJ) and a tendency of decrease of rainfall for the farming season B (FMAM), is liable to occur (NDORIMANA L. et al (2001). The present study analyzed the behavior of water resources according to the projected changes of the principal climatic parameters that are the temperature and precipitations and led to an increase in the annual average flows of about 7% of the present to the year 2050.

6.1. Climate Impacts

The climate changes might most probably induce disorders to the behavior of the hydro climatic parameters like precipitations and the flows in the rivers and lakes. The rise of temperature will cause an increase in evaporation and evapotranspiration. If no action was undertaken to maintain the ecological balance, the increase in precipitations might cause erosion on the hills and floods in low lands, the destruction of the socio-economic infrastructures like the roads, the bridges and other public infrastructures. The unequal space-temporal distribution of precipitations through the country might be induced in certain areas of the country. The excess of rainfall might cause problems to the plants (cultures) while, in other areas there might be water stress that might reduce crop production. The increase in the temperature and precipitations might involve a deterioration of water quality with the consequences of proliferation of the vector and water born diseases. On the agricultural level, rainy erosion might cause arable land losses and cultures of low lands due to floods, especially for the period of long rainy seasons. Strong rainy erosion might due to the weak hydroelectric energy production due to the reservoir sedimentation, and on-line losses due to the strong increase in temperature.

6.2. Without Climate Impacts

If current demographic growth rate was maintained and if the habitat remained dispersed as it is it today, both the water supply and electrical energy might constitute a real problem of socio-economic development of the country. From now on till year 2050, no unbalance will be established between the availability of drinking water surface and the demand due to the demographic pressure that might prevail at this period. This unbalance will involve necessarily an increased competition in the exploitation of ground water resources which is still intact of pollution till now. The industrial development and the increased use of the agricultural inputs (fertilizers) projected in order to nourish the population always in increasing, combined with an increase in precipitations and temperature (floods and droughts) will have a negative impact on the water quality (pollution) of surface and ground water.

6.3. Uncertainties

Due to the absence of a reliable database (to allow the development of the regional models), with the national or local scales, due to climate change envisaged at the 21st century, it was to recognize the delay of certain developing countries, including Burundi, with regard to its expected climate change. In general, the climate models have a horizontal resolution of several hundred kilometers. It is known that Burundi (with its modest dimensions) could not provide precise results of the outputs of these models. Due to the fact that Burundi being a mountainous country and due to model MAGICC/SCENGEN that do not take into account the effect of altitude, is then underprivileged by the fact that its climate is moderated by this parameter which is the altitude.

7. ASSESSMENT OF THE ADAPTATION

According to the GIEC, the adaptation is defined as the whole autonomous adjustments and proactive or reactive measurements of technical, policy, legislature order or other. This facilitates a system to minimize the negative impacts of the climate changes and to exploit new opportunities (SINARINZI E., 2006). After analyzing the harmful effects of the climate changes and their impacts on the water resources sector, it is important to propose that measures and the actions of adaptation of these resources to these changes should be established.

Here are some proposals for measures and actions of adaptation of water resources to the future climate changes:

7.1 Identification and Classification of the Options

1. Control and development of knowledge on the availability of the national water resources;
2. Improve the seasonal climatic forecasts;
3. Control and manage floods and drought;
4. Install a national database and information on water;
5. Study the water resources for domestic and industrial use;
6. Build the capacity in the water field;
7. Protect the water quality and water pollution treatment;
8. Manage the integral watershed and wetlands;

8. CONCLUSION AND RECOMMENDATION

The water resources in the study area are sensitive to climate change. The impact of CC on water availability is uncertain. Hence, disorders are expected in the hydro climatic parameters behavior of like precipitations and the flows in the rivers and lakes. Erosion is most likely to occur on hills and floods in low lands and for a certain period of the year; the water shortage in the areas (North-eastern of the country); an unbalance between the availability and the demand for water.
An elaboration to the possible options (to plan appropriate adaptation measures in ahead of time) is needed.The implementation of the projects helps in restoring the environmental balance in order to assure the food security of the population.
However, the government is challenged to draw attention and adapt suggestions given in the present study (i.e. implementation of the projects aiming at the restoration of environmental balance) in order to ensure the food safety of the population and the promotion of sound.

9. LIST OF ABBREVIATIONS

GIEC	Intergovernmental Experts Group on Climate Evolution
CC	Climate Change
IGEBU	Geographic Institute of Burundi
LPM	Linear Perturbation Model
MAGICC	Model of Assessment of Greenhouse Gas Induced Climate Change
SCENGEN	Scenario Generator
SCNCC	Second National Communication on Climate Change

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