DROUGHT ANALYSIS

A case study of Eastern Burundi

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A case study of Eastern Burundi

By

Dieudonné Nduwimana

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Integrated Water Resources Management of the University of Dar es Salaam

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance by the University of Dar Es Salaam the dissertation entitled: ***Drought Analysis, A case study of Eastern Burundi***, in partial fulfillment of the requirements for the degree of Masters in Integrated Water Resources Management of the University of Dar es Salaam.

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Date……………………………………….

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Date…………………………………….

DECLARATION

AND

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I, **Dieudonné NDUWIMANA**, declare that this dissertation is my original work and that it has not been presented, and will not be presented to any other University for a similar or any other degree award.

Signature: …………………………………….

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DEDICATION

This work is dedicated to my wife, Nimenya M. Clémentine and my three Kids Bellie Milinthia, Jacob Colbert and L**é**vi Jodel. Special thanks to you Madam for your prayers, encouragement, supports and for all you did on my behalf during my absence.

ABSTRACT

This study aims to identify and characterize meteorological and agricultural droughts occurred in Eastern Burundi during the last 30 years. Daily and monthly rainfall and temperature data of 11 meteorological stations provided by IGEBU are used. The percentage of normal precipitation index and the water requirement satisfaction index have been applied in the identification and analysis of the respectively meteorological and agricultural droughts. The potential evapotranspiration equivalent to the crop water requirement was estimated using the Blaney-Criddle formula and applied to the maize crop farming in the context of rainfed agriculture. On the characterization matter, main drought characteristics that are duration, drought volume, intensity severity, frequency and physical coverage were determined.

From the results of the analysis it was observed that both meteorological and agricultural droughts occurred in the eastern Burundi. It was found that droughts have increased in frequency, duration, severity and intensity during the last 15 years. Meteorological droughts are observed more at natural region level. Most of them were moderate for the most of time. The interpolation for the whole area showed one meteorological drought year that is 2005. For agricultural drought, crop performance was found to be good to very good for only 50% of the time. Results showed also that crop growing during season A (October-January) was more threatened by drought occurrence than during season B (February-May). From the spatial analysis, 50% of the study the area was found drought prone area. This includes the northern (the whole Bugesera and a part of Bweru) and the southern part constituted essentially by Moso.

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LIST OF ABBREVIATIONS

AET	Actual Evapotranspiration
EM-DAT	International Emergency Disasters Database
ENSO	El Niño–Southern Oscillation
FAO	Food and Agriculture Organization
HOORC	Harry Openheimer Okavango Research Center
IFAD	International Fund for Agriculture Development
IGEBU	Institut Géographique du Burundi
ITCZ	Inter-Tropical Convergence Zone
IWRM	Integrated Water Resources Management
NGOs	Non Governmental Organizations
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
PNP	Percent of Normal Precipitation
SPI	Standardized Precipitation Index
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USA	Unites States of America
USGS	United States Geological Survey
WFP	World Food Program
WRSI	Water Requirement Satisfaction Index

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL INTRODUCTION

Drought is a normal, recurrent feature of climate. It occurs almost everywhere, although its features vary from region to region. Defining drought is therefore difficult; it depends on differences in regions, needs, and disciplinary perspectives. Till now, there is no a universally agreed definition of drought. Scientists have only agreed on very general definitions of a drought. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector (www.drought.unl.edu/whatis/concept.htm).

Drought is the third most common disaster by occurrence in Africa, accounting for 31% of all natural disaster events in Africa during 1975 – 2002 (Vordzorgbe 2003). During the past ten years, three-quarters of the droughts in the world have occurred in Africa. Droughts in African countries are rendering the population utterly vulnerable. They exert environmental, economic and social impacts that retard sustainable development in Africa. Samata (2004) summarized the effects of African droughts as following: From 1900 to 2004, 459 drought events occurred in Africa; a total of 314,238,582 people have been affected with 1,046,394 killed and 48,000 homeless, value of damage estimated to 4,472,093,000 USD.

In Eastern Africa, droughts are recurrent events. Kenya and Ethiopia are part of the countries in Africa reporting the highest frequency of drought together with Chad, Botswana, Burkina Faso, Mozambique and Mauritania (www.amcow.org/exco/droughtsituationinafrica.doc). Other eastern African countries are also regularly facing droughts.

Burundi is part of this sub-region and during the last 10 years, drought events are occurring annually especially in the north and eastern parts of the country. The 1998/1999 and 2004/2005 drought events were the greatest (Barakiza, 2006). The International Emergency Disasters Database (EM-DAT) shows that 2005 was the worst drought disaster in Burundi; From January 2005 to January 2006, 120 peoples were killed and a total of 2,150,000 people were affected (http://www.embdat.be/database). The 2005 year has been declared a national drought disaster year by the Government. The Word Food Program affirmed that the country has been also affected by a severe drought in 2006 (http://www.wfp.org/country_brief/indexcountry.asp?country=108).

Because of this increasing situation of drought occurrences, politicians are being aware of the problems caused by droughts and measures are taken. The actions undertaken relate to emergency relief. Middle and long term measures are still lacking. Improved approaches, methods and tools to detect and analyse droughts are needed to help the understanding and the ability to respond effectively to droughts.

1.2 DESCRIPTION OF THE STUDY AREA

Burundi is a landlocked nation covering 27 834 km^2, located between 2°15” and 4°30” South in East - Central Africa and between 29 and 31° east, bordering Rwanda to the north, Tanzania to the east and south, and the Democratic Republic of Congo to the west.

1.2.1 Study area location and Extent

The concerned study area is the eastern part of Burundi as shown by the Figure 1.1.

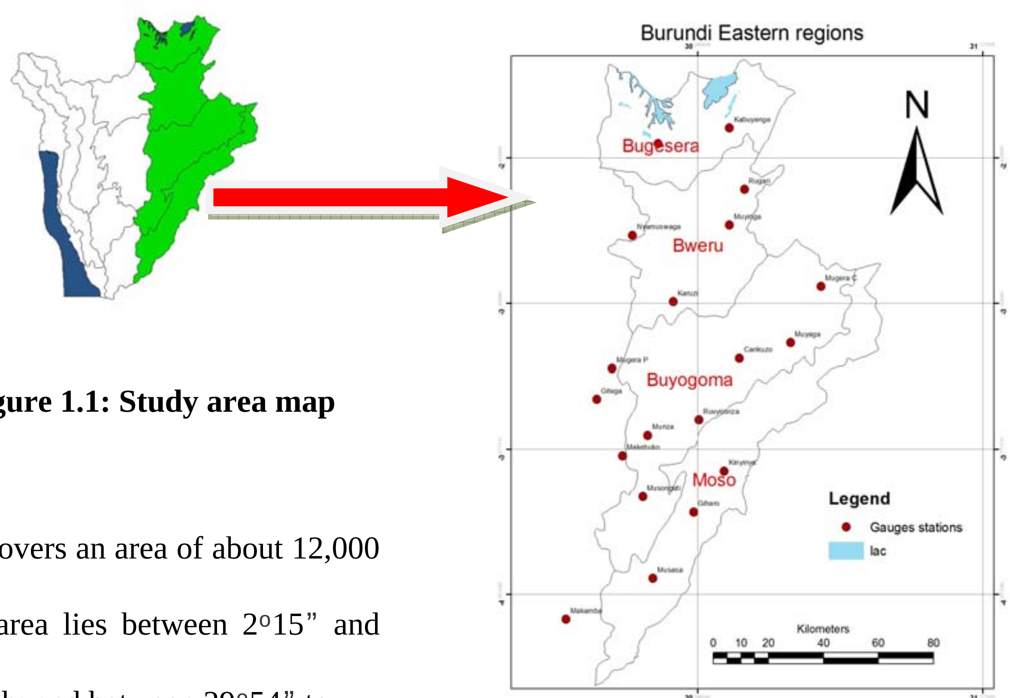

Figure 1.1: Study area map

That part covers an area of about 12,000 km^2. The area lies between 2°15” and 4°20” South; and between 29°54” to 31° East.

From North to South, it is constituted by the following natural regions: Bugesera, Bweru, Buyogoma and Moso. Provinces fully located in the study area are, from the north to the south, Kirundo, Muyinga, Karuzi, Cankuzo, Ruyigi and Rutana. The study area extent equals 1,148,561 ha (41% of the Burundi area).

1.2.2 Water resources

In general, Burundi has sufficient water resources. According to Ministry of Land, Tourist and Environment, the eastern part is the last with less quantity of water resources especially in Bugesera and Moso natural regions. The area is characterized by a weak rainfall, with irregular and reduced precipitations that often cause a drying up of the existing shallow surface water sources and a reduction in the agricultural productions (Ministère de l'Aménagement du Territoire, du Tourisme et de l'Environnement, 2000). A big part of that area is drained by Ruvubu river. The remaining part is drained by two bordering rivers: Kanyaru at the Rwandan border and Maragarazi at Tanzanian border.

1.2.3 Elevation and climate

The study area is located in the part of the country with the lowest altitudes. It comprises the lowest part of the central plateau and the eastern depressions. The elevation lies between 1200 and 1500m of altitude.

The eastern part and the plain of Imbo are considered the hottest areas of the country. In the part of concern, the daily average temperature is in general higher than 20°C. It is also the part with less precipitations of high variability. The dry season period lasts from 4 to 6 months, some time even 7 months. The longest dry season is met in the eastern depressions. In the area, annual rainfall estimation varies between 900 and 1200 mm.

1.2.4 Land cover

Vegetation in Burundi has decreased in area these last fifteen years. Two major factors cause that situation. The increasing population is making high pressure on vegetation converting forests into crop farming land. Another factor is the ware faced by Burundi in nineties from 1993. A part the destruction related to security purpose, many people have taken advantage of the war to make illicit wood trade through illicit wood trade. That situation has lead to massive loss of forests in different regions of the country, the study area regions included. The comparison of protected natural and planted forests areas before and after 1993 by Koyo (2004), shows the following: Protected forests areas passed from 138,800 ha in 1970 to 71,700 ha in 2000 (decrease of 48%); Also, plantations areas decreased from 151,000 ha in 1993 to 109,000 ha in 1997 showing a decrease in area of almost 30%. In my study area, the area of the protected open forest of southern and eastern parts of the country was estimated at 20,000 ha when it was 30,000 ha in 1950 (Koyo, 2004).

1.2.5 Population

Burundi is one of the countries with the highest population densities. The population is about 7.5 millions and the average density is estimated to 270 people per km^2. The population is unequally distributed in the country. The eastern Burundi has the lowest population density. One of the reasons is now the repetitive drought occurrences during these last 10 years.

1.2.6 Agriculture and food security

In general, the area has fertile soils. The main soil type is hygroxeroferrisols with a high crop farming aptitude. Main cash crops include cotton et sugar can in Moso and coffee Arabica in Bugesera, Bweru and Buyogoma. For food crops, different types exist: banana: 10 – 15%, leguminous: 20 – 30%, cereals: 30 – 40%, and tubers: 10 to 20% for Moso, and less than 10% for the three others natural regions.

Burundi was traditionally self-sufficient in food production. Crop farming land occupies 22 to 35 % of the area. The Bugesera, Bweru and Buyogoma regions (in the study area) used to be the big producers of beans and cereals like maize and sorghum which are most consumed in the country. These last years, situation has progressively changed and the rural population is facing an increasing food insecurity and poverty resulted mainly in high population pressures on overcultivated and eroded land supporting farms, persisting drought, poor quality of agricultural implements and technology, and limited market incentives, low productivity of labor, low cash incomes from subsistence agriculture or limited non-agricultural activities, etc. (IFAD, 2007).

The study area has been the most affected. According to the IFAD (2007), the adverse effects of three last years of drought, the expansion of crop pests and decreasing land productivity are most apparent in the eastern and northern regions. In those regions an estimated 100,000 households are at permanent risk of food insecurity and fragile nutritional conditions.

1.3 PROBLEM STATEMENT

According to the UNDP development report, Burundi ranks among the six nations with the lowest human development index in the world. Agriculture is the backbone of the country. It is the main source of livelihood for nine in ten Burundians. In 2004, the sector accounted for 51 per cent of the country's gross domestic product (GDP). Burundi, traditionally self-sufficient in food production, is nowadays facing food insecurity. For the IFAD (2007), one of the main causes of that increasing poverty and food insecurity is the persisting drought.

During the last 10 years, drought events frequently occurred in Burundi especially in the north and eastern parts of the country (Barakiza, 2006). Some of them had lead to serious socio-economic problems (deaths, increased poverty, food insecurity/famines, displacement). The greatest drought occurred in 2005 and was officially declared national drought disaster by the government. The International Emergency Disasters Database (EM-DAT) shows that 2,150,000 people were affected and 120 were killed from January 2005 to January 2006 in Kirundo, Muyinga, Ruyigi, Cankuzo and Rutana provinces (http://www.emdat.be/database).

The famines and deaths observed resulted from food shortages. WFP estimated a food deficit of 334,000 tones in 2005. In Muyinga province, 84,093 people - representing 80% of Muyinga's population - were facing food shortages as crop production had drastically dropped. IRIN has confirmed on 20 January 2006 that the 120 Burundians have died because of the food shortages brought on by drought prevailing in the mentioned provinces of the study area. The food shortages have also lead to population displacements towards other regions in and outside of the country (IRIN, 2006). A total of 2,500 people in Ruyigi (Province) have crossed to Tanzania since December (2005). For Muyinga province, 2,512 residents had fled, either to other provinces in the country or to neighboring Rwanda and Tanzania (IRIN, 2006).

Responding to the previous drought events, just emergency actions have been undertaken by the government to reduce their impacts. Measures taken were just emergency actions. The country doesn’t have a drought plan for a medium and long term and a reactive, crisis management approach is the one used. Tools to identify and characterize drought events in Burundi are still lacking for appropriate drought preparedness and prevention. In this study, meteorological and agricultural droughts will be analyzed. The analysis will give a better understanding of drought occurrence, risk and impact.

1.4 OBJECTIVES OF THE STUDY

General objective: The purpose of the study is to analyze droughts in Eastern Burundi.

Specific objectives:

1. Meteorological drought events identification and characterization
2. Agricultural drought analysis using the Water requirement Satisfactory Index approach

1.5 SIGNIFICANCE OF THE STUDY

The study aims to identify and characterize droughts in the Eastern Burundi. It will allow a better understanding of drought occurrence, risk and impact. It is envisaged that the results of the study will enable the policy makers and the planners to make more informed choices in drought preparedness and planning.

It is also known that there have been very few studies on droughts in Burundi. Furthermore, our country is trying to implement an IWRM plan which obviously will include drought aspects. It will add up knowledge that is needed in decision making and policy making for improving the management of water resources in general and droughts in particular. The research report will be very useful in the sense that it will include data and practical indicators and methods to detect and characterize droughts.

1.6 DISSERTATION LAYOUT

The chapter one describes the study area, the problem statement, the objectives and the significance of the study. The chapter two contains the literature review. Chapter three relates to the methodology. Chapter four includes the results and discussions. The chapter five is reserved for conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 DROUGHT CONCEPT

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes. Drought occurs in high as well as low rainfall areas and is a temporary aberration, in contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event.

Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought year is unique in its climatic characteristics. This factor complicates the estimation of impacts.

Drought differs from other natural hazards in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as a creeping phenomenon. Climatologists continue to struggle with recognizing the onset of drought and scientists and policy makers continue to debate the basis (i.e., criteria) for declaring an end to a drought.

Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed (Wilhite and Glantz, 1985).

Although many definitions exist, many do not adequately define drought in meaningful terms for scientists and policy makers. For example, the thresholds for declaring drought are arbitrary in that they are not linked to specific impacts in key economic sectors. These types of problems are the result of a misunderstanding of the concept by those formulating definitions and the lack of consideration given to how other scientists or disciplines will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, drought declarations or revocations for eligibility to relief programs). Third, drought impacts are nonstructural in contrast to floods, hurricanes, and most other natural hazards. Its impacts are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. Emergency managers, for example, are more accustomed to dealing with impacts that are structural and localized, responding to these events by restoring communication and transportation channels, providing emergency medical supplies, ensuring safe drinking water, and so forth. These characteristics of drought have hindered the development of accurate, reliable, and timely estimates of severity and impacts and, ultimately, the formulation of drought contingency plans by most governments

2.1.1 Definition and types of drought

There is no a universal agreed definition but scientists have agreed on some general definitions. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector (www.drought.unl.edu/whatis/concept.htm). Conceptual and operational definitions exist. From them, it has been recognized that drought is spatial, temporal and application specific.

From the disciplinary Perspective on Drought, different types of drought have been defined. Wilhite and Glantz (1985) categorized the definitions in terms of four basic approaches to measuring drought: meteorological, hydrological, agricultural, and socioeconomic. The first three approaches deal with ways to measure drought as a physical phenomenon. The last deals with drought in terms of supply and demand, tracking the effects of water shortfall as it ripples through socio-economic systems. The different types of drought may coexist or may occur separately.

2.1.1.1 Meteorological drought

It is defined as a deficiency in the normally expected rainfall over a substantial area. It is usually an expression of precipitation’s departure from normal over some period of time. Meteorological drought can be defined on a decadal, monthly and annual time interval. These definitions are usually region-specific, and presumably based on a thorough understanding of regional climatology.

2.1.1.2 Agricultural drought

Agricultural drought occurs when there isn’t enough soil moisture to meet the needs of a particular crop and pasture growth at a particular time. Agriculturalists are usually concerned with the soil moisture deficiencies as they relate to crop development and yield. Agricultural drought occurrence doesn’t depend only on the amount of rainfall, but also on the correct use of that water. The deficiency of water in sensitive crop stages even for short period can reduce the agriculture production severely. Water shortage is considered relative to some long-term average condition of balance between precipitation and evapotranspiration in a particular area.

2.1.1.3 Hydrological drought

Hydrological drought refers to deficiency in surface and subsurface water supplies. Hydrologists are more concerned with how this deficiency plays out through the hydrological cycle. Hydrological drought occurs when the water content in rivers, lakes, dams, groundwater and soil is below the average and cannot sustain normal water supplies. Hydrological drought analysis is catchment based. It is measured as streamflow and as lake, reservoir, and groundwater levels.

There is a time lag between lack or deficiency of rain and less water in streams, rivers, lakes, and reservoirs, so hydrological measurements are not the earliest indicators of drought. When precipitation is reduced or deficient over an extended period of time, this shortage will be reflected in declining surface and subsurface water levels.

2.1.1.4 Socio-economic drought

Socioeconomic drought occurs when physical water shortage starts to affect people, individually and collectively, by reduced availability of goods dependent on precipitation. Or, in more abstract terms, most socioeconomic definitions of drought associate it with the supply and demand of an economic good.

2.1.2 Relationship and succession of the different types of droughts

All drought droughts originate from a deficiency of precipitation. Agriculture is usually the first economic sector to be affected by drought. With the increasing complexity of impacts and the lasting of time and duration of the event, the order of occurrence of the different types of droughts has been determined as in Figure 2.1 below.

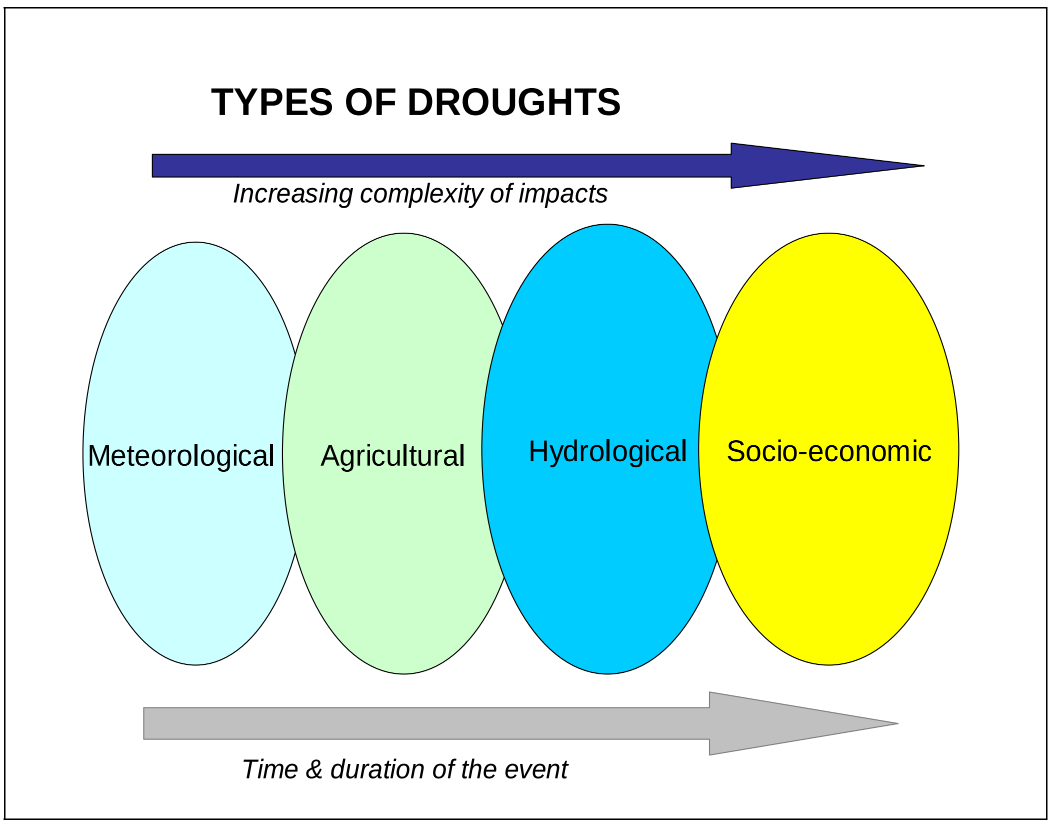

Figure 2.1: Relationship and succession of different types of droughts

Source: HOORC (2007)

2.1.3 Causes of droughts

Droughts are manifestations of persistent large-scale disruptions in the global circulation pattern of the atmosphere. Drought is not exclusively the result of a single cause. Drought typically results from a synergistic interaction between regional and remote influences. The processes leading to circulation anomalies have to be analysed in the context of coupled interaction of climate system components including atmosphere, land and ocean). Factors affecting climate/rainfall are external (solar radiation, volcanic eruptions, man through land cover changes and gas emissions) and internal through:

- Turbulent transport of heat, mass and momentum in a complex global atmospheric circulation system
- Ocean and atmosphere interactions through turbulent transport of heat, mass and momentum within oceans
- Land and atmosphere interactions: short-term feedbacks (soil moisture forcing) and long-term feedbacks (vegetation forcing). In this regard, human can negatively or positively play a role through vegetation and land management.
- The linkages of regional atmospheric-circulation features across global distances mean that effects of anomalous circulations or boundary conditions can be manifested at great distances.
- These long-distance connections interact with feedback mechanisms within an affected area.

Forecast model experiments during the past few years indicate that drought conditions themselves may play a role in the perpetuation of the drought through a feedback between the land surface and the overlying atmosphere that reinforces the drought sustaining circulation features.

In a global context, extensive research during the past two decades clearly indicates the central role of tropical Pacific sea surface temperature variations, associated with the El Niño–Southern Oscillation (ENSO) phenomenon, in year-to-year global climate variations. The effect of these ocean variations is transmitted to remote areas of the globe through recurrent, seasonally varying patterns of atmospheric circulation anomalies referred to as teleconnections. These teleconnections affect the precipitation regime over much of the tropics, and over large areas of the extratropics as well, including Australia, eastern Asia, southern Africa, and regions of both North and South America. Observational studies and model experiments have also demonstrated a significant link between Atlantic sea surface temperatures and precipitation over the drought-prone areas of the African Sahel and northeast Brazil.

Below normal rainfall (drought) over southern Africa is specifically due to low phase Walker circulation (descending limb over southern Africa), weakening of ITCZ, tendency to high pressure with diminished occurrence of tropical lows and weakening of the South Atlantic High Pressure Cell.

2.1.4 Characteristics of drought

The characteristics of drought are drought magnitude, severity, duration, intensity, frequency and spatial coverage.

2.1.4.1 Drought magnitude

Drought magnitude is often expressed as the drought volume or drought index. Drought volume is the total deficit over the period of drought. It is determined by cumulating rainfall deficiencies over the period. Rainfall deficiency is defined as the difference between the expected rainfall and what is actually received.

2.1.4.2 Duration

Another distinguishing feature of drought is its duration. Each drought event has a duration defined by its beginning and end. Droughts usually require a minimum of two to three months to become established but then can continue for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event. As droughts extend from one season to another and from one year to another, the potential impacts become much greater since surface and subsurface water supplies continue to be depleted and a larger number of users are affected. From an agricultural perspective, consecutive years of drought depletes farm income and places in serious jeopardy the financial solvency of farm or ranch operations.

Drought develops slowly and impacts accumulate as conditions persist for seasons or years. Impacts are usually first apparent in agriculture, but gradually ripple to other sectors such as transportation, energy, recreation and tourism, and urban water supplies. For example, hydrologic storage systems (e.g., reservoirs, lakes, and rivers) are often used for multiple and competing purposes. Competition for water in these storage systems escalates during drought, and conflicts between water users increase significantly. Impacts continue well beyond the end of the meteorological event because the recovery time for water stored in surface and subsurface systems is quite long in many cases.

2.1.4.3 Intensity

Drought intensity is a value which shows the seriousness of the drought; the higher the value, the more disastrous the drought. It is estimated as the ratio of the magnitude over the duration. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact.

2.1.4.4 Severity

Drought severity is measured by a drought index. The severity is dependent on the duration, intensity, and spatial extent of a specific drought episode. It is also dependent on the demands made by human activities and vegetation on a region's water supplies. Several types of indices used in describing the degree of severity of drought episode existent. They are described in the section 2.1.5.

2.1.4.5 Frequency

Drought frequency physics the number of times that drought occurs within a specific period. A drought (volume) duration curve and return period curve are useful means of representing the probability of occurrence of droughts.

2.1.4.6 Spatial coverage

In drought analysis, it is necessary and imperative that the results be clearly represented. There exist many methods of representing drought. It includes graphical methods, mapping techniques, textual presentations, model definitions etc. The mapping technique serves as a good way of representing large amounts of information.

2.1.5 Drought indicators

Drought indicators are variables used to describe drought characteristics; (magnitude, duration, intensity, frequency, severity, and spatial extent). They are important for detecting and monitoring drought conditions. Indicators also assist in determining the timing and level of response to a drought**.**

Drought indicators are often categorized into two groups:

1. Meteorological Indicators use climatic variables (precipitation, temperature, evapotranspiration). Precipitation is the widely used since it reflects the water supply.
2. Hydrological Indicators use variables such as stream flows, soil moisture, groundwater levels and storage, reservoir levels and storage.

2.1.5.1 Drought Index

Drought index is an indicator of drought severity. It is typically a single number, far more useful than raw data for decision making. A drought index assimilates thousands of data on rainfall, snowpack, streamflow and other water-supply indicators into a comprehensible picture. Several indices measure how much precipitation for a given period of time has deviated from historically established norms. Many indices of drought are in widespread use today, such as the deciles approach (Lee, 1979; Coughlan 1987) used in Australia, the Palmer Drought Severity Index (PDSI) and Crop Moisture Index (Palmer, 1965 and 1968; Alley, 1984) in the United States, and the Yield Moisture Index (Jose et al. 1991) in the Philippines, Standardized Precipitation Index (SPI) in USA and elsewhere, etc.

2.1.5.2 Precipitation based indices

The main precipitation based indices are: The Percent of Normal Precipitation, Deciles, Standardized Precipitation Index and the Palmer Drought Severity Indicator.

1) Percent of Normal Precipitation (PNP)

The "Normal" may be, and usually is, set to a long-term mean or median precipitation value. The percent of normal precipitation is the ratio of actual to normal precipitation for a given location and a given period, expressed as a percentage. This can be calculated for a variety of time scales that usually range from a single month to a group of months representing a particular season, to calendar or water year. The PNP can also be used for small time intervals like daily, weekly or decadal, depending on the objective. (www.drought.unl.edu/whatis/indices.htm)

They are several definitions of drought based on the percentage of normal. Bates (1935) suggested defining drought in USA when annual rainfall is 75% of the normal or monthly precipitation. Banerji and Chabra (1964) considered severe drought conditions in the State of Andhra Pradesh, India, to be coincident with seasonal rainfall deficit of more 50% (which means rainfall of less than 50% of normal). Generally, meteorological drought in India is defined when rainfall in a month or a season is less than 75% of its long-term mean. If the rainfall is 50-74% of the mean, a moderate drought event is assumed to occur, and when rainfall is less than 50% of its mean, a severe drought occurs. In South Africa, period with precipitation less than 70% of normal precipitation is considered as a drought. This becomes a disaster or severe drought when 2 consecutive seasons experience 70% of normal precipitation or less (Bruwer, 1990).

2) Deciles

The deciles indicator is used by the Australian Drought Watch. It requires long-term precipitation data (more than 30 years) for estimation and gives an idea of the severity of the drought. A frequency distribution of rainfall is constructed for a particular month. Deciles technique classify rainfall into 10 classes, each called a deciles. Drought conditions are concerned by the four first deciles. From the sixth to the tenth deciles, wet conditions are of concern. The fifth deciles relates to the median conditions. Regarding drought qualification, deciles are then described as following:

- 1st deciles when rainfall is not exceeded by the lowest 10% of the records: extremely drought
- 2nd deciles (rainfall not exceeded by the lowest 20% of the records): severe drought
- 3rd deciles (rainfall not exceeded by the lowest 30% of the records): moderate drought
- 4th deciles (rain not exceeded by the lowest 40% of the records) – mild drought.

The disadvantage of the use of this indicator is that it does not consider cumulative effects of rainfall during preceding months or years.

3) Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is relatively new index that has gained considerable popularity in the United States and worldwide. It has been developed by McKee et al. (1993 and 1995). The index is currently in use as a part of a routine monitoring program in more than 40 countries. It requires long-term data and use different time scales to reflect effects on various water related variables, e.g. soil moisture, stream flows, groundwater.

Precipitation data for the desired time interval is fitted to a probability distribution function such as a Gamma or Pearson Type III distribution. For a given precipitation value (*x*), its cumulative probability (*p*) is determined. Where *p* is the probability of having precipitation less than or equal to *x*, $P(X<=x) = p$. The standard normal variate or z-score with a cumulative probability of *p* is determined by using the normal distribution. The z-score is the Standardize Precipitation Index (SPI). SPI tend to vary from -3.0 to +3.0 and drought situation is qualified as follow:

1. From 0.00 to 0.99 : Mild drought
2. From -1.00 to -1.49 : Moderate drought
3. From -1.50 to -1.99 : Severe drought
4. -2.00 or less : Extreme drought

4) Palmer Drought Severity Index (PDSI)

The PDSI is widely used in the USA and Canada. It uses meteorological and hydrological variables and attempts to incorporate the supply and demand side of water by undertaking a water balance analysis of a particular location. Recharge (R), actual evapotranspiration (AET), Runoff (RO), and loss (L), and potential values of these parameters are estimated for each month.

Using the PDSI, drought conditions are categorized as follow:

PDSI < -4.0 extreme drought

-3.0 < PDSI < -2.0 severe drought

-0.2 < PDSI < -1.0 mild drought

2.2 DATA INTERPOLATION

2.2.1 Necessity for data interpolation

Hydro-meteorological indicators are important tools in water resources management. They vary in space and time. Monitoring and analysis of areal data need having adequately dense recording stations. In developing countries, these are in general less dense in space due to economic and natural causes. Another problem is the presence of recording errors and missing values in the recorded data causing the data to be less useful. Spatial interpolation enables the estimation of values at unknown locations within the area covered by existing observations.

2.2.2 INTERPOLATION METHODS

Interpolation methods are used to estimate areal and gridded data from point data. The methods are grouped in three main: graphical, Empirical and Numerical.

2.2.2.1 Graphical Methods

Graphical methods involve mapping of data, sometimes in combination with elevation. They include: Thiessen Method, Grid-Point Method and Isohyetal Mapping

Thiessen Method

It is a geometric method developed by Thiessen (1911) to estimate the areal average rainfall. The rainfall gauge stations are plotted on a map and connecting lines are drawn. The perpendicular bisectors of the lines joining gauges form a network of polygons.

This method allow the estimation of areal average rainfall for non-uniform distribution of gauges when some of them are more representative of the area than others, by providing a relative weighted factor for each gauge. This factor is determined from the corresponding areas of application in the Thiessen polygon network and the areal average rainfall is estimated by the following equation:

$$\overline{P} = \frac{1}{A}\sum_{i=1}^{i=N} A_i P_i \qquad \text{With} \qquad A = \sum_{i=1}^{N} A_i$$

Where,

$\overline{P}$ is the watershed's average areal precipitation

A is the total watershed's area

P_i is the precipitation point data from polygon of influence, i.

A_i is the area of polygon of influence, i.

Grid-Point Method

This method averages the estimated data at all points of the superimposed grid. It is practical only with the aid of a computer. The reliability of the approach depends on the method used to estimate data at the grids.

Isohyetal Mapping

Isohyetal map is constructed with lines joining points with equal amounts of precipitation called Isohyets or isohyetal lines. The isohyetal mapping involves the interpolation and generalization from rainfall data recorded at gauged points. To compute the areal average precipitation, the area Ai sandwiched between each pair of isohyets, within the area, is measured and multiplied by the average Pi of the rainfall depths of boundary isohyets.

2.2.2.2 Empirical methods

These methods involve the correlation of point with an array of topographic and synoptic parameters such as slope, exposure and point altitude, location of barriers, wind speed, distance from large water body and wind pattern and direction.

2.2.2.3 Numerical Methods

Inverse Distance Weighting Method

In this case, weighting of the estimator data points is prescribed to decrease with an increase in distance from point of estimation. In case of rainfall interpolation,

the average precipitation of the estimation point is given by the equation below (www.emsi.com/smshelp/Data_Module/Interpolation/Inverse_Distance_Weighted.htm).

$$MAP = \sum_{i=1}^{N} w_i P_i$$

In which, for traditional IDWM, $w_i = \dfrac{h_i^{-p}}{\sum_{i=1}^{N} h_i^{-p}}$

Usually p=2

For modified IDWM, $w_i = \dfrac{\left[\dfrac{R-h_i}{Rh_i}\right]^2}{\sum_{i=1}^{N}\left[\dfrac{R-h_i}{Rh_i}\right]^2}$

Where,

MAP is the Mean Average Precipitation of the estimation.

w_i is the weighting contribution from station i

h_i is the distance of the estimator point from a target point

R is the distance of the furthest estimator point from target estimation point

Kriging Method

Kriging method is a regression technique used in geostatistics to approximate or interpolate data in one or more dimensions. It is based on the assumption that the parameter being interpolated can be treated as a regionalized variable. A regionalized variable is intermediate between a truly random variable and a completely deterministic variable in that it varies in a continuous manner from one location to the next and therefore points that are near each other have a certain degree of spatial correlation, but point that are widely separated are statistically independent. Kriging is a set of linear regression routines which minimize estimation variance from a predefined covariance model.

CHAPTER THREE

METHODOLOGY

3.1 DATA COLLECTED AND SOURCES

The time series data collected are daily and monthly rainfall and temperature from eleven meteorological stations located in or neighboring the study area. All the data were analyzed using excel spreadsheet package. Seasonal and annual rainfalls were also calculated.

The time series data collected and their sources are shown in Table 3.1 below.

Table 3.1: Data collected and Institution providers

Purpose	**Types of collected data**	**Institution provider**
Meteorological droughts identification and characterization	Monthly rainfall (mm)	IGEBU
Agricultural drought analysis using WRSI	- Daily rainfall - Daily and monthly temperature	IGEBU
Mapping purpose	Mapping files data	FAO, IGEBU

The stations were the data are coming from are presented in the following Table 3.2.

Table 3.2: Stations for the collected data

	Station ID	Station Name	Longitude	Latitude	Data
1	10030	Cankuzo	30.38	-3.28	Rainfall and temperature
2	10061	Karuzi	30.17	-3.10	Rainfall and temperature
3	10102	Mugera	29.97	-3.32	Rainfall
4	10112	Muriza	30.08	-3.53	Rainfall and temperature
5	10116	Musasa	30.10	-4.00	Rainfall and temperature
6	10122	Musongati	30.07	-3.73	Rainfall
7	10125	Muyaga	30.55	-3.23	Rainfall
8	10127	Muyinga	30.35	-2.85	Rainfall and temperature
9	10075	Kinyinya	30.33	-3.65	Rainfall and temperature
10	10079	Kirundo	30.12	-2.58	Rainfall and temperature
11	10142	Nyamuswaga	30.03	-2.88	Rainfall and temperature

The period from 1978 to 2007 has been chosen for the study. This was motivated by the presence and quality of records. Before 1978, many gauges stations have a lot of missing data.

3.2 DATA PROCESSING

The data processing conducted includes:

- **In filling of missing data**: For the study period chosen, there were some few missing rainfall data which are in filled by averaging.
- **Average calculations**: estimation of monthly, seasonal and annual averages has been done for all the raingauge stations.

- **Computation of study area rainfall**

The areal average rainfall has been estimated using Thiessen method with the data from different gauges stations disseminated in and neighboring the study area. The method is described in the section 2.2.2.1

3.3 DATA ANALYSIS

3.3.1 Drought identification

3.3.1.1 Time scale

The analysis was done on a calendar year and crop growing season (4 months) time scale basis for meteorological and agricultural droughts. The crop crowing length includes the season A (from October to January) and Season B (from February to May).

3.3.1.2 Identification of the drought seasons / years

From the historical rainfall data, the PNP was calculated by year and season for each gauge station. It is the ratio of current to average rainfall expressed as percentage. All the years and seasons with PNP lower than 75% have been considered as a meteorological drought year / season. For agriculture drought, WRSI has been estimated each season for all the stations. Season with WRSI lower than the average was considered as drought season (Bates, 1935 ; Banerji and Chabra,1964)

3.3.1.3 Temporal based analysis

To carry out a temporal based analysis, the 30 years study period was divided into two periods of 15 years each, one from 19978 to 1992, the second starting from 1993 to 2007. This was motivated by the opinion that drought occurrence has increased a lot during these last 10 years.

3.3.1.4 Spatial based analysis

Areas of coverage of the raingauges stations

The considered raingauges stations are not uniformly spaced in the study area. To allow a good discussion of the results, it was found necessary to know about the effective areas assumed for each station, named in this report area of influence. Their physical extent and the natural regions concerned were determined using the Thiessen Method. With their coordinates, the raingauge stations were plotted on a GIS map of the eastern natural regions of Burundi with a map scale of 1cm for 10 km. Thiessen polygons were drawn with the regions, thus the regions concerned were seen. For that, adjacent stations were joined by straight lines thus dividing the area into a series of triangles. Perpendicular bisectors were then erected on each of the connecting lines to form polygons around each station. The sides of the polygons were considered the boundaries of the areas of influence of the stations. The areas of the polygons were determined by the plannimeter, $25mm^2$ (5mm x 5mm) area on map representing $25km^2$ (5km x 5km) area on the ground.

Spatial analysis

A spatial analysis of drought has first been done based on point data analysis. For all the stations, drought seasons / years have been identified. Droughts identified at station level are here called local droughts. Considering each station rainfall as an average of precipitation of the area around the point, the spatial extent (in %) for each year was roughly approximated as the ratio of the number of observed drought cases at all the stations over the total number of the considered stations, this for each year. The estimation provided the first figure of drought occurrence in terms of areal extent.

On a natural region level, discussion was based on the observations made from the stations having their zones of influence in the regions in question. Main conclusions were based especially on the stations located in the region of concern.

On the study area level, averages data were generated by interpolation from the point (station) data. Current average for each year was then compared with the mean of the averages. The average methods used include Arithmetic mean and Thiessen methods. In the mapping, interpolation used is the Inverse Distance Weighting Method through ArcGIS software.

3.3.2 Drought characterization

This section aims quantifying the drought events characteristics that are mainly the duration, the drought volume, intensity, frequency and spatial coverage.

3.3.2.1 Duration

The duration is the time length (in months, seasons or years) defined by the number of successive drought prone seasons or years (where the current values are lower than 75% of the historical average). Practically by using the Microsoft Excel Software, the computer was asked to write 1 where the rainfall is lower than 75 of the historical average and 0 if not the case. The duration of a drought event is then shown by the number of successive 1 value. For example if there is two successive 1, it means that the duration of the event is 2 seasons or years depending on the time scale.

3.3.2.2 Drought volumes and Intensities

The given data were used to calculate rainfall deficiencies as the difference between the normal rainfall and what is actually received. The calculated deficiencies were then cumulated over drought periods to determine the drought volumes. The intensity has been determined as drought volume over duration.

3.3.2.3 Frequency

The frequency was expressed as return period and estimated using the Weibull formula.

Weibull Formula: $F(x) = \frac{i}{(\mathrm{N}+1)}$ Where F(x) = Non-exceedance probability

i = Rank (1,2,3,…., N)

N = Total number of data points

Return period $T = \frac{1}{(1 - (\mathrm{F(x)})}$

Frequency was also analyzed as percentage of time the drought is observed. It was estimated as a ratio of the number of times that drought occurs over the concerned period of analysis.

3.3.2.4 Severity

1) Meteorological drought

The percentage of normal precipitation index was used to determine the degree of severity of the identified droughts. This index was estimated as the rainfall received over the average multiplied by 100.

Based on the suggestions of Bates (1935) and Smakhtir and Hughes (2004), the degree of severity was determined as follow: there is moderate drought when the PNP is 50 – 74 % of the normal precipitation, when the PNP is less than 50%, it is a severe drought.

2) Agricultural drought

The agricultural drought severity was analyzed using the Water requirement Satisfaction Index (WRSI) with regard to the crop performance.

WRSI was estimated using the USGS approach.

$$WRSI = \frac{100 * AET}{\mathrm{WR}}$$ **(**HOORC, 2007)

Where WR = PETc

WR is the crop water requirement

PETc is the crop potential evapotranspiration

PETc = Kc . p. (0.457Ta+8.13) : Blaney-Criddle formula

PET : Potential evapotranspiration

Kc : Crop coefficient

Four growth stages, with different crop coefficients and different lengths of time period, as given by FAO (2006) were adopted in estimating the seasonal average Kc. The given crop coefficient and period for each stage are as shown in Table 3.3.

Table 3.3: Crop factors and period for maize crop growth stages

	Initial stage	Crop development stage	Mid-season stage	Late season stage
Crop factor	0.40	0.80	1.15	0.70
Period (days)	20	35	40	30

Source: FAO (2006)

Using the values of period and crop factor in Table 3.3, a weighted seasonal average was estimated to be 0.82.

For each crop growing season, the WRSI was calculated for all the stations to show if water requirements were satisfied or not with regards to maize crop farming. The severity of the agricultural drought is related to the likely potential of crop water stress on crop yield in accordance to the following FAO norms adopted from Martin and al (2000).

Table 3.4: Classification of Water-limited Crop Performance

Expected percentage of max (potential) yield	Classification of crop performance	Water Requirements Satisfaction Index (WRSI) (%)
100	Very good	100
90 – 100	Good	95 – 99
50 – 90	Average	80 – 94
20 – 50	Mediocre	60 – 79
10- 20	Poor	50 – 59
< 10	Complete failure	< 50

3.3 DROUGHT MAPPING

3.3.1 Meteorological droughts mapping

Meteorological droughts were mapped using the estimated percentage of normal precipitation index.

3.3.2 Agriculture drought mapping

The drought severity and maize crop performance are the variables mapped. The different water requirement satisfaction index computed were put in the FAO classes, corresponding with the crop performance classes as shown in the Table 3.4, and then mapped using ArcGIS software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 METEOROLOGICAL DROUGHTS

4.1.1 Drought identification

Two times scales basis were considered in the identification of drought events: annual and seasonal time scale basis.

4.1.1.1 Annual time scale basis

The areas of coverage of the considered raingauges stations and their physical extent within the different natural regions concerned are presented in Table 4.1.

Table 4.1: Areas of coverage of the raingauges stations and their corresponding regions

	Station	**Area (km^2)**	**%**	**Regions**
1	Kirundo	2087	18.2	Bugesera
2	Muyinga	1400	12.2	Bweru
3	Nyamuswaga	475	4.1	Bweru
4	Karuzi	987	8.6	Bweru, Buyogoma
5	Cankuzo	1050	9.1	Buyogoma, Moso
6	Muyaga	1800	15.7	Buyogoma, Moso
7	Mugera P	312	2.7	Buyogoma
8	Muriza	700	6.1	Buyogoma
9	Musongati	687	6.0	Buyogoma, Moso
10	Kinyinya	900	7.8	Moso
11	Musasa	1087	9.5	Moso
	Total	**11485**	**100**	

Each station measures rainfall of a part of one or two natural region. Buyogoma region is covered by the highest number of stations, probably because it is the biggest region in the area. From north to south, Muyaga, Cankuzo, Muriza and Musongati stations are located in Buyogoma and seem to be the main stations of Buyogoma because almost the whole area covered by their areas influence is located in the region, thus conclusions made on that region are mainly based on the data from those stations.

For Moso, Kinyinya and Musasa are the ones located in the region. Because of its proximity, Muyaga station has also a big zone of influence in the Moso (Northern Moso) accounting almost one third of the total area of Moso natural region. The most of conclusions made on that region were based on the data from those three stations. For Bugesera, the only station considered is Kirundo. Bweru is concerned by Muyinga, Karuzi and Nyamuswaga. The area of influence of Karuzi station extents also in Buyogoma.

1) Drought prone years and temporal based analysis

The droughts have been defined locally for each station using the estimated percentage of normal precipitation (PNP). Table 4.2 shows the PNP for each year and for each station.

Table 4.2: Percentage of Normal Precipitation for all the stations

	Kirundo	Muyinga	Nyamuswaga	Muyaga	Cankuzo	Karuzi	Mugera	Muriza	Musongati	Kinyinya	Musasa
1978	114.4	95.9	100.0	116.5	124.1	110.2	108.9	131.5	112.4	125.2	90.7
1979	98.2	105.0	100.0	103.3	96.9	139.3	114.6	105.1	106.6	114.6	107.0
1980	85.8	84.2	105.8	75.8	75.6	73.4	79.9	83.7	90.1	105.8	71.9
1981	111.6	81.5	90.5	117.9	124.0	97.3	103.0	91.4	119.1	93.3	92.3
1982	100.0	99.9	125.3	105.3	100.1	85.1	124.5	120.0	95.7	121.8	126.3
1983	93.1	94.3	123.0	103.3	89.8	68.5	80.0	87.2	92.7	93.2	82.3
1984	82.5	94.2	121.1	89.6	99.7	65.4	101.1	90.1	112.4	88.6	85.3
1985	120.1	115.7	111.3	98.9	102.5	140.9	100.6	112.6	122.8	127.6	93.5
1986	113.1	110.5	111.4	100.2	100.3	109.7	118.3	113.2	104.8	124.8	131.1
1987	125.5	133.6	121.3	99.2	95.9	96.4	88.7	110.5	93.7	111.2	102.4
1988	109.6	130.5	132.1	130.7	121.1	92.7	131.0	115.4	104.3	90.1	122.1
1989	91.2	97.8	109.8	115.8	121.0	93.1	116.5	141.6	113.9	137.6	115.3
1990	109.3	93.0	102.1	102.5	101.1	94.3	80.2	98.2	90.4	107.8	83.4
1991	93.5	91.4	102.1	110.1	103.3	94.6	97.8	103.2	102.8	108.3	109.5
1992	88.0	96.7	81.8	103.6	111.0	96.9	91.6	100.9	97.9	95.1	84.7
1993	100.8	100.8	72.0	87.6	84.1	86.1	81.7	82.2	90.9	87.1	72.4
1994	95.0	93.0	93.7	121.5	107.9	109.3	87.8	116.6	76.1	106.6	104.6
1995	108.0	87.6	102.3	93.7	100.0	50.4	76.7	97.2	102.1	152.9	87.0
1996	89.0	111.7	88.0	100.4	98.0	63.8	100.9	85.4	89.6	107.4	81.6
1997	98.4	140.2	115.2	127.9	126.9	114.7	107.7	119.5	109.8	141.5	108.1
1998	130.1	84.9	105.1	73.2	89.1	138.9	101.3	108.0	102.2	128.4	131.9
1999	70.7	72.8	82.7	87.7	83.2	108.0	110.7	108.6	88.1	105.4	86.3
2000	74.8	76.1	80.1	76.1	72.1	107.1	93.9	69.6	70.9	92.2	89.1
2001	94.4	109.4	94.4	90.3	98.4	136.8	108.3	107.2	100.2	104.1	101.0
2002	91.7	94.1	84.6	108.0	106.1	139.9	96.6	95.0	110.5	89.5	98.0
2003	109.7	92.0	88.3	96.2	95.0	87.0	103.4	86.8	90.7	60.2	81.1
2004	99.8	102.5	95.1	84.3	82.0	110.4	117.6	104.2	111.3	58.9	96.1
2005	98.9	76.4	82.6	62.3	63.1	81.7	80.4	73.2	88.6	30.3	62.1
2006	105.9	93.7	99.3	131.3	129.3	143.9	108.8	117.8	97.7	62.0	112.0
2007	107.0	93.1	79.2	84.4	84.9	88.5	87.4	90.8	122.4	48.4	87.0

Considering a year with PNP equal or less to 75%, drought prone years have been identified for all stations. Table 4.3 summarizes the drought years identified by station.

Table 4.3: Drought years of all the stations

Drought years	Number of concerned stations	Names of the stations	Concerned regions
1980	2	Karuzi et Musasa	Bweru, Buyogoma, Moso
1983	1	Karuzi	Bweru, Buyogoma
1984	1	Karuzi	Bweru, Buyogoma
1993	2	Nyamuswaga, Musasa	Bweru, Moso, Buyogoma
1995	1	Karuzi	Bweru, Buyogoma
1996	1	Karuzi	Bweru, Buyogoma
1998	1	Muyaga	Buyogoma and Moso
1999	2	Kirundo, Muyinga	Bugesera, Bweru
2000	4	Kirundo, Cankuzo,Muriza, Musongati	Bugesera, Buyogoma, Moso
2003	1	Kinyinya	Moso
2004	1	Kinyinya	Moso
2005	5	Muyaga, Cankuzo, Muriza, Kinyinya, Musasa	Buyogoma, Moso
2006	1	Kinyinya	Moso
2007	1	Kinyinya	Moso
Total		10 stations	4 regions

From the table above, it can be observed that ten out of eleven stations show at least one drought prone year during these last 30 years. The number of drought years varies from 1 to 5 for the whole period. Nine out of ten stations are located within the study area. Two stations are located out of the limits but very closer the areal limits at the oust side. They have been considered in this study as their area of coverage extent within the study area. These stations are Nyamuswaga and Mugera which have area of influence within the study area limits of respectively 4.1 and 2.7% of the total study area. The Nyamuswaga station showed one drought year that is 1993. Only Mugera station did not experienced a drought year. This can be understood in the sense that the station is located in transition toward an area / region with rainfall higher than the study area.

Generally, for all the stations, it can be seen that the majority of drought prone years start from 1993. Except Karuzi that accounts 3 out of 5 drought years before 1993 and Musasa with only a third of its drought years located in the first part of the period, other stations experienced drought after 1995 with a number varying between one and five drought years per station. With that observation, it can be thought an increasing drought occurrence in the area during these last 15 years.

2) Spatial analysis

Local drought analysis

From the Table 4.2, it can be seen some tendencies of certain areas to reduce or increase the drought occurrence. For example, for the 8 drought years observed before 1999, Bweru was concerned 7 times. After that year, the region has not again faced droughts. For the 6 following drought years, Bweru is not concerned. For the Bugesera, in the north, the last drought year is 2000. Also it is seen that Buyogoma was always concerned by the droughts occurred in the eighties and nineties till 1998, but from that year, the frequencies has reduced. For Moso, it was also concerned by some droughts occurred before and to 2000. The actual tendency is a persisting drought occurrence in the region. From the same table, it has been observed that area monitored by the Kinyinya station, has experienced drought from 2003 to 2007 without interruption.

From the observations made from the table above, there is impression that drought occurrence is increasing in the southern part of the study area (Buyogoma and Moso) and decreasing in the northern part (Bweru and Bugesera). The situation is being worsened in the Moso.

Interpolated rainfall data based analysis

The interpolated areal data rainfall from point rainfall and their corresponding drought status are presented in Table 4.4 below.

Table 4.4: Interpolated areal rainfall and drought year identification

Year	Rainfall	PNP	Drought status
1978	1305.9	111.9	0
1979	1250.5	107.1	0
1980	962.3	82.5	0
1981	1214.8	104.1	0
1982	1244.1	106.6	0
1983	1087.2	93.2	0
1984	1064.4	91.2	0
1985	1317.5	112.9	0
1986	1308.4	112.1	0
1987	1272.4	109.0	0
1988	1368.8	117.3	0
1989	1283.0	109.9	0
1990	1139.1	97.6	0
1991	1204.2	103.2	0
1992	1130.3	96.8	0
1993	1029.9	88.2	0
1994	1216.3	104.2	0
1995	1135.9	97.3	0
1996	1083.3	92.8	0
1997	1418.8	121.6	0
1998	1263.4	108.3	0
1999	1005.4	86.1	0
2000	941.8	80.7	0
2001	1199.5	102.8	0
2002	1172.5	100.5	0
2003	1073.3	92.0	0
2004	1096.1	93.9	0
2005	863.2	74.0	**1**
2006	1292.7	110.8	0
2007	1069.1	91.6	0
Average	**1167.1**		

The results in the table above show a one moderate drought year in 2005. Tables 4.2 and Table 4.3 show many cases of local droughts years. With this phenomenon, it is thought a high variability of rainfall in space and time. It is the opinion of the Burundian Ministry of Land, Tourism and Environment and UNFCCC (2007). They have established that since the years 1999 to 2006, the annual evolution shows a shortening of the rainy season in the North-Eastern regions of the country, but with punctually violent rains coupled with thunders and lightning, and an extension of the dry season. They noted also that since 1999, there is a strong variability of rainfall mode with a tendency of a long dry season from May to October (6 months) in the lower altitude outlying areas (Moso, Bugesera). These considerations show the necessity of drought analysis at regional level and at a small time scale basis to view more details in drought occurrence. The following section identifies droughts on season time scale basis.

4.1.1.2 Seasonal time scale basis

1) Season A

The results of seasonal PNP for this season A are included in the appendix 6. Table 4.5 shows Season A meteorological drought status for all the stations.

Table 4.5: Drought status for season A for all stations

Season	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Mugera	Muriza	Muyaga	Musongati	Kinyinya	Musasa
1977/78	0	0		0	0		0	0	0	0	0
1978/79	0	0		0	0	0	0	0	0	0	0
1979/80	0	0		0	0	1	1	0	0	0	0
1980/81	0	0	0	1	0	0	0	0	1	0	0
1981/82	0	1	0	0	0	0	0	0	0	0	0
1982/83	0	0	0	1	0	0	0	0	0	0	0
1983/84	0	1	0	0	0	0	0	0	0	0	1
1984/85	0	0	0	1	0	0	0	0	0	0	0
1985/86	0	0	0	0	0	0	0	0	0	0	0
1986/87	0	0	0	0	0	0	0	0	0	0	0
1987/88	0	0	0	0	0	1	0	0	0	0	0
1988/89	0	0	0	0	0	0	0	0	0	0	0
1989/90	0	0	0	0	0	0	0	0	0	0	0
1990/91	0	0	0	0	0	1	0	0	0	0	0
1991/92	0	0	0	1	0	0	0	0	0	0	0
1992/93	0	0	0	0	0	0	0	0	0	0	0
1993/94	0	0	1	1	0	1	0	0	0	1	1
1994/95	0	0	0	0	0	0	0	0	0	0	0
1995/96	0	0	0	1	0	1	1	1	0	0	1
1996/97	0	0	0	1	0	0	1	0	0	1	0
1997/98	0	0	0	0	0	0	0	0	0	0	0
1998/99	0	1	0	1	1	1	1	1	1	1	0
1999/2000	1	1	1	0	0	0	0	0	1	0	0
2000/01	0	0	0	0	0	0	0	0	0	0	0
2001/02	0	0	0	0	0	0	0	0	0	0	0
2002/03	1	0	0	0	0	0	0	0	0	1	0
2003/04	0	0	0	0	0	0	0	0	0	1	0
2004/05	0	0	1	0	0	0	0	0	0	1	0
2005/06	1	1	1	1	1	1	1	1	0	1	0
2006/07	0	0	0	0	0	0	0	0	0	1	0

This table shows that occurrence of drought is observed at more stations during the seasons 93/94 and 95/96 (at 5 over 11 stations: almost 50% of stations), the season 1999/2000 (4 stations over 11: 36%), the season 1998/99 (at 8 over 11 stations: 73%) and 2005/06 (9 over 11 stations: 82%). As seen for the annual time scale basis, drought occurrence is higher in these 15 last years. Looking at a spatial extent, the main noted droughts occurred in almost all regions. Except the 1999/2000 drought which was particularly more observed in the northern part in Bugesera and Bweru, the big number of local droughts was observed in the southern part of the area, especially in Moso and southern Buyogoma.

Interpolation of Season A rainfall data by Thiessen method

As discussed above, the seasons 1998/99 and 2005/06 are the main seasonal meteorological droughts that are recognized at the whole area level as confirmed by the analysis of PNP generated from interpolated areal rainfall. The results are presented in Table 4.6.

Table 4.6: Interpolated rainfall based meteorological drought identification for season A

Season	Rainfall	PNP	Drought status
1977/78	544.5	100.3	0
1978/79	627.9	115.6	0
1979/80	465.3	85.7	0
1980/81	466.6	85.9	0
1981/82	465.9	85.8	0
1982/83	594.0	109.4	0
1983/84	538.9	99.3	0
1984/85	491.7	90.6	0
1985/86	587.0	108.1	0
1986/87	636.3	117.2	0
1987/88	663.3	122.2	0
1988/89	589.8	108.6	0
1989/90	486.0	89.5	0
1990/91	517.7	95.4	0
1991/92	495.2	91.2	0
1992/93	556.8	102.6	0
1993/94	422.7	77.9	0
1994/95	659.0	121.4	0
1995/96	471.8	86.9	0
1996/97	454.6	83.7	0
1997/98	874.5	161.1	0
1998/99	392.5	72.3	1
1999/2000	443.7	81.7	0
2000/01	637.1	117.3	0
2001/02	560.4	103.2	0
2002/03	499.1	91.9	0
2003/04	493.6	90.9	0
2004/05	499.0	91.9	0
2005/06	348.7	64.2	1
2006/07	675.2	124.4	0

The two drought occurrences are resulted from low rainfall generally observed in October and particularly in 1998 and 2005. From the monthly rainfall, it has also been observed some cases of low rainfall amount in January.

2) Season B

During season B, rainfall amount is relatively better than A. Lower rainfall was particularly observed in season 1979/80, 1983/84, of normal precipitation, 1999/2000, 2000/2001, 2004/2005 where rainfall is lower than 80 % of normal precipitation as it can be seen in the table below.

Table 4.7: Interpolated rainfall based meteorological drought identification for season B

Season	Average	PNP	Drought status
1977/78	638.2	116.8	0
1978/79	688.1	125.9	0
1979/80	436.2	79.8	0
1980/81	597.1	109.3	0
1981/82	530.5	97.1	0
1982/83	540.9	99.0	0
1983/84	410.7	75.2	0
1984/85	665.9	121.9	0
1985/86	641.2	117.3	0
1986/87	526.3	96.3	0
1987/88	614.1	112.4	0
1988/89	575.8	105.4	0
1989/90	617.9	113.1	0
1990/91	609.4	111.5	0
1991/92	563.7	103.2	0
1992/93	526.4	96.3	0
1993/94	506.4	92.7	0
1994/95	593.1	108.5	0
1995/96	519.9	95.1	0
1996/97	579.1	106.0	0
1997/98	679.9	124.4	0
1998/99	445.1	81.5	0
1999/2000	378.4	69.3	**1**
2000/01	426.7	78.1	0
2001/02	591.0	108.2	0
2002/03	504.7	92.4	0
2003/04	513.6	94.0	0
2004/05	431.9	79.1	0
2005/06	568.3	104.0	0
2006/07	472.4	86.4	0

Interpolated areal rainfall analysis revealed the 1999/2000 as a recognized drought for the area. It was observed at 8 out of 11 stations concerned by this study. Even for the remaining stations, the PNP was at the lower side (75.5, 75.9 and 82.4) as it can be seen in Table 4.8. The drought is a result of low rainfall amounts observed generally in May.

Table 4.8: PNP for the season B at all stations

Season	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Mugera	Muriza	Muyaga	Musongati	Kinyinya	Musasa	Average
1977/78	115.1	113.0		105.9	125.9		117.9	127.8	116.9	124.8	100.9	**116.5**
1978/79	143.5	98.6		208.4	108.5	158.6	129.2	118.9	126.8	125.3	118.9	**133.7**
1979/80	101.5	70.3	94.1	74.5	61.1	84.3	81.0	73.6	96.7	103.8	75.4	**83.3**
1980/81	57	81.6	82.7	108.1	135.5	120.0	82.1	136.3	110.0	98.2	98.9	**100.9**
1981/82	32.2	88.3	119.7	96.0	104.2	104.2	109.3	101.2	100.2	102.6	122.2	**98.2**
1982/83	90.7	113.9	134.5	62.6	96.1	92.8	90.1	115.2	89.7	88.2	94.3	**97.1**
1983/84	73.1	50.0	71.3	71.9	83.3	75.8	80.1	67.1	114.7	80.9	82.1	**77.3**
1984/85	178.5	114.1	110.1	119.3	107.5	98.8	138.4	103.5	166.7	155.2	102.9	**126.8**
1985/86	71.9	122.5	151.0	117.3	105.2	122.1	109.6	104.3	87.4	119.6	138.3	**113.6**
1986/87	94.2	129.9	103.5	93.8	85.4	75.5	102.8	70.9	88.7	105.1	105.7	**96.0**
1987/88	83.5	121.9	168.0	87.1	121.7	108.5	104.4	131.9	104.6	86.8	106.2	**111.3**
1988/89	93	102.0	97.6	78.7	107.0	141.3	130.4	107.8	115.2	140.6	115.6	**111.7**
1989/90	165.5	95.4	109.2	84.0	145.9	93.6	125.7	135.1	96.9	140.0	86.0	**116.1**
1990/91	84	99.2	105.8	128.1	98.4	115.2	105.6	121.6	128.9	119.0	107.0	**110.2**
1991/92	30.7	109.6	85.0	109.5	113.9	96.3	121.8	114.0	101.8	105.9	83.2	**97.4**
1992/93	133	101.1	80.3	92.9	93.6	76.3	74.7	107.6	86.6	97.0	99.2	**94.7**
1993/94	97.6	82.8	88.6	86.7	94.8	73.2	93.7	99.2	56.6	100.1	121.9	**90.5**
1994/95	98.8	95.2	100.1	46.2	123.5	109.9	114.6	118.1	118.9	153.1	122.2	**109.2**
1995/96	104.5	128.4	100.8	48.6	90.9	116.2	101.7	100.8	80.0	121.1	67.4	**96.4**
1996/97	22.8	121.5	93.9	105.6	106.3	78.5	113.5	114.5	77.8	118.1	89.4	**94.7**
1997/98	142.1	99.2	111.3	201.2	101.6	149.4	137.3	84.8	133.0	147.6	156.5	**133.1**
1998/99	11.7	83.9	70.9	94.5	80.5	83.8	106.2	70.6	85.5	92.6	74.2	**77.7**
1999/2000	74.2	68.2	75.6	82.4	63.7	71.5	58.3	64.5	46.0	75.9	72.2	**68.4**
2000/01	36.8	87.3	81.0	84.4	77.9	100.3	91.8	68.5	76.7	85.9	90.5	**80.1**
2001/02	95.1	102.3	84.5	151.5	109.4	77.6	106.6	92.4	121.8	99.3	93.7	**103.1**
2002/03	88.8	87.8	92.3	95.0	97.5	113.6	86.5	87.9	97.3	47.5	85.5	**89.1**
2003/04	174.8	124.9	114.3	128.3	64.2	91.3	89.3	75.5	109.8	58.7	63.2	**99.5**
2004/05	160.3	85.0	87.9	78.9	67.3	84.3	64.6	72.3	92.0	31.7	54.4	**79.9**
2005/06	46	94.8	122.0	114.1	114.2	118.8	105.3	127.8	91.5	65.4	82.6	**98.4**
2006/07	147	84.2	64.1	80.8	77.6	68.1	86.5	77.2	113.7	51.8	101.4	**86.6**

With this table and considering also the Table 4.1 related to the areas of coverage of the different stations, it can be seen that Bugesera and Moso constitute a case to worry about. In these regions, frequency and duration of meteorological drought occurrence is high compared to the others regions. It is also observed a number of severe droughts (PNP<50). The situation is particularly grave in Bugesera where drought is observed 30% of the time. Within drought period, severe drought is observed 67% of the time. In the same region, Extreme severe droughts are observed particularly for the seasons1996/97 (PNP of 22.8%) and 1998/99 with a PNP of only 11.7%. These two periods were for sure characterized by crop failure. These were disastrous as they occurred directly after and in continuity with season A drought. This situation of consecutive severe drought in the region was also observed for the 2005/2006 seasons and this was the cause of the local population depth and displacement reported for that time.

4.1.2 Drought characterization

4.1.2.1 Duration and Frequency

The duration and frequency have been determined for all the ten stations where droughts were identified. The time scale is a year. The duration is the number of successive drought years. The duration of the observed droughts for each station has been estimated as shown in Table 4.9. The number 1 means a drought year and 0 means absence of drought.

Table 4.9: Meteorological drought occurrence in the different locations

	Kirundo	Muyinga	Cankuzo	Muyaga	Karuzi	Muriza	Kinyinya	Musasa	Musongati	Nyamuswaga	Mugera
1978	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	1	0	0	1	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	1	0	0	0	0	0	0
1984	0	0	0	0	1	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	1	0	1	0
1994	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	1	0	0	0	0	0	0
1996	0	0	0	0	1	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	1	0	0	0	0	0	0	0
1999	1	1	0	0	0	0	0	0	0	0	0
2000	1	0	1	0	0	1	0	0	1	0	0
2001	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	1	0	0	0	0
2004	0	0	0	0	0	0	1	0	0	0	0
2005	0	0	1	1	0	1	1	1	0	0	0
2006	0	0	0	0	0	0	1	0	0	0	0
2007	0	0	0	0	0	0	1	0	0	0	0

From the table above, the drought events durations of all the stations have been summarized in Table 4.10 below.

Table 4.10: Droughts events duration

Station	No of drought events	Period	Duration (years)
Kirundo	1	1999-2000	2
Muyinga	1	1999	1
Cankuzo	2	2000	1
		2005	1
Muyaga	2	1998	1
		2005	1
karuzi	3	1980	1
		1983-1984	2
		1995-1996	2
Muriza	2	2000	1
		2005	1
Kinyinya	1	2003-2007	5
Musasa	3	80	1
		93	1
		2005	1
Musongati	1	2000	1
Nyamuswaga	1	1993	1
Total	**17**		

From Table 4.9 and 4.10, it can be seen that single year drought events are significantly more frequents occurring in almost all locations. The number of drought events decrease with the increasing of duration. The results shows that the drought events of one year represent 76%, the 2 years duration droughts represent 18%; and the 5 years duration drought 6%. The drought of the higher 5 years duration has been observed at the Kinyinya station located in Moso natural region. This comes to enforce what has been said in the section 4.1.1.2 that the Moso is the region of worst drought conditions. It is known that the severity of a drought event increase with its duration. In South Africa for example, two consecutive seasons experiencing 70% of the normal precipitation is considered as a drought disaster (Bruwer, 1990). The occurrence of such 5 years duration drought calls for more attention, it may lead to desertification if it continues persisting and extending in area.

Another characteristic that can be analyzed is the percentage of time with drought that is a sort of frequency as shown in Table 4.11. The table shows the estimates of the percentage of time of drought conditions in the different locations. It is here the ratio of the number drought years over the total number of years of the whole study period which is 30 years.

Table 4.11: Percentage of time of drought conditions

	Number of drought years	Percentage of time
Kirundo	2	7
Muyinga	1	3
cankuzo	2	7
Muyaga	2	7
Karuzi	5	17
Muriza	2	7
Kinyinya	5	17
Musasa	3	10
Musongati	1	3
Nyamuswaga	1	3
Mugera	0	0
Average	**2**	**7**

The percentages of times are low. The average percentage is 7%. It is normal because droughts, like other natural extreme conditions such as floods, are likely to occur rarely. The highest percentage of time (17%) is found at Kinyinya and Karuzi stations. The areas of influence of these Kinyinya station is fully located in Moso, for Karuzi station it extends in Bweru and Buyogoma regions. The second station to show relatively high percentage is Musasa (10%) also located in Moso. This also shows that the region is the more concerned by drought occurrence. High temperature in the area is one of the causes of that situation.

4.1.2.2 Drought severity

The severity was based on the percentage of normal precipitation (PNP) index. It has been determined per drought year and for each station. Based on the suggestions of Bates (1935) and Smakhtir and Hughes (2004), there is moderate drought when the PNP is 50 – 74 % of the normal precipitation. When the PNP is less than 50%, it is considered a severe drought.

Table 4.12: Drought severity by station

Station	Drought prone years	PNP	Severity
Kirundo	1999	70.7	Moderate
	2000	74.8	Moderate
Muyinga	1999	72.8	Moderate
Cankuzo	2000	72.1	Moderate
	2005	63.1	Moderate
Muyaga	1998	73.2	Moderate
	2005	62.3	Moderate
karuzi	1980	73.4	Moderate
	1983	68.5	Moderate
	1984	65.4	Moderate
	1995	50.4	Moderate
	1996	63.8	Moderate
Muriza	2000	69.6	Moderate
	2005	73.2	Moderate
Kinyinya	2003	60.2	Moderate
	2004	58.9	Moderate
	2005	30.3	Severe
	2006	62.0	Moderate
	2007	48.4	Severe
Musasa	1980	71.9	Moderate
	1993	72.4	Moderate
	2005	62.1	Moderate
Musongati	2000	70.9	Moderate
Nyamuswaga	1993	72.0	Moderate

The droughts observed vary from moderate, the majority cases, to severe. The severe drought cases are found at the Kinyinya station in Moso region. In that location, the lasting moderate drought of 2003-2004 has resulted in a severe drought in 2005 and 2007. It is observed that severe drought is observed 8% of time, moderate drought being observed 92% of time.

4.1.2.3 Drought volumes and Intensities

Drought volumes and intensities results are presented in Table 4.13.

Table 4.13: Drought volumes and intensities

Station	Period	Duration (years)	Drought volume (mm)	Drought Intensity (mm/year)
Kirundo	1999-2000	2	587.6	293.8
Muyinga	1999	1	306.8	306.8
Cankuzo	2000	1	331.5	331.5
	2005	1	438.0	438.0
Muyaga	1998	1	326.9	326.9
	2005	1	458.9	458.9
Karuzi	1980	1	319.6	319.6
	1983-1984	2	794.9	397.4
	1995-1996	2	1031.3	515.6
Muriza	2000	1	347.5	347.5
	2005	1	306.8	306.8
Kinyinya	2003-2007	5	2741.4	548.3
Musasa	80	1	327.7	327.7
	93	1	322.0	322.0
	2005	1	442.0	442.0
Musongati	2000	1	346.8	346.8
Nyamuswaga	1993	1	370.9	370.9

The two highest values of drought volumes and intensities are observed at Kinyinya station for the period 2003-2007 and at Karuzi station for 1995-1996 period. The following other high values are observed at Muyaga and Musasa for the year 2005. From the table above, it is also seen that Kirundo and Muyinga experienced the lowest drought volumes and intensities. Remembering that the areas of influence of the Kinyinya station extent in Moso region only; and that Musasa, Karuzi and Kinyinya stations have their areas of influence in Moso and Buyogoma, the following are shown: With respect to the two characteristics, Moso natural region is the more affected followed by Buyogoma; the northern part of the area constituted by Bugesera and Buyogoma is found experiencing drought of lowest intensities.

4.1.2.4 Drought coverage

The interpolation by Thiessen method revealed that only 2005 can be considered as drought year within the period of concern for the study. That time, droughts were observed at Cankuzo, Muyaga, Muriza, Kinyinya, Musasa. The total area assumed for the 5 stations corresponds to 48.2% of the whole area, according to the calculations made in Table 4.1. The 2005 drought coverage area is therefore estimated to approximately 5537 km^2. The distribution of the drought coverage is shown by the map in the figure below.

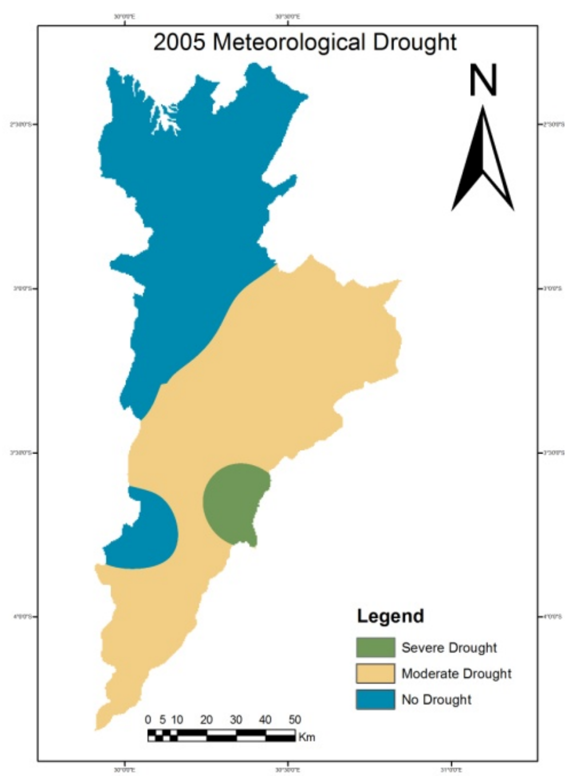

Figure 4.1: The 2005 meteorological drought map

4.1.2.5 Frequency analysis

The current frequency analysis concerns the Moso natural region using rainfall data of Musasa station. The rainfall data considered are included in the appendix 7. The following Table 4.14 summarizes the results of the drought frequency analysis of Musasa.

Table 4.14: Probability of drought occurrence and return period for Musasa

Period covered	1961-2007
Total number of years of records	47
Number of drought years	3
Non-exceedance probability	0.94
Exceedance probability	0.06
Return period (years)	16

From the table of the appendix 7, it can be seen that all the three drought years are 1980, 1993 and 2005. Drought didn't occur during the 19 years period of before 1980. Considering only the recent thirty years, the exceedance probability becomes 0.1 meaning a return period of 10 years corresponding to a return period reduction of 37.5%. With these observations, one can say that the frequency and probability of drought occurrence is increasing in the Eastern Burundi. This confirms the already observed increasing drought occurrence in the previous discussions.

4.2 AGRICULTURAL DROUGHT

Results of seasonal WRSI are compiled in Table 4.15 and 4.17 for respectively crop growing season A and season B.

4.2.1 Agricultural drought identification

4.2.1.1 Crop growing season A.

Table 4.15 below contains the WRSI of the crop growing season A.

Table 4.15: Water Requirement Satisfaction Index for crop growing season A

Year	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Muriza	Kinyinya	Musasa	Average
1977/78		87		88			100	100	**94**
1978/79		100		100			100	100	**100**
1979/80		87		100	100	75	100	84	**91**
1980/81	75	99	100	89	100	100	100	95	**95**
1981/82	65	74	100	100	100	100	100	82	**90**
1982/83	100	100	100	89	100	100	100	100	**99**
1983/84	89	75	100	100	100	100	100	78	**93**
1984/85	69	100	100	54	100	100	89	89	**88**
1985/86	97	100	100	100	100	92	100	100	**99**
1986/87	100	100	100	100	100	100	100	100	**100**
1987/88	100	100	100	100	100	100	88	100	**99**
1988/89	100	90	100	100	100	100	100	100	**99**
1989/90	82	95	100	100	100	96	100	90	**95**
1990/91	100	97	100	100	100	96	100	100	**99**
1991/92	68	92	100	83	100	100	88	99	**91**
1992/93	97	100	100	100	100	100	87	96	**98**
1993/94	85	88	92	83	100	100	76	38	**83**
1994/95	94	100	100	100	100	100	100	100	**99**
1995/96	100	82	100	78	100	78	100	75	**89**
1996/97	75	100	96	76	100	73	71	88	**85**
1997/98	100	100	100	100	100	100	100	100	**100**
1998/99	85	59	100	86	78	73	74	100	**82**
1999/2000	41	64	93	100	98	100	100	93	**86**
2000/01	97	100	100	100	100	100	100	100	**100**
2001/02	83	100	100	100	100	100	84	93	**95**
2002/03	62	98	100	100	100	96	77	100	**92**
2003/04	72	100	100	100	100	100	45	100	**90**
2004/05	80	80	90	100	100	100	75	100	**91**
2005/06	62	61	87	81	90	61	29	86	**70**
2006/07	100	96	100	100	100	100	76	100	**96**
Average	**84**	**91**	**98**	**94**	**99**	**94**	**89**	**93**	**93**

The two lower average WRSI that are 84 and 89 are found at Kirundo and Kinyinya stations respectively in Bugesera and Moso natural regions. The highest WRSI value is 99 found at Cankuzo station, all located in Buyogoma region. It can also be seen some cases of WRSI less than 50 meaning crop failure in the Bugesera (at Kirundo station during the season 1999/2000 A) and Moso (at Kinyinya station for season 2003/04 for and 2005/06 and Musasa station for season 1993/94). Compared to stations located in Buyogoma, the frequency analysis (Table 4.16) shows low percentages of time when WRSI equals 100 (very good crop performance).

Table 4.16: Percentage of time based frequency analysis for WRSI of season A

	<50	**50-59**	**60-79**	**80-94**	**95-99**	**100**	**Total**
Kirundo	4	0	30	26	11	30	100
Muyinga	0	3	13	23	17	43	100
Nyamuswaga	0	0	0	15	4	81	100
Karuzi	0	3	7	23	0	67	100
Cankuzo	0	0	4	4	4	89	100
Muriza	0	0	18	4	11	68	100
Kinyinya	7	0	20	17	0	57	100
Musasa	3	0	7	27	10	53	100

Also from this Table 4.16, it is observed in Bweru at Muyinga station low percentage of time when WRSI equals 100. Crop water requirement is fully satisfied 43% of time.

For Buyogoma on other hand, the percentage of time the crop water requirement is satisfied is high, varying from 67 (at Karuzi) to 89 (at Cankuzo).

From what is discussed above for the growing season A, it is observed that Bugesera and Bweru in the north and Moso in the south are in general under agricultural water shortage conditions, especially Bugesera where the crop performance is not good for less than 50% of the time. Good and very good conditions together are observed 41% of the time in the season A. The region between, Buyogoma in the major part, seems to be less affected, crop performance being considered good, as shown by the map below (Figure 4.2).

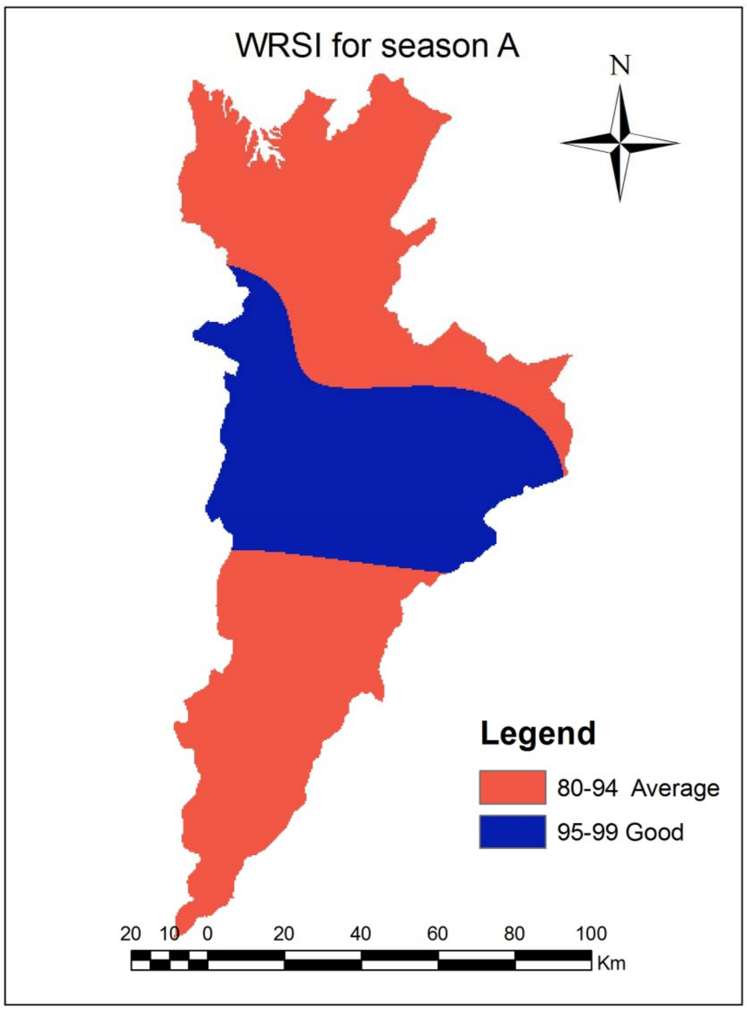

Figure 4.2: Crop performance map of Eastern Burundi during Season A

The map reveals two zones: The first zone in blue, accounting for around one third, is characterized by a good crop performance.

The second zone, in red, accounts for roughly two third of the total study area, and crop performance is not good. Its average WRSI varying between 80 and 94 indicates average crop performance. This part can be considered as agricultural drought prone area during season A. Based on the FAO estimations in Table 3.4, the average crop yield is estimated to be 70 % of the potential crop yield in optimal water conditions.

4.2.1.2 Crop growing season B.

The following Table 4.17 shows the WRSI of season B for all stations.

Table 4.17: Water Requirement Satisfaction Index for crop growing season B

Year	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Muriza	Kinyinya	Musasa	Average
1977/78		100		100			100	100	**100**
1978/79		100		100	100	100	100	100	**100**
1979/80	89	79	100	88	68	99	100	84	**88**
1980/81	100	92	100	100	100	100	100	100	**99**
1981/82	70	100	100	100	100	100	100	100	**96**
1982/83	100	100	100	72	100	100	98	100	**96**
1983/84	79	57	91	83	93	99	89	91	**85**
1984/85	100	100	100	100	100	100	100	100	**100**
1985/86	100	100	100	100	100	100	100	100	**100**
1986/87	99	100	100	100	95	100	100	100	**99**
1987/88	100	100	100	100	100	100	100	100	**100**
1988/89	87	100	100	93	100	100	100	100	**97**
1989/90	100	100	100	98	100	100	100	95	**99**
1990/91	100	100	100	100	100	100	100	100	**100**
1991/92	93	100	100	100	100	100	100	93	**98**
1992/93	100	100	100	100	100	91	100	100	**99**
1993/94	97	94	100	100	100	100	100	100	**99**
1994/95	100	100	100	55	100	100	100	100	**94**
1995/96	99	100	100	58	100	100	100	76	**92**
1996/97	100	100	100	100	100	100	100	100	**100**
1997/98	100	100	100	100	100	100	100	100	**100**
1998/99	78	96	92	100	91	100	100	82	**92**
1999/2000	80	79	99	100	73	70	84	80	**83**
2000/01	61	100	100	100	90	100	95	100	**93**
2001/02	100	100	100	100	100	100	100	100	**100**
2002/03	100	98	100	100	100	100	52	94	**93**
2003/04	100	100	100	100	74	100	65	69	**88**
2004/05	100	90	100	89	76	77	34	59	**78**
2005/06	100	100	100	100	100	100	73	92	**96**
2006/07	100	95	82	93	91	100	57	100	**90**
Average	**94**	**96**	**99**	**94**	**95**	**98**	**91**	**94**	**95**

From this table, the Moso region experiences the most agriculture water shortfall. The lower average WRSI for the period is observed at Kinyinya station. The main stations of the region, Kinyinya and Musasa, are the only ones to show crop failure (season 2004/05 at Kinyinya) and poor crop performance (season 2002/03 and 2006/07 at Kinyinya; season 2004/05 at Musasa). For other stations, there is no significant trend difference. The interpolation through ArcGIS software reveals two zones regarding crop performance as shown by the map of the Figure 4.3 below.

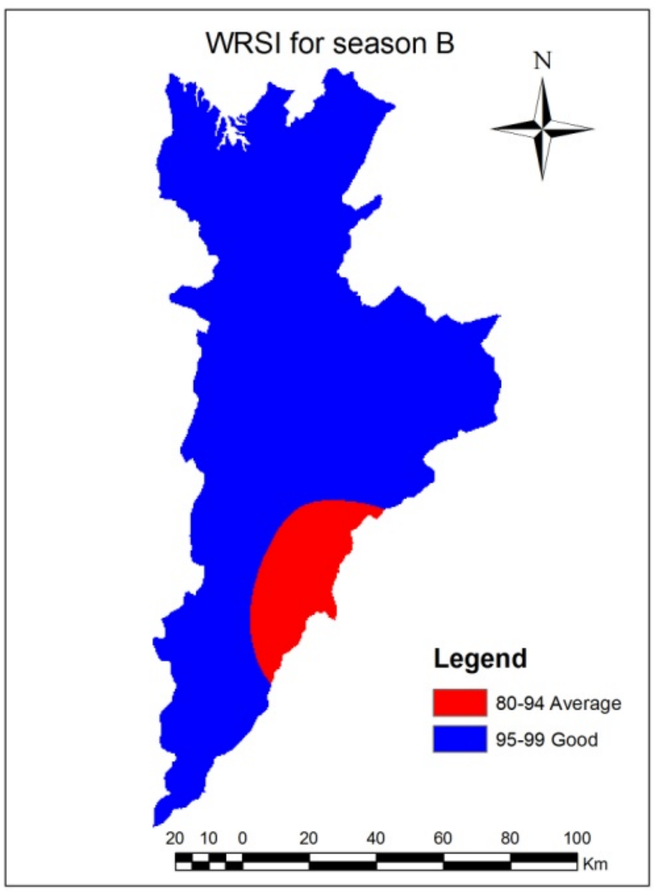

Figure 4.3: Crop performance map of Eastern Burundi during season B

For the major part (in blue), areal average WRSI varies from 95 to 99 meaning good crop performance. Only a small area around Kinyinya is characterized by average crop performance, it can be considered as agricultural drought prone area in season B.

Compared to the season A, Season B is considered to have better crop yield. Good crop performance is observed for about 90% of the area during season A and about only 33% of the total area during season B, as shown by the maps in Figure 4.2 and Figure 4.3.

This situation results from the fact that rainfall amount of October is often low in cases of late starting of the rainy season or false starting season. From the rainfall data, it can some time be seen a reduced rainfall in January, due probably of early starting of the dry spell which is generally starting by the end of January. For season, there is generally enough rainfall in March and April, when crops are at development and Mid season stages requiring more water.

4.2.1.3 Average WRSI for the two seasons A and B

The average WRSI for the two crop growing seasons have been estimated as shown in Table 4.18 below.

Table 4.18: Average WRSI for the two season A and B

Year	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Muriza	Kinyinya	Musasa	Average
1977/78		94		94			100	100	**97**
1978/79		100		100			100	100	**100**
1979/80		83		94	84	87	100	84	**89**
1980/81	88	96	100	94	100	100	100	97	**97**
1981/82	68	87	100	100	100	100	100	91	**93**
1982/83	100	100	100	81	100	100	99	100	**97**
1983/84	84	66	96	92	97	99	94	85	**89**
1984/85	84	100	100	77	100	100	95	95	**94**
1985/86	98	100	100	100	100	96	100	100	**99**
1986/87	100	100	100	100	97	100	100	100	**100**
1987/88	100	100	100	100	100	100	94	100	**99**
1988/89	93	95	100	96	100	100	100	100	**98**
1989/90	91	97	100	99	100	98	100	93	**97**
1990/91	100	98	100	100	100	98	100	100	**100**
1991/92	80	96	100	92	100	100	94	96	**95**
1992/93	99	100	100	100	100	96	93	98	**98**
1993/94	91	91	96	92	100	100	88	69	**91**
1994/95	97	100	100	78	100	100	100	100	**97**
1995/96	99	91	100	68	100	89	100	75	**90**
1996/97	87	100	98	88	100	87	85	94	**92**
1997/98	100	100	100	100	100	100	100	100	**100**
1998/99	81	78	96	93	85	87	87	91	**87**
1999/2000	61	71	96	100	86	85	92	87	**85**
2000/01	79	100	100	100	95	100	98	100	**96**
2001/02	91	100	100	100	100	100	92	97	**98**
2002/03	81	98	100	100	100	98	64	97	**92**
2003/04	86	100	100	100	87	100	55	84	**89**
2004/05	90	85	95	94	88	88	54	80	**84**
2005/06	81	81	93	90	95	80	51	89	**83**
2006/07	100	96	91	97	96	100	66	100	**93**
Average	**84**	**93**	**99**	**94**	**97**	**96**	**90**	**93**	**93**

Table 4.18 shows same trends as shown in Table 4.15 regarding WRSI of the season A. Kirundo in Bugesera is characterized by the lowest WRSI followed by Kinyinya in Moso. After come Musasa also located in Moso and Muyinga in Bweru. It is observed also in the table the worst agriculture drought in the last 15 years period where droughts are observed more frequently, the situation being accentuated from season 2002/2003, period characterized by a general persisting agriculture drought.

4.2.1.4 Drought identification

After estimating average WRSI for all stations, agricultural drought was defined when WRSI is lower than the average. The drought seasons have then be identified for all stations and for each year as shown by the Table 4.19, the number 1 meaning the drought season.

Table 4.19: Agricultural drought seasons

Year	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Muriza	Kinyinya	Musasa	Whole area
1977/78		0		0			0	0	**0**
1978/79		0		0			0	0	**0**
1979/80		1		1	1	1	0	1	**1**
1980/81	0	0	0	0	0	0	0	0	**0**
1981/82	1	1	0	0	0	0	0	1	**0**
1982/83	0	0	0	1	0	0	0	0	**0**
1983/84	0	1	1	1	1	0	0	1	**1**
1984/85	0	0	0	1	0	0	0	0	**0**
1985/86	0	0	0	0	0	0	0	0	**0**
1986/87	0	0	0	0	0	0	0	0	**0**
1987/88	0	0	0	0	0	0	0	0	**0**
1988/89	0	0	0	0	0	0	0	0	**0**
1989/90	0	0	0	0	0	0	0	1	**0**
1990/91	0	0	0	0	0	0	0	0	**0**
1991/92	1	0	0	1	0	0	0	0	**0**
1992/93	0	0	0	0	0	1	0	0	**0**
1993/94	0	1	1	1	0	0	1	1	**1**
1994/95	0	0	0	1	0	0	0	0	**0**
1995/96	0	1	0	1	0	1	0	1	**1**
1996/97	0	0	1	1	0	1	1	0	**1**
1997/98	0	0	0	0	0	0	0	0	**0**
1998/99	1	1	1	1	1	1	1	1	**1**
1999/2000	1	1	1	0	1	1	0	1	**1**
2000/01	1	0	0	0	1	0	0	0	**0**
2001/02	0	0	0	0	0	0	0	0	**0**
2002/03	1	0	0	0	0	0	1	0	**1**
2003/04	0	0	0	0	1	0	1	1	**1**
2004/05	0	1	1	0	1	1	1	1	**1**
2005/06	1	1	1	1	1	1	1	1	**1**
2006/07	0	0	1	0	1	0	1	0	**0**

The table above shows some temporal and spatial trends that are discussed in the following sections.

Temporal analysis

From Table 4.19, it is seen frequent agricultural drought occurrence in the period after 1992. It is seen an increase in frequency and duration. On the frequency side, it can be observed that from the 1992/93 season, drought occurrence is observed 60% of the time. For the previous 15 years period, it is observed only 13 of the time. The number of drought passed from 2 in the first to 4 in the second period. Another big difference is the duration. For the first period, the droughts were observed in single seasons. But during the second period, it is found that droughts are observed in successive more seasons, the duration varying from a one single season to 4 seasons, like the 2002-2006 agricultural drought.

From these observations above, it can be concluded that the last 15 years, the area has increasingly experienced frequent drought occurrence than it was before. A part the global atmospheric factors influencing climate changes in general and rainfall and temperature in particular, the increased drought occurrence situation can be linked to the decreased land cover observed after 1993 due to the long war started in the end of that year. Artificial and natural forests have been destroyed for secured purposes or by the displaced people, thus contributing to increased air movement and temperature and leading to higher evapotranspiration rates.

Spatial analysis

A part the seasons 1979/80 and 1983/84, it is observed that drought coverage has increased during the last 15 years. In this period, drought seasons are often observed in more than 50% of stations. It is especially visible during 1998/99, 1999/2000, 2004/2005 and 2005/2006. Here, agricultural drought is observed at 7 to 8 stations over the 8 considered stations. This situation is due to less amount of precipitation experienced during those time periods which was not sufficient to meet crop water requirements.

For the whole study period, spatial interpolation mapping reveals two zones regarding WRSI and crop performance ranges as showed by the Figure 4.4 below.

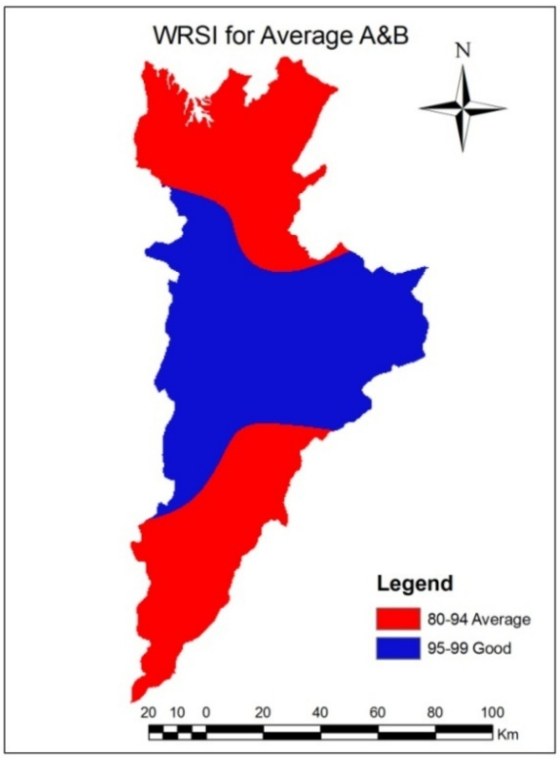

Figure 4.4: Crop performance map for seasons A and B

The first zone, in blue, accounts for almost a half of the total area with WRSI varying from 95 to 99. In this part, crop performance is considered good. The second, in red, is located at the 2 sides of the first one. The 80 – 94 WRSI range means average crop performance which is not good and which is conferring it a drought prone area character. That repartition results from the rainfall trend showing better precipitation in the big part of Buyogoma, especially during season B. On another hand, the southern Moso around Kinyina–Musasa and Bugesera on the northern part experience low amounts of precipitation especially in season A. Another factor is the temperature which is high in the eastern depressions including Moso and Bugesera, compared to Buyogoma.

4.2.2 AGRICULTURAL DROUGHT CHARACTERIZATION

4.2.2.1 Rainfall deficiency, drought severity and frequency

The Table 4.20 includes two agricultural drought characteristics that are severity and water deficit determined for each season, drought season is hereby shown by number 1. The severity is expressed by the crop performance.

Table 4.20: Crop performance and rainfall deficit for each season

Season	WRSI	Drought status	Crop performance	Deficit (mm)
1977/78	97	0	Good	116.9
1978/79	100	0	Very good	0.0
1979/80	89	1	Average	627.9
1980/81	97	0	Good	242.7
1981/82	93	1	Average	534.4
1982/83	97	0	Good	192.9
1983/84	89	1	Average	851.1
1984/85	93	1	Average	480.4
1985/86	99	0	Good	53.1
1986/87	100	0	Very good	28.9
1987/88	99	0	Good	80.4
1988/89	98	0	Good	143.9
1989/90	97	0	Good	210.4
1990/91	100	0	Very good	35.1
1991/92	95	0	Good	418.5
1992/93	98	0	Good	138.8
1993/94	91	1	Average	754.6
1994/95	97	0	Good	234.8
1995/96	90	1	Average	737.3
1996/97	92	1	Average	602.3
1997/98	100	0	Very good	0.0
1998/99	87	1	Average	997.5
1999/2000	85	1	Average	1170.1
2000/01	96	0	Good	282.1
2001/02	98	0	Good	201.4
2002/03	92	1	Average	621.5
2003/04	89	1	Average	876.7
2004/05	84	1	Average	1260.8
2005/06	83	1	Average	1394.1
2006/07	93	1	Average	537.3

From this table, a frequency analysis has been done in the following Table 4.21.

Table 4.21: Crop performance frequency analysis

Class	Case number	Percentage of time (%)
Very good	4	13
Good	11	37
Average	15	50
Total	**30**	**100**

Three classes of crop performance are observed: two class concern seasons with good to very good crop performance, meaning crop water requirement sufficiently satisfied, and class where crop performance is not good and that determine drought prone seasons. This last drought seasons class is observed 50% of time. From Table 4.20, it is observed a certain crop performance trend showing two contrary cases for the two half period seasons. In the first 15 years, drought prone seasons are few compared to the number of seasons with good to very good crop performance. By opposition, the second half period starting by the season 1992/93 is characterized by a significant number high number of drought prone seasons where good crop performance is not met. This observation clearly shows an increased agricultural drought occurrence during these last 15 years. The situation has been worsened from the season 2002/03 where a persisting agricultural drought is observed.

In addition to the frequency, agricultural drought has increased in crop water deficit. Higher deficits are also observed these last 10 years as it can be seen for the season 1998/99, 1999/2000, 2004/05 and 2005/06. This situation resulted from the reduced amount of rainfall received during the concerned seasons. For example, during season 2005/06 A in the majority of the stations, rainfall is found less than the seasonal average.

4.2.2.2 Duration and intensity

Intensity is a ration expression of magnitude over duration. In drought analysis, drought volumes are often used in the determination of drought intensity. The Table 4.22 below relates to the agricultural drought duration, volumes and intensities.

Table 4.22: Drought duration, volume and intensity

Season	**Duration**	Drought volume (mm)	Intensity (mm)
1977/78	1	116.9	116.9
1979/80	1	627.9	627.9
1981/82	1	534.4	534.4
1983/84 - 1984/85	2	1331.6	665.8
1991/92	1	418.5	418.5
1993/94	1	754.6	754.6
1995/96 - 1996/97	2	1339.7	669.9
1998/99 - 1999/2000	2	2167.5	1083.8
2002/03 - 2006/07	5	4690.3	938.06

As agricultural water deficit, higher intensities are observed in the recent fifteen years with maximum intensity during the 1998/98 – 1999/2000 drought seasons. The same raisons relating to rainfall and temperature apply here. This strengthens the idea that serious droughts occurred during this last 15 years. From 1993, agricultural droughts tend to progressively increase in intensity in addition to the increased frequency and duration as shown by the following Figure 4.5, Figure 4.6 and Figure 4.7.

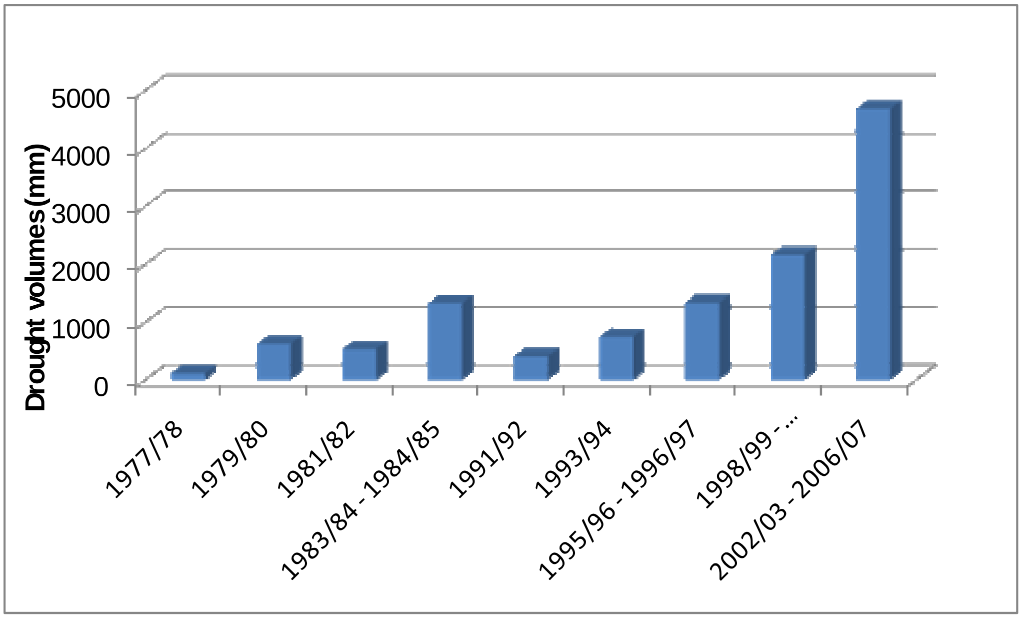

Figure 4.5: Agricultural drought volumes

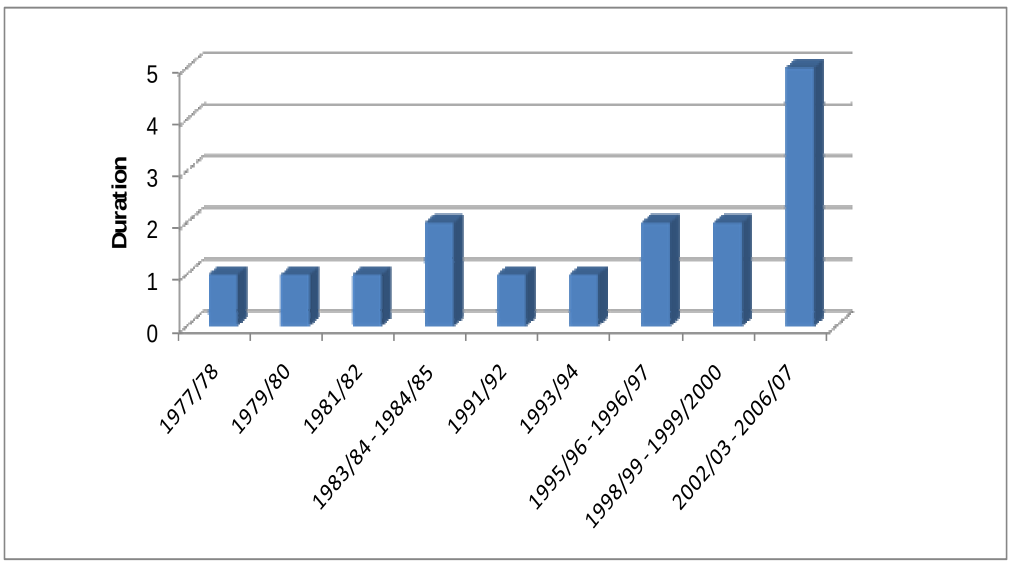

Figure 4.6: Agricultural drought duration

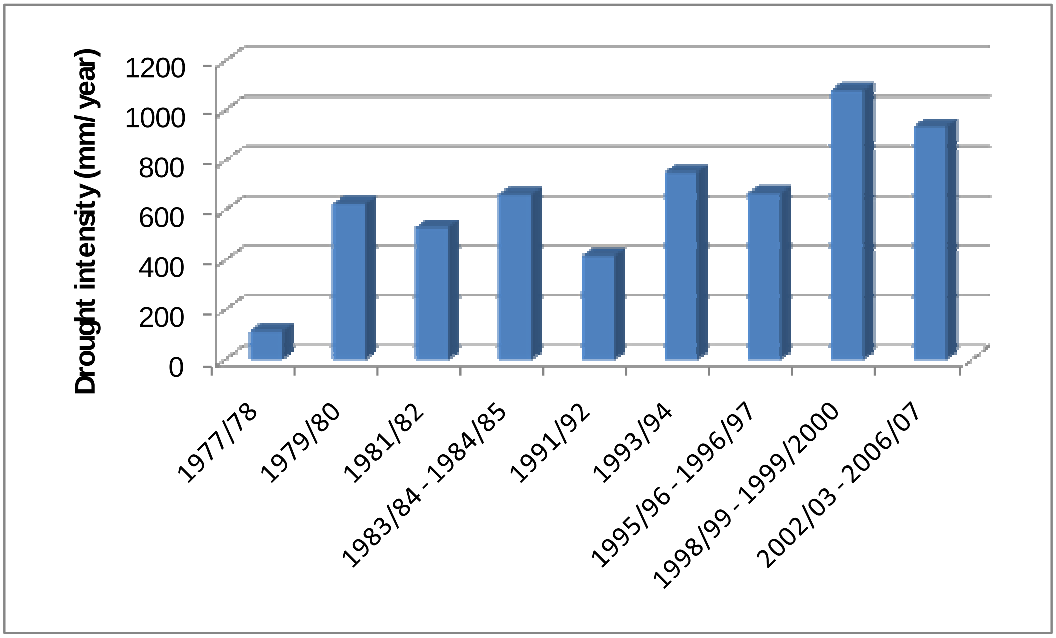

Figure 4.7: Agricultural drought intensity

The over-increase and lasting tendency observed from the season 1998/99 and specifically the very long agricultural drought of 2002/03 – 2006/07 is a situation to worry about as it may still ongoing with this year. As seen in the literature review, it is recognized that drought conditions themselves can play a role in the perpetuation of the drought through a feedback between the land surface and the overlying atmosphere that reinforces the drought sustaining circulation features. That phenomenon can also happen in the area and lead progressively to desertification of the area with possibility to extent.

4.2.2.3 Agricultural drought coverage maps

The agricultural drought coverage are shown by maps in the following figures. Only the main and recent agriculture droughts are here mapped (Figures 4.8 and Figure 4.9).

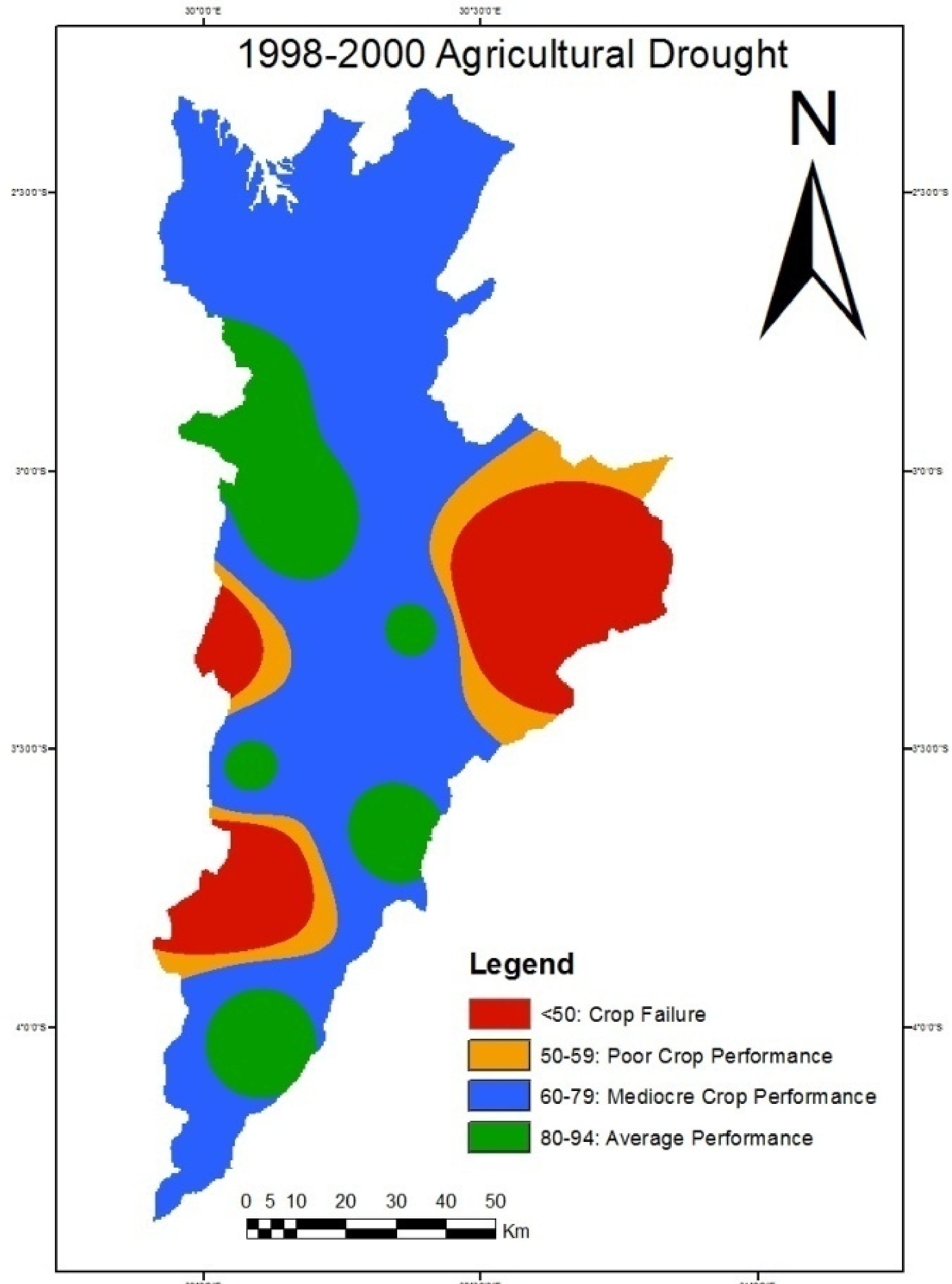

Figure 4.8: The 1998-2000 agricultural drought map

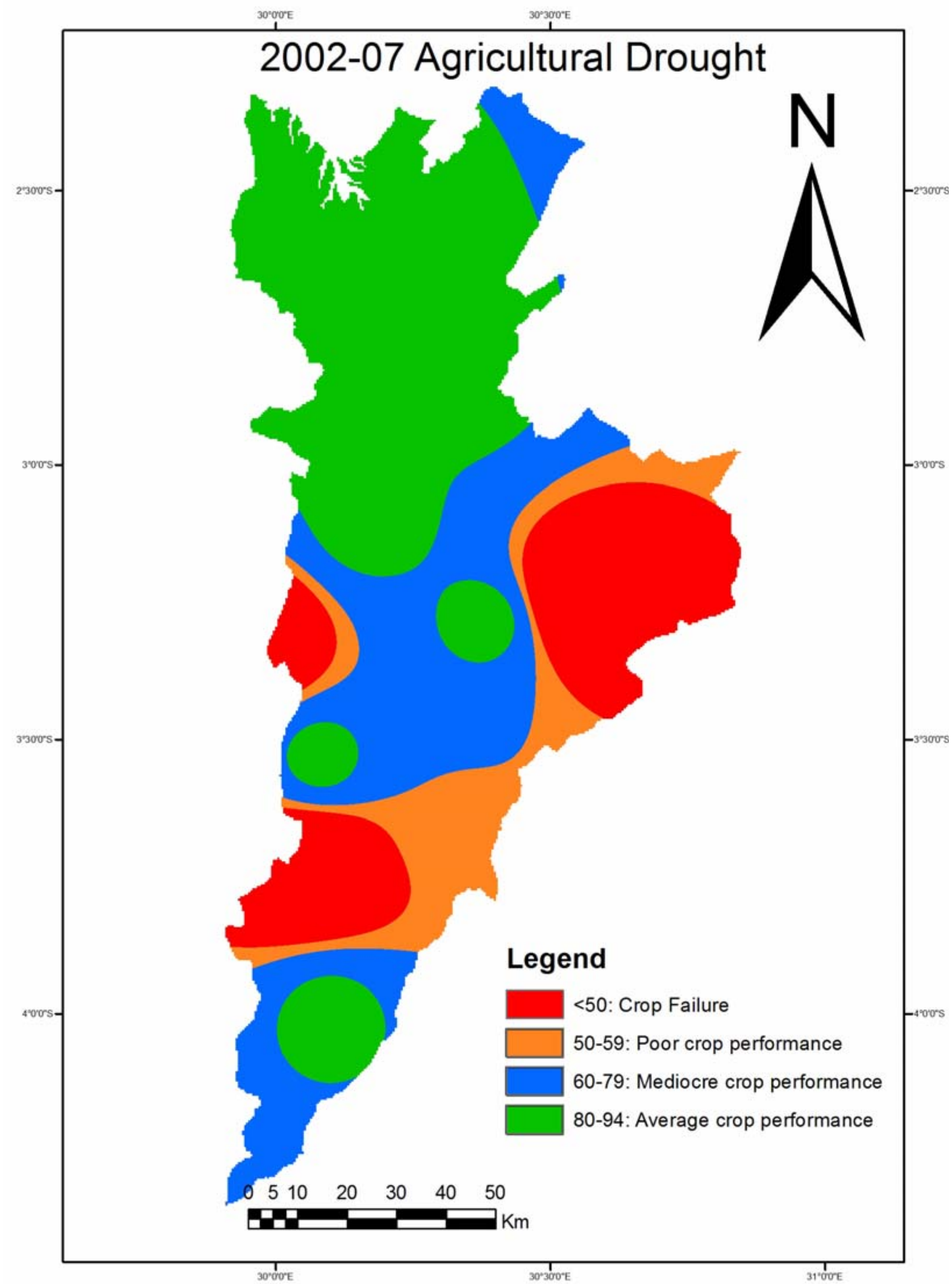

Figure 4.9: The 2002-2007 agricultural drought map

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Both meteorological and agricultural droughts occurred in the area during the last 30 years. Agricultural drought was found more occurring than meteorological drought. This results from the undistributed rainfall in time and space, climate change: temperature increasing trend leading to increased evapotranspiration (crop water needs), soil properties, erosion and land (cover) degradation. Also, it was seen that droughts are more observed at regional level than the whole area. At the region level, climatic conditions are more homogeneous than the whole area. Looking at the time scale basis, it was observed more drought occurrence at a season time scale basis than a year time scale basis.

In times, droughts have increased in frequency, duration, severity and intensity these last 15 years for both meteorological and agricultural drought. A frequency analysis of the Musasa rainfall data in Moso showed an increase of drought occurrence probability and return period. The return period reduction is estimated to 37.5%. From the agricultural drought analysis, it was noted the existing of a persisting agricultural drought from the season 2002/03 to 2007 which may still be ongoing to year 2008. If this is the case, and if mitigation measures are not taken, it could lead to disastrous environmental and socio-economic problems such as desertification, extreme famines and poverty, population displacements, etc. This phenomenon was found related to climate change and land degradation.

For meteorological and agricultural droughts, it was found that the northern part of the study area constituted by Bugesera and a big part of Bweru, and the southern part including a big part of Moso and the southern Buyogoma parts constitute drought prone area. The zone in the middle is receiving better rainfall and crop water performance is generally good. In this zone, rainfall and temperature are favorable. It is characterized by better rainfall amounts and tends to be temporally regular in terms of starting season dates and monthly rainfall. It has also temperature relatively low compared to the Moso and Bugesera.

For both meteorological and agricultural droughts, it was also found that Bugesera and Moso natural regions are more threatened by drought occurrence. These areas need more attention in terms of agro meteorological monitoring facilities and water development projects. These two regions are characterized by lower rainfall and higher temperatures in the area. That situation leads to crop water requirement often not satisfied, reaching sometimes a level of poor crop performance and even completely crop failure.

At the crop growing season level, agricultural drought is more occurring during crop growing season A than during crop growing season B. The cause was found related to rainfall trends: many cases of less than normal precipitation in October and January.

Also, false starting season and rainfall interruption are often the cause of that situation. Insufficient rainfall in October and sometime in early November as it was observed can stop or reduce the crop growth at the early development stage causing crop failure or very poor quality plants. Also, the starting of the small dry period in the earlier of January corresponding to the late crop season stage of season A when crops are at the grain development stage is particularly dangerous in that sense that grains can stop or poorly develop, leading to reduced and/or poor quality harvests, deteriorating the already existing food insecurity.

5.2 RECOMMENDATIONS

Firstly, we recommend irrigation development to supplement agricultural water shortfall in the area. Priority should be given to Bugesera and Moso natural regions. The first stapes would focus on rehabilitation of the existing irrigation schemes. Then new schemes should be constructed. Water should be diverted from some of the rivers crossing the regions from the neighboring highlands of the Central plateau towards the northern lakes in the north, Rubuvu River in the middle and Malagarazi in the Moso. In fact, the regions in question are drained by a relatively dense river network with permanent water flows generally varying from around 2 to 10 m^3/s as it can be seen in the map of the Appendix 8 (Direction Générale de l'Eau et de l'Energie, 2000).

Beneficiary communities and local administration should be massively involved from the project identification to hydro-infrastructure operation and maintenance. Basic training and education at the lowest stakeholder level should be continually undertaken in different field of water, land and environment management.

To reach that objective, an Irrigation Fund needs to be established. Workshops should be organized to deliberate on ways and means of mobilizing local resources and other funding sources. The alternative sources of funds to be explored are Central Government grants, fees earned from water charges, Donors, penalties charged against consumers contravening the Water Act and special individual contributions.

Improved agricultural practices should be promoted with respect to the use of water: promotion of species less demanding in crop water requirement, and species with short growing period as adaptation measure to the very late beginning of precipitations, cultivation methods which avoid or reduce erosion contributing to the irrigation infrastructure protection.

Commercial farming needs to be promoted. Commercial farmers are supposed to have better willingness to pay for water services, this will allow the collecting of small funds for maintenance and operation of hydro-agricultural infrastructure. Small scale irrigation can also be developed with such local small funds. With commercial farming, it is also easier to improve agricultural practices which allow water savings and high production on small lands.

Intensification of land restoration and protection activities should be implemented. Actions to be undertaken could include forestation and reforestation on non agricultural lands, agroforestry in crop farming system and paddocks in livestock system.

Use and management of both surface and groundwater should be done in an integrative manner considering costs, land use in the various sub-catchments and water saving practices. Currently, enough amount of ground water resources have been found in Moso. This resource should be exploited in periods of rainfall and surface water shortage. Also, rainfall harvesting can be promoted in some areas experiencing high intra-seasonal rainfall variability (heavy rainfall and low rainfall amounts within one season).

There is need of policy reforms in water resources. A National organization/institution to coordinate water resources at State level needs to be put in place. There is need of a Water related disaster management unit with a Drought Early Warning system component. A decentralization based water management system should be promulgated together with the establishment of Catchment and Sub-catchment Management Councils to oversee all operational water resources management functions; e.g: irrigation, water supply, allocations etc.

Nowadays, very few meteorological and hydrological recording stations are working. The IGEBU estimates that only 16% of the meteorological stations of 1993 are working. Therefore, there is an imperative necessity of rehabilitation and increase the number of the meteorological stations.

During this research, it was observed that very few studies on drought have been done in Burundi and we recommend further research. For that matter, different drought indices should be tested to find out the most applicable for Burundi conditions. There is also a need of a complement study extending drought analysis on hydrological and socio-economic aspects. Integrated studies linking drought indices with risk and impacts of droughts for different regions and groups (humans, natural resources) should be implemented to facilitate a better understanding of drought issues and support decision making.

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APPENDICES

Appendix 1: Average annual rainfall

Year	Kirundo	Muyinga	lyamuswag	Karuzi	Cankuzo	Muyaga	Mugera	Muriza	Musongati	Kinyinya	Musasa
1978	1231.4	1082.8	1325.6	1324.1	1467.4	1418.1	1209.3	1504.8	1338.3	1429.1	1059.0
1979	1057.2	1186.4	1325.6	1673.8	1145.7	1258.2	1271.9	1202.6	1268.9	1308	1248.7
1980	923.3	951.4	1402.9	881.9	894.3	923.5	887.6	957.7	1071.9	1207.6	839.5
1981	1200.9	920	1200	1168.9	1465.9	1435.8	1143.0	1045.7	1417.2	1065.4	1077.0
1982	1075.6	1128.5	1660.4	1022.7	1183.8	1282.7	1382.5	1372.6	1138.5	1389.6	1473.9
1983	1001.5	1065.4	1631	823.0	1062.1	1258.1	888.1	997.7	1103.4	1063.9	960.6
1984	887.3	1063.7	1604.8	785.2	1178.4	1091.1	1122.9	1030.8	1337.5	1010.7	995.3
1985	1292.3	1306.9	1475.1	1692.6	1212.1	1204.8	1117.1	1288.8	1461.4	1455.8	1091.5
1986	1217.2	1248.1	1476.9	1317.7	1186	1220.4	1313.9	1295.2	1247.7	1424.8	1530.4
1987	1350.3	1508.9	1607.7	1158.6	1134.3	1208.5	984.9	1264.4	1115.5	1268.9	1195.7
1988	1179.5	1473.9	1751.2	1113.8	1432	1591.9	1454.4	1320.1	1241.3	1028.3	1425.7
1989	981.1	1104.3	1455.6	1118.1	1430.3	1410.2	1293.0	1620	1356.1	1570.6	1345.3
1990	1175.9	1050.4	1352.8	1133.5	1195.4	1248.6	890.8	1123.1	1075.9	1230.6	973.5
1991	1006.1	1032.9	1352.9	1136.6	1221.7	1340.2	1085.9	1180.7	1223.5	1235.8	1278.0
1992	947	1092.5	1083.8	1163.9	1312	1261.4	1017.5	1154.2	1165.5	1085.3	988.6
1993	1084.4	1138.6	954.7	1034.7	994.1	1066.2	907.0	940.4	1082.4	994.3	845.2
1994	1022.2	1050.3	1242.5	1312.8	1276.4	1479.5	974.9	1334.2	905.8	1216.2	1220.7
1995	1162.1	989.8	1356.7	605.5	1181.9	1141.4	851.7	1112.3	1215.2	1745.2	1015.0
1996	957.2	1261.1	1166.2	766.3	1158.2	1222.3	1120.6	976.8	1066.1	1225.7	952.4
1997	1059.3	1584.1	1526.8	1378.4	1500.8	1557.3	1195.2	1367.5	1307.3	1614.5	1261.3
1998	1400.3	958.4	1393	1668.8	1053.5	890.8	1124.4	1235.5	1216.2	1465	1539.2
1999	760.3	822.7	1096.7	1298.2	984.3	1068	1228.5	1242.6	1049.1	1203.3	1006.9
2000	804.4	859.6	1061.7	1286.3	853.1	926.1	1042.1	796.7	843.4	1052.2	1040.5
2001	1015.8	1235.6	1251.2	1644.2	1163.2	1099.7	1202.6	1226.1	1192.8	1188	1178.4
2002	987.3	1063.3	1121.1	1680.9	1255	1314.9	1073.0	1086.9	1315.1	1021.7	1144.2
2003	1180.2	1039.7	1170	1045.6	1123.5	1171.8	1148.5	993.5	1079.1	687.1	947.1
2004	1073.9	1157.2	1261.1	1326.5	969.9	1026.7	1305.7	1192.1	1324.2	671.9	1121.7
2005	1064.3	862.6	1095.3	982.0	746.6	758.8	892.4	837.4	1054.8	345.3	725.2
2006	1139.5	1058.6	1315.9	1728.4	1528.4	1599.4	1207.5	1347.4	1163.3	708	1306.8
2007	1151.8	1051.7	1049.9	1063.2	1003.8	1027.6	969.9	1039.4	1456.7	552.7	1015.3
Average	1076.1	1129.5	1325.6	1201.5	1184.6	1217.7	1110.2	1144.2	1190.2	1141.3	1167.2

Appendix 2: Average monthly rainfall by station

Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Kirundo	88.1	98.6	128.1	189.2	113.6	16.4	7.2	26.0	73.6	107.8	122.8	104.8
Muyinga	120.8	114.4	151.0	189.9	91.2	13.6	2.7	22.4	52.4	105.4	143.6	122.2
nyamuswaga	132.2	130.5	163.8	217.8	96.8	14.3	6.3	21.7	79.8	137.5	177.1	147.8
Karuzi	138.1	129.3	172.4	178.6	84.4	8.2	5.3	14.4	43.8	104.6	166.1	156.4
Cankuzo	155.5	131.5	154.2	169.6	76.2	3.5	5.0	13.8	42.9	90.1	164.8	177.4
Muyaga	142.4	139.4	160.1	192.6	85.4	5.5	3.8	11.2	40.2	94.4	164.3	178.5
Mugera	155.2	124.5	142.7	153.9	70.9	4.4	3.7	21.0	44.4	88.2	150.9	150.5
Muriza	151.4	127.9	165.0	188.8	80.2	4.5	5.4	12.9	34.3	74.1	151.6	148.1
Musongato	160.8	154.1	168.3	194.6	78.7	10.6	3.8	18.1	34.1	72.0	139.5	155.4
Kinyinya	156.9	120.4	167.5	193.2	79.4	6.6	2.2	8.6	32.9	77.1	142.0	154.5
Musasa	168.7	138.5	161.6	190.9	87.0	7.2	1.7	10.0	30.2	81.1	139.4	151.0
AVERAGE	**142.7**	**128.1**	**157.7**	**187.2**	**85.8**	**8.6**	**4.3**	**16.4**	**46.2**	**93.8**	**151.1**	**149.7**

Appendix 3: Season A average rainfall

Season	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Mugera	Muriza	Muyaga	Musongati	Kinyinya	Musasa	Average
1977/78	481	421.8		425.3	599.9		641.1	660.9	525.7	570	594.1	**546.6**
1978/79	466.5	570.6		630.6	803.7	514.2	814	711.9	623.3	638.1	622.1	**639.5**
1979/80	344.8	424.3		518	519.4	390.8	350.1	560.1	490.6	570.6	429.6	**459.8**
1980/81	369.5	476.9	693.1	417.6	531.2	539.0	484	471.3	397.1	520.3	484.2	**489.5**
1981/82	320.4	357.1	607.1	505.9	564.6	424.7	486.1	503.2	735.3	514.8	420	**494.5**
1982/83	508.3	499.2	712.6	420.1	564.5	713.9	713.6	683.3	500.8	687.1	738.8	**612.9**
1983/84	434.7	352.9	907.7	479.1	651.9	502.4	543.5	715.2	591.6	599.9	396.4	**561.4**
1984/85	334	643.6	685.6	258.9	542.1	569.7	541.9	578.1	605.1	445.5	446.9	**513.8**
1985/86	472	587.6	704.5	1102.8	547.7	601.3	431.6	517	469	641.3	567.4	**603.8**
1986/87	499.5	543.5	553.5	520.5	642.6	716.0	712.6	723.8	707.3	793.8	761.2	**652.2**
1987/88	752.4	820.3	684.8	606.6	742.2	377.9	493.9	780.1	491.2	447.1	540.6	**612.5**
1988/89	506.1	424.8	577.4	478.1	649.8	778.1	835	711.8	493.9	568.7	676.3	**609.1**
1989/90	394.1	449.7	622.7	504.8	527.9	420.3	446.6	545.3	540.9	537.9	461.5	**495.6**
1990/91	540.3	460.1	559.7	612.9	487.1	401.2	451.3	483.3	414	611.4	594.9	**510.6**
1991/92	334.4	436.9	535.3	389.9	626.5	585.2	558.5	719.7	417.2	442.3	485.9	**502.9**
1992/93	479.9	550.2	561.5	680.1	724.8	730.2	467.3	602.4	523.9	443.6	484.6	**568.0**
1993/94	415.4	426.2	436.3	393.7	469.5	331.5	525.2	523.4	463.6	396.4	196.7	**416.2**
1994/95	467.2	572.5	641	754	693.5	594.5	754.3	838.5	543.5	785.5	656.2	**663.7**
1995/96	519	391.3	669.2	359.4	529.3	259.5	368.5	437.7	525.5	736.2	378	**470.3**
1996/97	372	504.8	456	354.4	536.1	558.7	347.8	595.6	452.8	367	439.8	**453.2**
1997/98	667.3	940.3	976.6	860.7	975.9	717.1	841.5	920.3	798.4	1204.3	825.9	**884.4**
1998/99	421.6	285.8	505	401.4	369.9	301.4	349.1	380.7	356.1	380.7	544.4	**390.6**
1999/2000	203.4	299.5	435	646.8	458.9	662.7	512	566.7	395.5	612.8	477.2	**479.1**
2000/01	487.3	518.8	583.3	884.2	613.3	762.9	557.3	682.8	691.3	777.4	688.8	**658.9**
2001/02	413.7	601.8	510.8	1004.4	515.6	529.5	531.6	637.7	527	431	477.7	**561.9**
2002/03	310	474.7	514.4	664.5	623.1	635.3	459.9	572.4	497.5	394.7	569.6	**519.6**
2003/04	360.3	506.6	566.1	520.4	565	551.3	528.2	643.5	462.9	228.3	558.7	**499.2**
2004/05	405.3	397.3	426.9	513.7	553.9	672.8	636.8	535.4	618.6	377.9	600.5	**521.7**
2005/06	316.2	303.6	410.2	393.2	428	309.0	290.6	358.8	477.9	149	440.4	**352.4**
2006/07	563.4	451.2	565.5	992.2	813.8	568.6	802.2	860.9	602.3	380.753	734.6	**666.9**
Average	**438.7**	**489.8**	**596.4**	**576.5**	**595.7**	**542.1**	**549.2**	**617.4**	**531.3**	**541.8**	**543.1**	**547.0**

Appendix 4: Season B average rainfall

Season	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Mugera	Muriza	Muyaga	Musongati	Kinyinya	Musasa	**Average**
1977/78	632.3	607.6		586.3	669.1	584.7	662.8	695	696.5	699.3	565.1	**639.9**
1978/79	641.3	530.3		1153.9	576.5	771.5	726	646.7	755.2	702.1	666.2	**717.0**
1979/80	438.6	378	573.1	412.4	324.6	409.8	455	400.3	576.3	581.9	422.2	**452.0**
1980/81	608.7	438.7	503.5	598.6	720.1	583.5	461.2	741.4	655.3	550.3	554.2	**583.2**
1981/82	347.9	474.9	728.9	531.7	553.9	506.9	614.2	550.3	596.6	575.3	684.6	**560.5**
1982/83	517.8	612.2	818.8	346.5	510.6	451.1	506.1	626.5	534.1	494.1	528.1	**540.5**
1983/84	389	269	434.1	398	442.7	368.6	450.2	364.8	683.2	453.6	460.1	**428.5**
1984/85	680.5	613.5	670.3	660.6	571.3	480.3	777.6	562.8	992.9	870.1	576.4	**677.8**
1985/86	640.5	658.4	919.5	649.6	559.2	593.8	616.2	567.4	520.7	670.1	775	**651.9**
1986/87	492.6	698.5	630.5	519.1	454	367.1	577.8	385.6	528.6	589.2	592.1	**530.5**
1987/88	534.7	655.1	1023	482.4	647.1	527.7	586.8	717.5	622.9	486.4	595	**625.3**
1988/89	416.8	548.4	594.1	436	568.6	686.9	732.8	586.4	686.3	787.9	647.8	**608.4**
1989/90	577.6	512.9	665.1	465.1	775.2	455.3	706.7	734.5	577.1	784.8	482	**612.4**
1990/91	545.1	533.3	644	709.1	523	560.2	593.7	661	767.8	667.2	599.5	**618.5**
1991/92	465.4	589.4	517.8	606.2	605.2	468.3	684.4	619.7	606.5	593.6	466.1	**565.7**
1992/93	532.7	543.5	488.8	514.6	497.3	371.0	419.7	585.1	515.8	543.5	555.7	**506.2**
1993/94	481	445.3	539.6	479.8	503.8	355.8	526.6	539.5	336.9	561.1	682.8	**495.7**
1994/95	521.2	511.8	609.4	255.8	656.4	534.4	644.1	642.3	708.4	858.3	684.9	**602.5**
1995/96	493.3	690.5	613.7	269.1	482.9	565.1	571.4	548.2	476.8	678.9	377.6	**524.3**
1996/97	551.2	653.2	571.6	584.7	564.8	382.0	637.6	622.6	463.7	661.7	501.1	**563.1**
1997/98	591.2	533.3	677.7	1114.2	540.1	726.8	771.4	461.2	792.1	827.4	876.8	**719.3**
1998/99	386.2	451	431.9	523.4	427.7	407.4	597.1	383.7	509.3	518.8	415.6	**459.3**
1999/2000	396.5	366.9	460.1	456.4	338.8	347.6	327.6	350.8	274	425.5	404.7	**377.2**
2000/01	302.8	469.1	493.5	467.4	414.1	487.9	516.1	372.3	456.8	481.6	507	**451.7**
2001/02	633.9	549.7	514.6	838.6	581.5	377.4	599.3	502.3	725.5	556.5	525	**582.2**
2002/03	610.3	471.8	562.3	525.8	518.1	552.5	485.9	478	579.6	266	479.2	**502.7**
2003/04	579.2	671.5	696	710.6	341.1	444.1	502	410.8	653.8	328.9	354	**517.5**
2004/05	623.4	457.2	535.3	436.7	357.5	410.0	363.1	393.4	547.8	177.6	304.8	**418.8**
2005/06	549.6	509.5	742.6	631.5	606.8	577.9	591.7	695.1	545.3	366.7	462.8	**570.9**
2006/07	567.7	452.8	390.4	447.5	412.6	331.0	485.9	419.7	677.4	290.6	568.2	**458.5**
Average	**525.0**	**529.9**	**608.9**	**560.4**	**524.8**	**489.6**	**573.0**	**542.2**	**602.1**	**568.3**	**543.8**	**551.6**

Appendix 5: Average monthly temperature at different stations

Station	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**Average**
Kirundo	21.35	21.70	21.42	21.30	21.29	21.22	21.28	21.43	22.03	21.25	20.64	20.79	21.31
Muyinga	19.86	20.12	19.88	19.62	19.58	19.53	19.70	20.51	20.68	20.50	19.63	19.62	19.94
Nyamuswaga	19.69	19.88	18.92	19.01	19.53	16.92	17.05	18.08	19.21	17.83	18.49	18.58	18.60
Karuzi	19.29	19.48	19.42	19.40	19.32	18.80	18.88	19.62	20.34	20.18	19.23	19.14	19.42
cankuzo	19.03	19.33	19.35	19.33	19.27	18.76	19.08	20.29	20.94	20.40	19.00	18.90	19.47
Muriza	19.01	19.09	19.17	19.25	18.57	17.40	17.39	18.67	19.84	19.53	18.96	19.03	18.83
Kinyinya	21.82	22.05	21.94	21.93	21.69	20.87	20.77	22.20	22.90	22.82	21.77	21.41	21.85
Musasa	21.64	21.81	22.10	22.06	21.56	20.68	20.42	21.64	23.45	23.16	22.30	21.71	21.88
Average	20.21	20.43	20.28	20.24	20.10	19.27	19.32	20.30	21.17	20.71	20.00	19.90	**20.16**

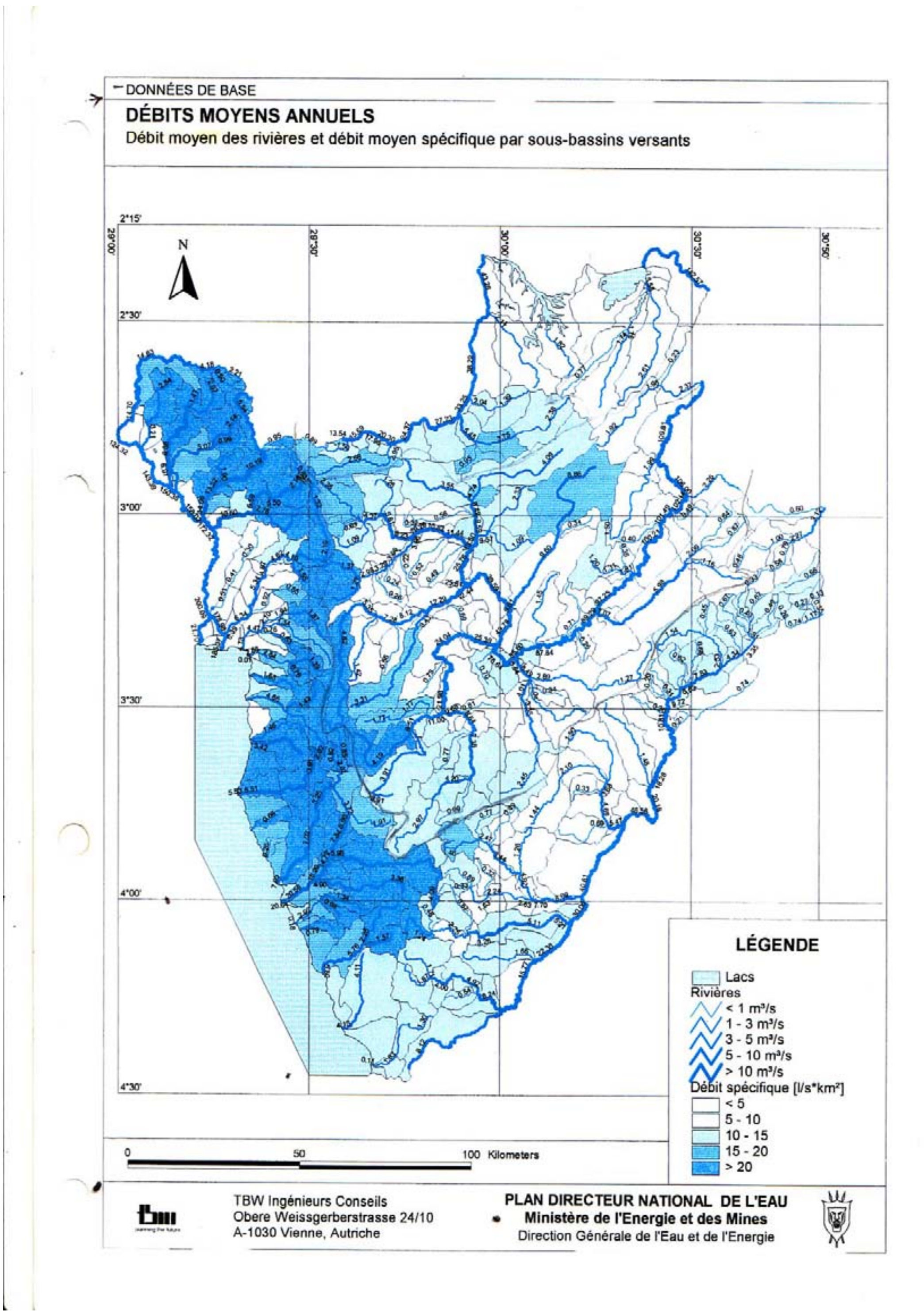
Appendix 6: PNP for Season A

Season	Kirundo	Muyinga	Nyamuswaga	Karuzi	Cankuzo	Mugera	Muriza	Muyaga	Musongati	Kinyinya	Musasa	Average
1977/78	113.1	87.9		75.4	101.5		120.1	111.5	99.2	106.3	110.7	**102.9**
1978/79	109.7	119.0		111.8	136.0	95.3	152.4	120.2	117.6	119.0	116.0	**119.7**
1979/80	81.1	88.5		91.8	87.9	72.4	65.6	94.5	92.6	106.4	80.1	**86.1**
1980/81	86.9	99.4	116.2	74.0	89.9	99.9	90.6	79.5	74.95	97.1	90.3	**90.8**
1981/82	75.4	74.5	101.8	89.7	95.5	78.7	91.0	84.9	138.8	96.0	78.3	**91.3**
1982/83	119.6	104.1	119.5	74.5	95.5	132.3	133.6	115.3	94.5	128.2	137.7	**114.1**
1983/84	102.3	73.6	152.2	84.9	110.3	93.1	101.8	120.7	111.7	111.9	73.9	**103.3**
1984/85	78.6	134.2	115.0	45.9	91.7	105.6	101.5	97.6	114.2	83.1	83.3	**95.5**
1985/86	111.0	122.5	118.1	195.5	92.7	111.4	80.8	87.3	88.5	119.6	105.8	**112.1**
1986/87	117.5	113.3	92.8	92.3	108.7	132.7	133.4	122.2	133.5	148.1	141.9	**121.5**
1987/88	177.0	171.0	114.8	107.5	125.6	70.0	92.5	131.7	92.7	83.4	100.8	**115.2**
1988/89	119.1	88.6	96.8	84.8	109.9	144.2	156.4	120.1	93.2	106.1	126.1	**113.2**
1989/90	92.7	93.8	104.4	89.5	89.3	77.9	83.6	92.0	102.1	100.3	86.0	**92.0**
1990/91	127.1	95.9	93.8	108.7	82.4	74.4	84.5	81.6	78.1	114.0	110.9	**95.6**
1991/92	78.7	91.1	89.8	69.1	106.0	108.5	104.6	121.5	78.7	82.5	90.6	**92.8**
1992/93	112.9	114.7	94.1	120.6	122.6	135.3	87.5	101.7	98.9	82.7	90.3	**105.6**
1993/94	97.7	88.9	73.2	69.8	79.4	61.4	98.4	88.3	87.5	73.9	36.7	**77.7**
1994/95	109.9	119.4	107.5	133.7	117.3	110.2	141.3	141.5	102.6	146.5	122.3	**122.9**
1995/96	122.1	81.6	112.2	63.7	89.5	48.1	69.0	73.9	99.2	137.3	70.5	**87.9**
1996/97	87.5	105.3	76.5	62.8	90.7	103.5	65.1	100.5	85.5	68.5	82.0	**84.3**
1997/98	157.0	196.1	163.7	152.6	165.1	132.9	157.6	155.3	150.7	224.6	153.9	**164.5**
1998/99	99.2	59.6	84.7	71.2	62.6	55.9	65.4	64.3	67.2	71.0	101.5	**72.9**
1999/2000	47.8	62.4	72.9	114.7	77.6	122.8	95.9	95.6	74.7	114.3	88.9	**88.0**
2000/01	114.6	108.2	97.8	156.7	103.8	141.4	104.4	115.2	130.5	145.0	128.4	**122.4**
2001/02	97.3	125.5	85.6	178.1	87.2	98.1	99.6	107.6	99.5	80.4	89.0	**104.4**
2002/03	72.9	99.0	86.3	117.8	105.4	117.7	86.1	96.6	93.9	73.6	106.2	**96.0**
2003/04	84.8	105.6	94.9	92.3	95.6	102.2	98.9	108.6	87.4	42.6	104.1	**92.4**
2004/05	95.3	82.8	71.6	91.1	93.7	124.7	119.3	90.4	116.8	70.5	111.9	**97.1**
2005/06	74.4	63.3	68.8	69.7	72.4	57.3	54.4	60.6	90.2	27.8	82.1	**65.5**
2006/07	132.5	94.1	94.8	175.9	137.7	105.4	150.2	145.3	113.7	71.0	136.9	**123.4**

Appendix 7: Rainfall data used in the frequency analysis for Musasa station

Year	Annual Rainfall
1961	1389.5
1962	1238.0
1963	1508.0
1964	1189.1
1965	1119.2
1966	1039.4
1967	1371.8
1968	1313.4
1969	1097.7
1970	1272.6
1971	922.5
1972	1325.6
1973	1371.5
1974	1106.6
1975	1090.7
1976	1158.5
1977	1542.2
1978	1059.0
1979	1248.7
1980	839.5
1981	1077.0
1982	1473.9
1983	960.6
1984	995.3
1985	1091.5
1986	1530.4
1987	1195.7
1988	1425.7
1989	1345.3
1990	973.5
1991	1278.0
1992	988.6
1993	845.2
1994	1220.7
1995	1015.0
1996	952.4
1997	1261.3
1998	1539.2
1999	1006.9
2000	1040.5
2001	1178.4
2002	1144.2
2003	947.1
2004	1121.7
2005	725.2
2006	1306.8
2007	1015.3
Average	**1167.2**
75% of Av.	**875.4**

Appendix 8: Burundi river discharge map



Source: Ministry of Water, Energy and Minerals; Water and energy Division.