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CLIMATE CHANGE AND NATURAL DISASTERS IN AFRICA; CASE STUDY OF RWANDA

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DECLARATION

I, Nishimwe Clarisse NIBAGWIRE, hereby declare that the work presented in this report is my own contribution to the best of my knowledge. This work has never been presented or submitted to any other university or institution for the award of any degree. Therefore, I declare that the presented work in this report is my own contribution for the fulfillment of the award of the Master's degree in Energy Engineering.

The content of this report may be used for further research in similar topics at the Pan African University Institute of Water and Energy Sciences, including Climate Change – PAUWES, as well as in all Pan African Universities – PAU Institutes

Signed by:

Nishimwe Clarisse NIBAGWIRE ………………..

DEDICATION

I dedicate this research thesis to:

The Almighty God;

My parents, brothers and sisters;

My lecturers and classmates;

My fellow Rwandan PAUWES students and all PAUWES students;

And to all my friends

ACKNOWLEDGEMENT

I deeply and sincerely thank the Almighty God for his grace, for keeping me safe and healthy during the last 2 years of my studies at PAUWES and for all the achievements I made during those years.

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I finally thank my beloved family for the love and incessant encouragement despite my being thousands of miles away from them. I thanks all my friends who have always been there for me and the connections they helped me create in order to achieve the goals of this project.

May the Almighty God overwhelm them with his blessings and grace

ABSTRACT

Different theories emphasize the role climate change plays in the actual abnormal occurrence of climate related natural disasters. This is a stressful issue for researchers, Scientifics and politicians due to inevitable loss and the impact both climate change and natural disasters exert on the ecosystem. And the resulting consequences are harmful to the health and well-being of the human beings since they touch all the spheres. Therefore, by following these theories, climate change and natural disasters would be qualified as barriers to the development and well–being of human beings, especially in developing countries, since they are the ones that are more vulnerable to climate change and natural disasters due to lack of means of resilience to the latter's harmfulness.

From the above, two important points arise. Firstly, how climate change impacts occurrence of natural disasters in developing countries. And secondly, the rate at which climate change has driven the abnormal occurrence of climate related natural disasters. To answer these two points with relevant scientific evidences, one developing country, Rwanda, was taken as a case study, with the main objective of evaluating how climate change events correlate with the occurrence of these disasters. Historical records of climate related natural disasters that occurred in Rwanda, and records of temperature and precipitation were used as the parameters used to achieve the main objective of this study. Then, calculations were processed to evaluate the level of correlation between the temperature trend and climate related natural disasters trend.

Based on the obtained results, climate change in Rwanda is not negligible since the temperature increases at different consulted meteorological stations were varying from 0.48 degree Celsius to 1.99 degree Celsius over a period of 39 to 45 years. And this is higher than the global temperature increase of 0.85 degree Celsius over the past period of 132 years. The result of the analysis also indicates much fluctuation in precipitations as a result of weather disturbances. The occurrence of climate related natural disasters has increased by 31% over the last 41 years.

More precisely, the rise in temperature has influenced the occurrence of climate related natural disasters, but the identified influence is of low level. On the other hand, other factors, such as: fast growing population, geomorphological structure of the Rwandan soil mostly dominated by high elevated surface and poor cultivation practices, have increased the risk of vulnerability to climate related natural disasters. Therefore, they have boosted the abnormal occurrence of the stated disastrous events.

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ACRONYMS

°C: Degree Celsius

AU: African Union

CO2: Carbon Dioxide

CRED: Centre of Research on the Epidemiology of Disasters

DAAD: Deutscher Akademischer Austauschdienst – German Academic Exchange Service

DALYs: Disability Adjusted Life Years

DRR: Disaster Risk Reduction Strategy

EM-DAT: Emergency Events Database

GDP: Gross Domestic Product

GHG: Greenhouse gases

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit – Company specialized in international development

GoR: Government of Rwanda

HMD: Hydro-Meteorological Disasters

IPAR: Institute of Policy Analysis and Research

IPCC: Intergovernmental Panel on Climate Change

JICA: Japan International Cooperation Agency

KFW: Kreditanstalt für Wiederaufbau – German government development bank

MDG: Millennium Development Goals

MIDIMAR: Ministry of Disaster Management and Refugee Affairs

MININFRA: Ministry of Infrastructure

MMI: Modified Mercali Intensity scale

NASA: National Aeronautics and Space Administration

PAU: Pan African Universities

PAUWES: Pan African University Institute of Water and Energy sciences

REMA: Rwanda Environmental Management Authority

RMA: Rwanda Meteorological Agency

RNIS: Rwanda National Institute of Statistics

RURA: Rwanda Utilities Regulatory Authority

SPSS: Statistical Package for the Social Sciences

SREX: Special Report on Extreme Events and Disasters

SSA: Sub-Saharan Africa

UN ISDR: United Nations International Strategy for Disaster Reduction

WEF: World Economic Forum

WMO: World Meteorological Organization

SECTION 1: INTRODUCTION

Outline:

1.0. Introduction

During current and recent past times, climate change has been a subject of concern for both scientists and policy makers over the worldwide. The effects of climate change often lead to weather disturbances and associated harsh natural disasters, and both threat directly and indirectly human life on earth, especially in developing countries where the degree of vulnerability to climate change is higher.

This thesis report outlines the results of a research study conducted in order to identify and characterize the relationship between climate change and occurrence of natural disasters; by considering a case study of Rwanda.

1.1.Research Background

Since the second millennium back in the time, the global average temperature has increased. From 1880 until 2012, the average global temperature increase is 0.85 degree Celsius (IPCC, 2013). And also recent climate observations and researches have demonstrated evidences that prove climate change as a result of global warming. At the moment, human activities are much believed to be the main driving force of the global warming despite the fact that human beings are more affected by the resulting harmful consequences (Anderson & Bausch, 2006).

According to a recent Special Report on Extreme Events and Disasters SREX made by Intergovernmental Panel on Climate Change (IPCC), different weather events would increase in the 21st century (Banholzealr & al., 2014). Various scenarios advance that the world may experience an increase in annual disasters in the future that may cause the level of damages and loss to most likely rise. And the related consequences may affect the humanity on a global scale (Huppert & Sparks, 2006). Among these stated consequences there are changes in weather patterns that could result into extreme weather events, and shortage in food and water especially in arid and semi-arid zones. Shortage in water is manifested in terms of reduction of water of good quality and change in water stream. Food security will be threatened due to the fact that rise in temperature of 1 degree Celsius results into reduction of 5% of grain yield (Quirico, 2015).

Even though disasters can be forecasted due to advancement in technology, which would help in reducing the damages risks; developing countries in Sub-Saharan Africa (SSA) and Asia remain vulnerable. This is because strategies for disasters risk management and resilience developments are still at a low level or non-existent in these developing countries. This may be justified, on one hand, by the lack of skills and financial capability to support and implement tailored countries do not have means that would provide them with reliable disasters risk information on time and also suffer from a shortage in skilled human resource to interpret the data acquired. This may be due to the use of outdated equipment or even lack of it and lack of proper investment in the education. However, to getting such information in advance could assist them in alleviating harmful impacts of these disasters through adapting mitigation and adaptation measures (Wesenbeeck & et al., 2015).

1.2. Relationship between Climate Change and Natural Disasters

What comes to the mind for many people when it comes to natural disasters is that it is a result of climate change. However, there are two possibilities; Firstly, some of the extreme weather events may occur as a result of natural phenomena. Secondly, that occurrence of extreme weather events may be boosted by climate change (Anderson & Bausch, 2006).

Indeed, as years pass, natural disasters are getting intensified in rate and intensity more than ever. Greenhouse gases (GHG) used to naturally be present in the atmosphere at a balanced level to maintain the Earth at an inhabitable temperature. However, these gases have been intensively accumulated in the atmosphere, mostly due to the use of much fossil fuel as the main source of energy. And the more the GHG are released in the atmosphere, the more global average temperature increases due to much heat induced by these gases via greenhouse effect and the word becomes warmer. As a result the weather patterns change due to rise in global average temperature and result to extreme weather events (EPA, 2016).

1.3. Problem Statement

Rwanda’s economy is mainly based on climate sensitive sector, specifically agriculture and rain fed agriculture, where more than 80% of the population relies at that for food and economic gain.

For the past 40 decades, the rhythm of seasons in Rwanda has fluctuated, and those fluctuations are becoming more frequent as the time is going. It can be said that there has been a shift in seasons. It is not only seasons that have undergone changes, even natural disasters events that used to rarely occur in Rwanda have increased in their occurrence and frequency. The rate of disasters occurrence has radically increased nowadays, and the resulting losses and damages are significant. Both natural disasters and climate change constitute a big challenge to the agriculture sector, development of the country which relies heavily on agriculture and the wellbeing of the population especially in ensuring its food security.

It is now known that the global warming is the main cause of the observed climate change. Besides that, in most cases many people suspect climate change to be the main driving force of the strange rise of natural disasters events. Therefore, this research work focused on the assessment of the relationship between climate change and occurrence frequency of natural disasters with a case study of Rwanda over the past 40 years. And help to alleviate the impact of the two events on the society.

1.4.Research Significance and Objectives

It is globally known that SSA and Asian countries are more vulnerable to the effect of extreme weather events than any other part from the rest of the world (O'Loughlin & et al., 2014). Climate change driven natural disasters greatly affect the economic development and treat human lives especially in developing countries including Rwanda. Rwanda in particular is most vulnerable to weather related natural disasters due to its geomorphological structure and its high population density as well.

This research study of Climate Change and Natural Disasters in Africa seeks to identify and evaluate a correlation between the occurrences of natural disasters as consequences of climate change. To check if really the occurrence of those extreme weather events is mainly driven by climate change or other factors, it is in that framework that one Sub-Saharan developing country, Rwanda, has been chosen for this study. Note that there are other factors that could enhance the rate of climate related disasters events.

This kind of research work is very important for Africa and Rwanda in particular, since it can be used to set out appropriate strategies and precaution measures to reduce damages caused by climate driven natural disasters.

Specific objectives

- To assess the rate of climate change in Rwanda by analyzing both temperature and rainfall's data records;
- To collect and plot all the available climate related natural disasters events data records to evaluate the rate of these disasters events in Rwanda;
- To assess the rate of correlation between climate parameters, either temperature or rainfall, and the rate of climate related natural disasters events in Rwanda

To achieve the objectives of the study, historical records data since the earliest years: temperature from 1971 to 2015, rainfall from 1958 to 2014, disasters events from 1974 to 2015, were collected and processed. There has been assessment of whether or not climatic pattern and disasters events trends are correlated using statistical calculation. Finally, a conclusion will be made referring on the obtained results from the analysis.

Lastly, appropriate strategies and precautionary measures will be recommended to alleviate the damages and gravity of disasters on Rwandan population. And different strategies to achieve efficient resilience to these changes will be recommended as well.

1.5. Structure of the project

This report is subdivided into five mains parts. The first part includes an introduction to the topic, the problem statement, aim, objectives and scope of the study; as well as the project structure. The second part covers a brief literature review on climate change and natural disasters; and their relativeness and application in the current topic. Details on the used tools and methods for data collection, data analysis; and a detailed description of the chosen area for case study on demographic, geographic and economic points of view are all covered in the third part of the report. The fourth part includes interpretation of the obtained results and discussions. Finally, conclusions and recommendations are covered in part five.

SECTION 2: LITERATURE REVIEW

Outline:

2.0. Introduction

Due to the magnitude of climate change impacts and natural disasters damages and loss, a number of research studies and debates have been conducted all over the world; and others are still going on with the main purpose of looking for relevant and reliable strategies that would help in mitigation and resilient from climate change impacts and natural disasters. The present section summarizes different findings done on climate change and natural disasters in general.

2.1. Climate Change

Changes in global climate system, which mainly arose from rise of global average temperature, have resulted to what is known as climate change (Skeptical Science, 2015). Since 15,000 to 5,000 years ago, the global average temperature has increased of about 6 degree Celsius. According to IPCC 2007 report, the global average temperature was expected to increase by 1 to 5 degree Celsius in 21st century (Day & al., 2011). That increase mainly results from human activities that induce increase in greenhouse gases in the atmosphere (Mitchell & al., 2006).

2.1.1. Global warming

It is scientifically recognized that human activities are the main causes of climate change (Day & al., 2011). These human activities release greenhouse gases - GHG in the atmosphere that results into global warming (Skeptical Science, 2015). The main common way through which human beings pollute the atmosphere is through burning fossil fuels that are the most used source of energy all over the world. The GHG mostly emitted are carbon dioxide, methane, nitrous oxide and water vapor. All these stated GHG were since the beginning present in the atmosphere but at a moderate level, and their role is to keep the Earth' s temperature viable through greenhouse effect, otherwise without them the Earth would have been cold and uninhabitable. Thus when GHG are in balance they do not cause any harm, but when they are in excess they become harmful, and human activities have induced their excess increase in the atmosphere. They have started to drastically increase since 1958 due to industrial revolution (EPA, 2016).

The GHG reflect back the sun's heat on the Earth, thus when they are in excess they trap even the unnecessary outgoing heat from the Earth to the atmosphere and re-emit it on Earth. Therefore, global warming does not result from the sun that may have become more active as it is thought. The proof is that the upper layer of the atmosphere, close to the sun, is cool while the lower part, a bit away from the sun, is warm (Earth Science Communication Team, 2016) and the global warming in turn results into climate change (Skeptical Science, 2015). It is noticed that among the GHG released in the atmosphere, carbon dioxide is the most emitted and the most harmful as well. The rise in temperature induced by increase in carbon dioxide concentration is irreversible over at least 1,000 years after completely stopping the emission (Solomon & et al., 2009).

2.1.2. Impacts of climate change

It does not matter which country emits much GHG than others, or that such country does not emit GHG; since the emissions are stacked in the atmosphere that all the nations share, the resulting impacts have no border limit they affect all the countries without exception. Hence the reason why it is said that climate change is a global issues.

Climate change is responsible of changes in rainfall and freshwater discharge in tropical and sub-temperate areas, and the changes in frequency and intensity of tropical storms. By referring to some studies, it is expected that regions next to the equator and those in high latitude may experience heavy precipitation; while those beyond the tropics and in hot temperature zones may undergo shortage in precipitation. Developing SSA countries, located in tropical region, may experience increase in spread of pathogen due to heavy precipitations in some regions lacking sanitary infrastructure (Day & al., 2011). Generally, the depletion of surface water resources, in semi-arid regions, would lead to decline of surface water supply by 25% in the whole Africa. Noting that most of Africans use local rivers as source of water, people may experience shortage in access to fresh water (De Wit & Stankiewicz, 2006).

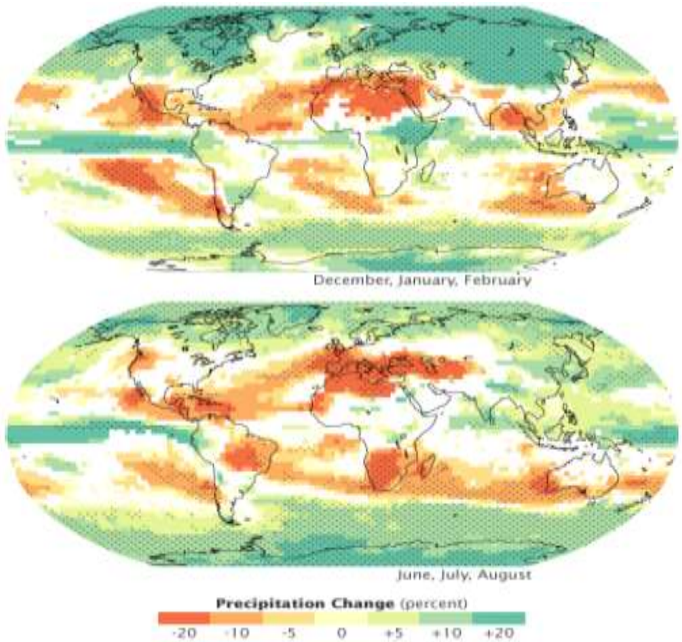

Figure 1: Future global precipitation changes according to IPCC 2007 report

Source: (Skeptical Science, 2015)

From the above figure, tropical and polar regions are expected to undergo increase in precipitation up to 20%, while arid and semi-arid zones will experience deficit in precipitation of up to 20%.

The hottest day usually occurs once after a period of twenty years, but after the 21st century they will occur in every year in most area around the world as a result to climate change. Extremely cold and hot days will result in increased mortalities (Day & al., 2011). The German Research Centre for Environment Health has discovered that extreme high or low temperature will result to increased mortality caused by increase in cardiovascular diseases, such as heart failure, arrhythmia and stroke to mostly oldest and pre-existing medical conditions people (Helmholtz Zentrum Muenchen, 2014).

By the end of 21st century, if nothing is done to reduce the GHG emissions, regions in the northern hemisphere will experience an increase of 20 – 30% of precipitation (Banholzealr & al., 2014). Also, the rise of temperature will cause the melting of ice, which could lead to the increase of the sea level. Therefore, by 2100s the rise in sea level will vary from 1.0 meter to 1.5 meters (Day & al., 2011).

It is shown in the figure below the trend of the sea level the since 19th century up to the 21st century. Obviously, the latter has been dramatically increasing due to rise in temperature.

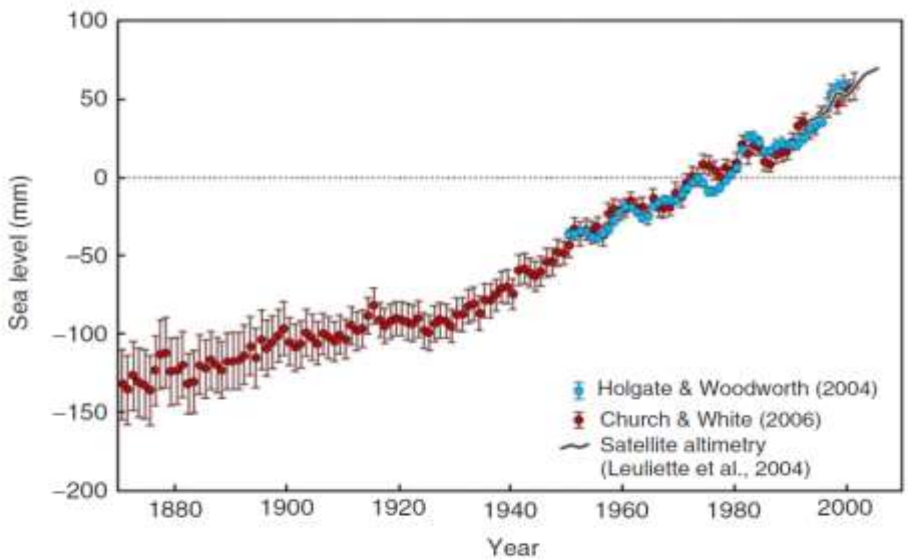

Figure 2: Global sea level changes from 19th century to the early twentieth century

Source: (Day & al., 2011)

Even though the probability is low, it is predicted that gradual change in climate may lead the climate system to exceed the threshold to a level at which it may not be able to be restored to normal, despite even restoring GHG to pre-industrial era concentrations (Mitchell & al., 2006).

Africa, specifically SSA is more vulnerable to impacts of climate change mostly due to high dependency on agriculture where 60% of Africans are the labour force, the inadequate capacity for resilience and the gravity of harmful direct effects. Therefore, the changes in Africa's climate will be probably more challenging than elsewhere due to Africa's economy dependency on climatic indicators. Concerning direct effects, some parts of Africa like Eastern Africa will become wetter while the southern Africa will be drier and hotter. Besides that, the agriculture production will remarkably reduce and disasters events will get intensified. Climate change could hinder the achievement of some of the sustainable development goals in Africa due to its effects on agriculture production, health and economy (Collier & et al., 2008). Generally, the net effects of climate change on African farms are driven by variation in precipitation and extended dry season; which will affect the yield income. Contrary to SSA, the Northern Africa economy is less vulnerable to climate change due to its diversity and reliance on crude oil (Kurukulasuriya & et al., 2006). Thus, because of the dependency on rain fed agriculture; food security in Africa may be threatened by climate change effect. Besides that, the poverty in Africa challenges the implementation of climate change adaptation strategies due to lack of financial means and therefore make the population more vulnerable (Wesenbeeck & et al., 2015).

2.1.3. Strategies for resilience and adaptability to climate change

According to public and policymakers perceptions, the predictions on different scenarios of climate change impacts in the coming decades are thought to be overstated by scientists due to their stiffness in extinction of some species, increase of temperature and other negative effects on the biodiversity in the coming decades. It is recommended to policy makers to first consult environmental biologists before making any decision on the issue of climate change and use transparent, standardized metrics of expertise when deciding which scientists to consult in order to make reasonable and reliable decisions (Javeline & et al., 2016). This could help to avoid the overestimation on different scenarios related to climate change, and make as well efficient measures and strategies that could help in climate change mitigation or resilience.

One of the approaches to sustainably achieve climate change management should be based on the ecosystem and species systems functioning. Therefore, this approach should rely on the ability to enhance natural systems to survive on climate change impacts, thus resulting in reliable and sustained climate change adaptability strategies (Day & al., 2011).

Since it is noticed that GHG emissions are the main cause of climate change, all the nations should be committed in reducing those emissions in order to reduce the rate of global warming. The population should be put aware of the climate change impacts exposed to them and be given all the facility and information on how to protect themselves (Wilbanks & et al., 2014).

2.1.4. Climate change in Africa

Africa is among the most vulnerable continent to climate change, although it contributes less to global GHG emissions. That vulnerability is mainly boosted by lack of means to adopt resilience strategies, mostly caused by poverty.

Most of the health issues found in SSA, like disability adjusted life years (DALYs) and non-vector borne morbidity and mortality are mainly attributed to climate change. However, there are no relevant evidences yet to prove it due to inefficient research and limited data collection capability, mostly driven by lack of finance (Amegah & et al., 2016).

Poverty and lack of technical assistance for climate change adaptation are the main challenges faced by most of African farmers to implement strategies for climate change effect adaptation. Thus this makes them more vulnerable to climate change effects (The World Bank Development Research Group, 2007). Among these climate change effect adaptation strategies in agriculture there are modern irrigation systems, mixed cropping and crop diversity methods, afforestation and soil conservation methods such as burying crop residues to enhance quick soil replenishment in nutrients and organic matter (Akinnagbe & Irohibe, 2014).

In case no relevant measures for climate change resilience are taken, some parts of Africa will suffer more than others. 95% of total agriculture practiced in Eastern Africa is small scale and rain fed with a total contribution of 40% to the regional Gross Domestic Product – GDP. Therefore, the main economic activity in Eastern Africa is agriculture, where 80% of the regional populations are farmers. Taking into consideration the above statement and the considerable weather variability experienced in the region during the main growing season, the agriculture yield would reduce in the range of 1.2% to 4.5 %, which would inevitably affect the regional economy (Kahsay & Hansen, 2015).

Below are shown precipitation and temperature trends in Eastern Africa region for the spring season.

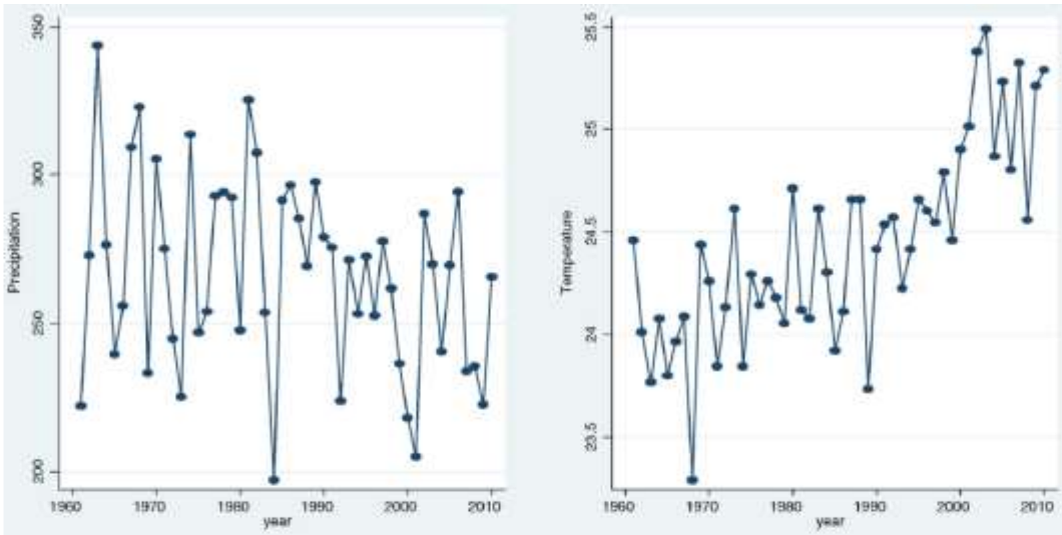

Figure 3: Average precipitation and temperature trends during spring season in East Africa

Source: (Kahsay & Hansen, 2015)

The above shown trends start from 1960 up to 2010. Accompanied with much fluctuation, it is clear that the precipitations have somehow decreased while the temperature has remarkably much risen.

2.2. Natural Disasters

Extreme weather and climate events naturally occurring on, under or above the Earth surface are usually called natural hazards (WMO). But when these hazards cause loss of human lives, goods or damages to the environment, they become natural disasters (Siyavula Uploaders, 2009). Therefore, natural disasters result from natural hazards and extreme weather events are liable to climate related natural disasters.

2.2.1. Natural disasters classification

Disasters are defined, according to CRED, as unforeseen and sudden events that cause great destruction and human loss in a way that exceed the local capability and necessitate external help. Natural and technological disasters are the main categories of disasters, according to

EM-DAT (Guha-Sapir & et al., 2015). Different sub-groups of natural disasters are shown below.

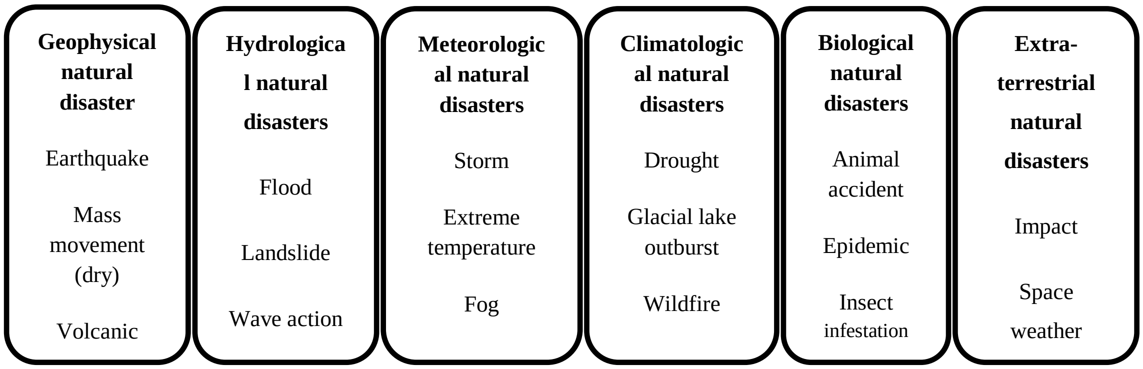

Figure 4: Natural disaster subgroup classification

Source: (Guha-Sapir & et al., 2015)

The World Economic Forum – WEF published a 2015 WEF global risk report that was based on consensus of the panel of corporate risk officers. In that report, extreme weather events, natural catastrophes and failure of climate change adaptation were classified among the ten major highlighted natural disasters (Harrison & Williams, 2016).

2.2.2. Natural disasters impacts

Natural disasters risk and impacts are mostly influenced by socio-economic factors, frequency and intensity of the event, capacity to cope with the event, geographical location, the nation's level of financial development and the quality of the existing political institutions (Banholzealr & al., 2014) & (Klomp, 2015). They affect sectors that are more related to climate, agriculture, tourism and water, but in general they touch the society, environment and the economy of the concerned country (Banholzealr & al., 2014). Natural disasters impacts are in form of two categories; direct and indirect impacts. Direct impacts are those that are immediately remarked, like collapse of buildings, loss of lives, etc. Indirect impacts are realized later after the disaster has occurred and are mainly related to economic activities, such as increased inflation, shift in trade terms, changes in income and unbalance between demand and supply. Thus, the net effect of natural disasters on overall economic performance is obtained by summing up the direct and indirect natural disasters impact (Bergholt & Lujala, 2012).

Referring to different findings, the economic costs of the damages resulting from disasters have been increasing, while the number of lives lost through these disasters is decreasing. But this is the case for developed countries. However, for developing countries both the rate of death and economic cost, measured as portion of their gross domestic product (GDP), keep increasing due to weak disasters risk management capacity (Banholzealr & al., 2014).

High risk of economic loss caused by natural disasters is proportional to population growth and economic assets exposed to events, and natural disasters occurrence risk increases in areas where the GDP and assets are not high. Thus limited economic strength and resilience make developing countries more vulnerable to natural disasters due to low capability to cope to those disasters effects (Banholzealr & al., 2014).

On an economic point of view, since climate related natural disasters, such as flood, heavy precipitation, storm etc., destroy crops, kill farm animals, postpone planting and harvesting season, destroy factories; all these result in decrease of harvest and people’s income and assets. Thus natural disasters negatively impact economic growth (Bergholt & Lujala, 2012).

2.2.3. Natural disasters effects and trend per each continent

Basing on the CRED report of 2014 on annual disaster statistical review, Africa has the second rank to experience hydrological disaster after Asia, and the first rank to endure climatological disaster compared to the rest of the continents (Guha-Sapir & et al., 2015).

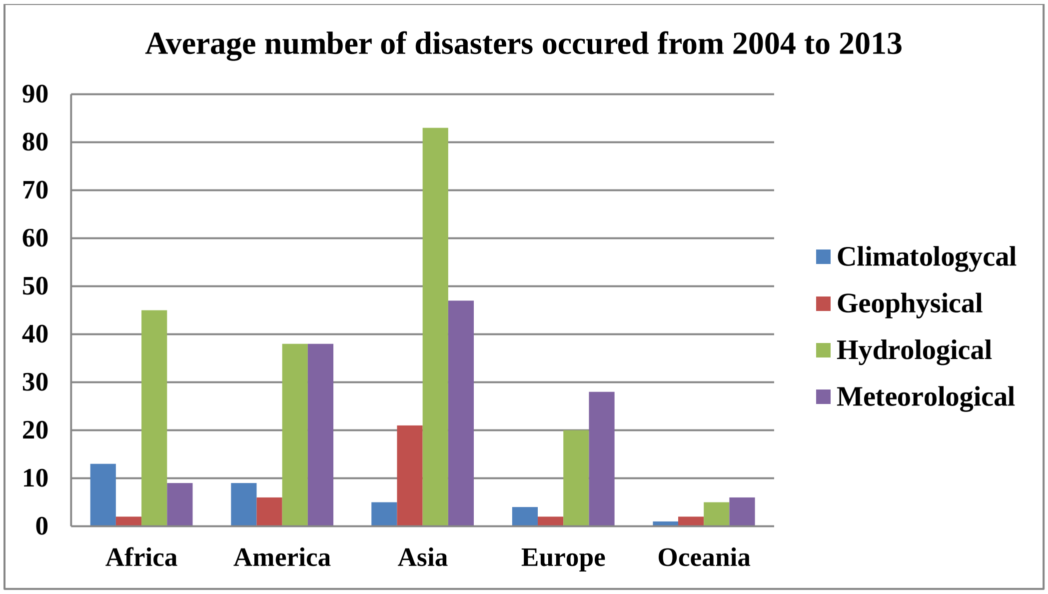

Figure 5: Average number of disasters occurred from 2004 to 2013

Source: (Guha-Sapir & et al., 2015)

When it comes to the resulting victims from climatological, hydrological, meteorological and geophysical disasters, Asia is leading with many victims and followed by Africa (Guha-Sapir & et al., 2015).

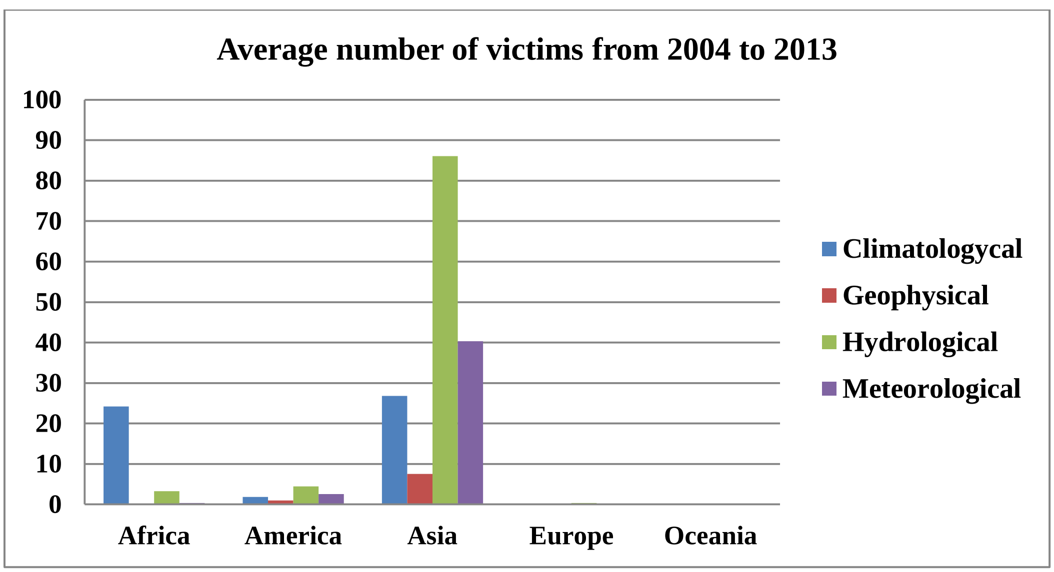

Figure 6: Average number of victims from 2004 to 2013

Source: (Guha-Sapir & et al., 2015)

Even though America, Europe and Oceania have less number of disasters' victims, however they present much valuable damages after Asia (Guha-Sapir & et al., 2015).

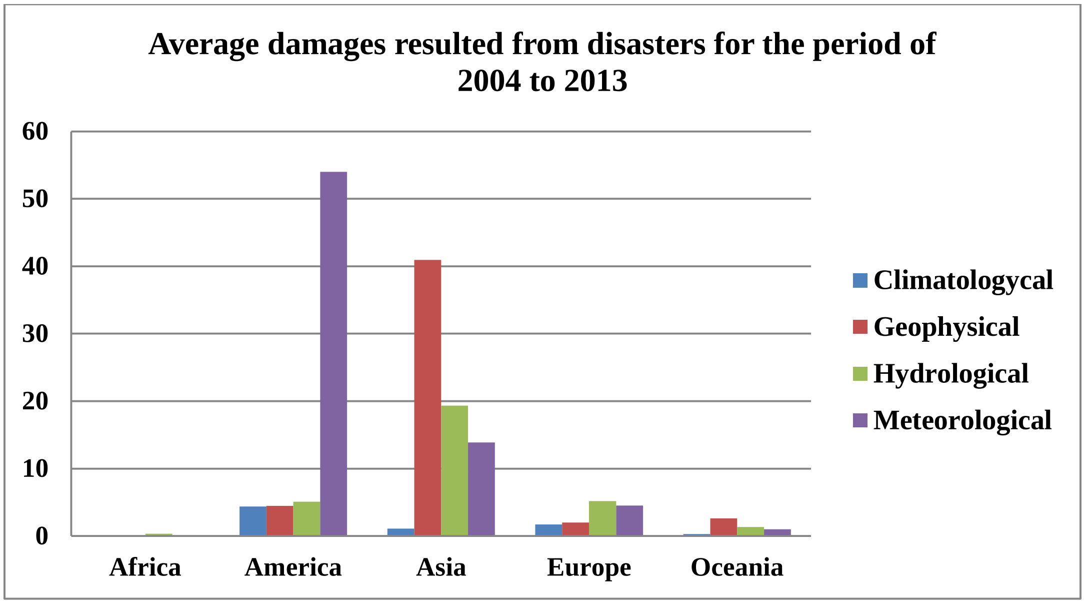

Figure 7: Average damages resulted from disasters for the period of 2004 to 2013

Source: (Guha-Sapir & et al., 2015)

Besides the increase in temperature resulting from global warming, initiated by human activities release of much GHG emissions in the atmosphere; there would be changes in the geographical distribution, intensity and frequency of extreme events (Mitchell & al., 2006).

2.2.3. Natural disaster trends and scenarios

Changes in climate are getting to another level and the weather events are becoming harsher. According to the recent Special Report on Extreme Events and Disasters - SREX made by Intergovernmental Panel on Climate Change – IPCC, different extreme weather events will increase in the 21st century (Banholzealr & al., 2014). Some of these extreme weather events include increase in frequency and magnitude of extreme warm days, increase in heat waves, increase in heavy precipitation, and drought will be intense due to reduced precipitation or increased evapotranspiration in some regions (IPCC, 2012).

As shown in figure below, disasters have been increasing in frequency as the time was passing.

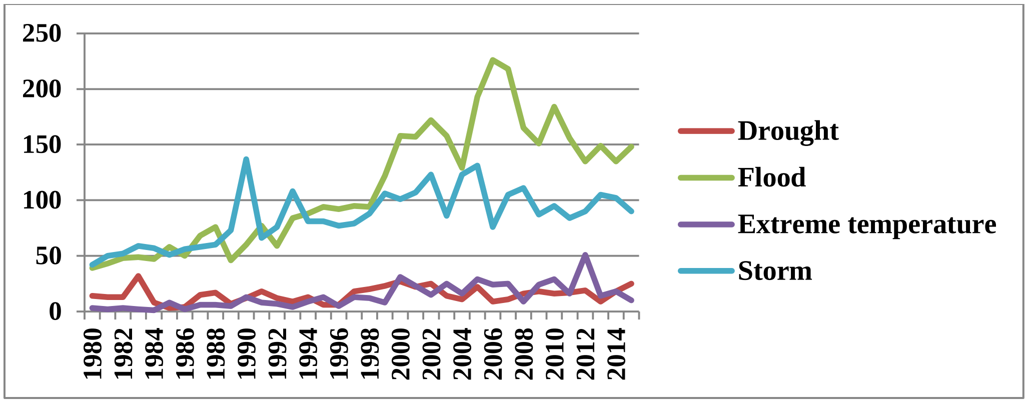

Figure 8: Some climate related disasters trends around the world from 1980–2015

Source: (EM-DAT, 2016)

Referring to the figure above, the world is suffering from flooding and storm view, which have dramatically increased in rate of occurrence. As it is seen in the figure above, flood and storm events seem to have galloped at a high rate after the year 1990.

2.2.4. Mitigation and resilience strategies for natural disasters

The UN International Strategy for Disaster Reduction - UN ISDR defines resilience to natural disasters as the ability the society exposed to hazards to resist and recover from the effects of a hazard in a timely and efficient manner, by restoring its essential basic structures and functions (Harrison & Williams, 2016). By considering the incapability of human being to prevent the occurrence of natural disasters, at least human being can mitigate or adapt to the occurrence of these events.

The rise of urbanization and migration rates increases the installation of the population in high risk zones. Therefore, incorporating natural disasters mitigation and adaptation approaches in regional urban planning would be of great benefit in reducing loss of humans and lives (Harrison & Williams, 2016). By doing an analysis on the historical records of disasters events that occurred in any such region, this could help in identifying zones of high risk and exposed people, which would help in adopting suitable measures to reduce the risks and damages caused by disasters events (Harrison & Williams, 2016).

Capacity development for disaster risk reduction strategy - DRR is believed to be relevant for reducing impact of natural disasters according to the World Conferences held in Japan on

DRR. However, there is still a challenge in their design and implementation resulting from the lack of academic research in capacity development for DRR (Hagelsteen & Burke, 2015).

2.2.5. Natural disasters in Africa

The trend of natural disasters in Africa shows a clear and large increase of the number of natural disasters.

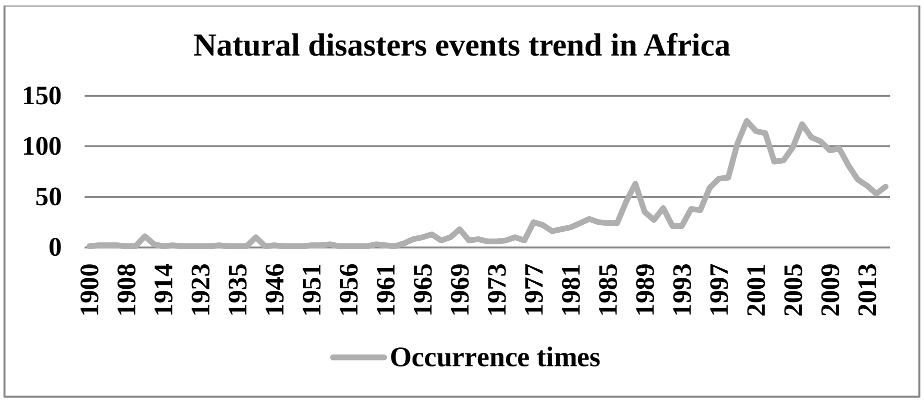

Figure 9: Natural disasters trend in Africa since the 20th century

Source: (EM-DAT, 2016)

The above graph shows the trend of all natural disasters events that occurred in Africa since 1900 to 2013. As it is shown, natural disasters events have been occurring even in the past years but their rate of occurrence was very low and a bit stable until the year of 1962. However, after 1962, the rate of disasters events started to rise at a higher frequency. The trend above includes all kinds of natural disasters found in Africa: drought, flood, landslide, mass movement dry, wildfire, storm, extreme temperature, Epidemic, insect infestation, earthquake, and volcanic activity (EM-DAT, 2016).

Since mid-1990s, hydro-meteorological disasters – HMD significantly increased in Africa (Tall & et al., 2013). The largest percentage of agriculture practiced in Africa is rain-fed and thus its sensitivity to rainfall and temperature instabilities. Noting that 57% of active Africans are farmers, where irrigation is applied at a rate of 6.8%, the rise in HMD dramatically affects the production and standard of living of the population (Arame Tall, 2013). See in appendix different natural disasters ‘effect and trends per continent.

African countries are classified into three categories basing on the three types of disasters management policies. Among the 55 countries of Africa, 33 are classified in the category of unprepared firefighters, nine countries are prepared firefighters and then six are disaster averters. The unprepared firefighters are those that late react to disasters and in ineffective way while the prepared ones react on time and effectively. Disaster averters are those that pay attention on the strategies to reduce risk factors that cause those disasters and not on the hazard itself (Tall & et al., 2013).

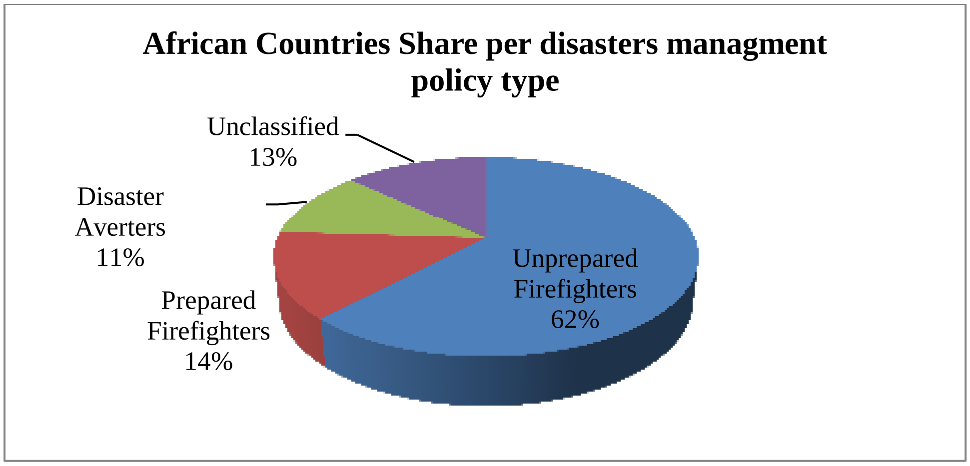

Figure 10: Distribution of African countries basing on the disaster management policy type

Source: (Tall & et al., 2013)

It is not surprising that Africa is so vulnerable to natural disasters events, since only fifteen countries among the fifty five countries are the only ones having efficient strategies for disasters resilience and risk reduction, and that react on time towards natural disasters events.

2.3. Correlation between Climate Change and Natural Disasters

In some cases, natural hazards and extreme events mean the same thing and can be used interchangeably. Climate extreme includes extreme weather or climate event and is defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value. According to IPCC 2012, climate change leads to alteration in frequency, intensity, spatial extent, duration and timing of extreme weather; and that would result in new extreme weather that never existed before (Banholzealr & al., 2014). All these events affect humanity socially, economically and ecologically (Day & al., 2011).

More evidence testifies that climate change is the main cause of intensification of natural disasters. To be more specific, scientific evidence confirmed extreme events to be linked to human induced climate change, but not all climate disasters are attributed to human activities impacts on climate. Some disasters occur by naturally as part of the climate system (Banholzealr & al., 2014).

2.4. Climate Change and Natural Disasters in Rwanda

Climate change and natural disasters hinder the development of countries and in particular the developing countries. Climate change causes are global, but what causes one country to be vulnerable or more vulnerable to natural disasters events changes from one country to another. The cause of vulnerability to natural disasters in Rwanda and the resulting effects are explained below.

2.4.1. Rwanda's general description

Rwanda is also popularly known as a land of thousand hills and it is located in East-Central of Africa between 1°04' and 2°51' south latitude, and 28°45' to 31°15' East longitude, Rwanda is a small country of 26,338 km^2 in area; whose geography is predominated by an elevated relief (World Atlas, 2015). It has an altitude varying from 900 meters to 4707 meters; which provides it with a moderated tropical climate (MIDIMAR, 2015). Rwanda's weather changes from one region to another, and is mostly influenced by the relief of the concerned region. From the figure below, different parties of the country are shown with the corresponding temperature and rainfall observed in each part.

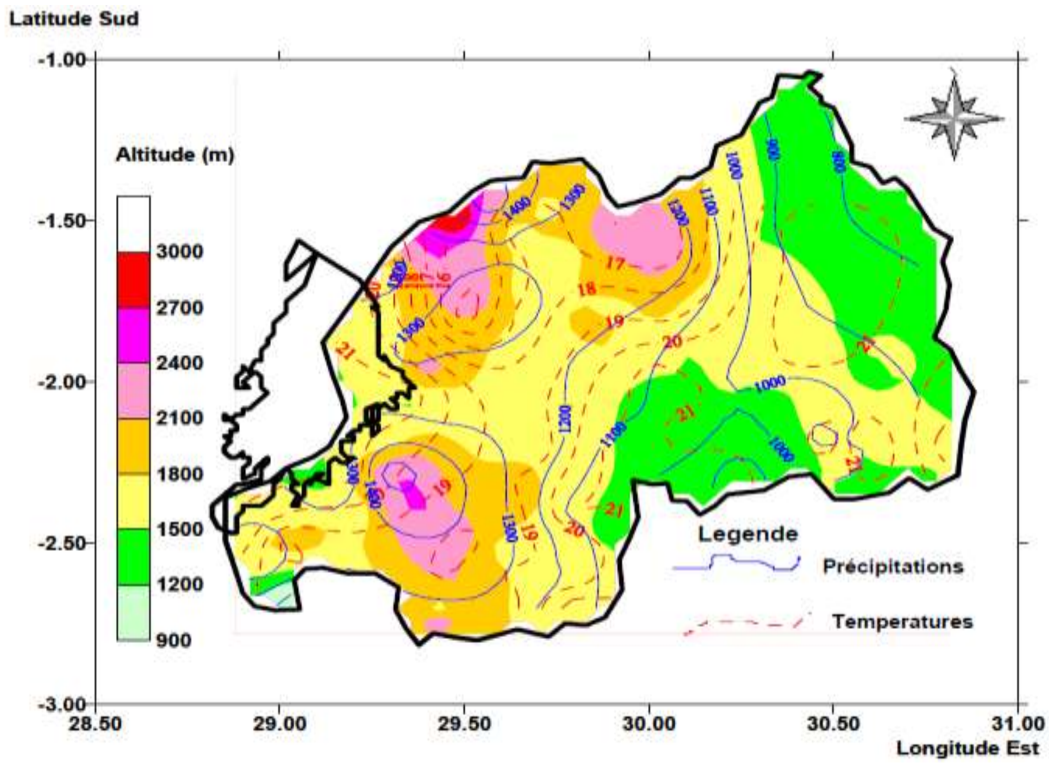

Figure 11: Rwanda's regional topography and the corresponding climate features

Source: (Mutabazi, 2011)

From the figure above, Rwanda's relief increases from Eastern part of the country to the West, and from Central to North and South West of the country. The temperature varies in opposite way, thus the temperature is low in regions with high altitude, while in low altitude areas it is a bit high compared to the rest part of the country. The level of precipitation is higher in high altitude zones, where the average of annual rainfall varies around 1400 mm; and regions with the lowest altitude in the country have a low level of precipitation compared to the rest parts, where annual average of rainfall varies from 900 mm and below.

Rwanda is situated in the great lakes region, along the Great Rift Valley. From West to the East of the country, Rwanda geomorphology is divided into five regions (MIDIMAR, 2015):

- The Congo-Nile Ridge in Western Rwanda,
- The Volcanic Virunga Mountains and high lava plains in North-West,
- The Great Rift Valley region along the lake Kivu,
- The rolling hills and valleys of central plateau in Central
- The savannah and marshlands in Eastern and South-Eastern regions

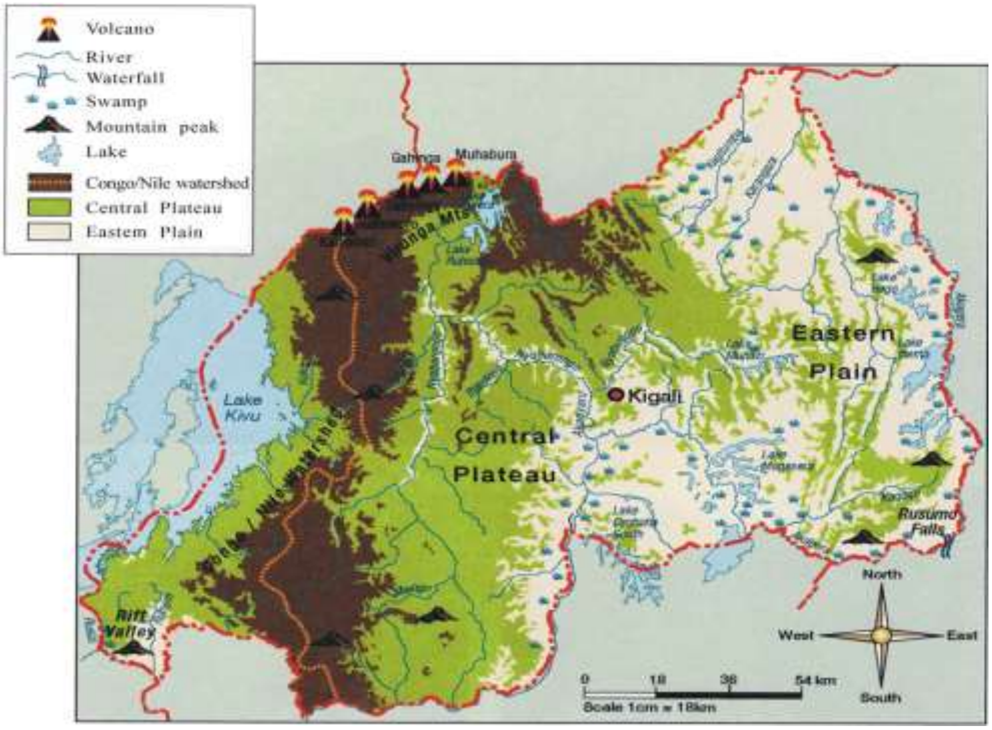

Figure 12: Rwanda Geomorphologic map

Source: (Henninger, 2012)

2.4.1.1. Rwanda's population and land trends

Despite its small land, Rwanda's population keeps on growing. The population growth rate in Rwanda was 2.6% since 1950 to 2015 (Madewulf, 2015).

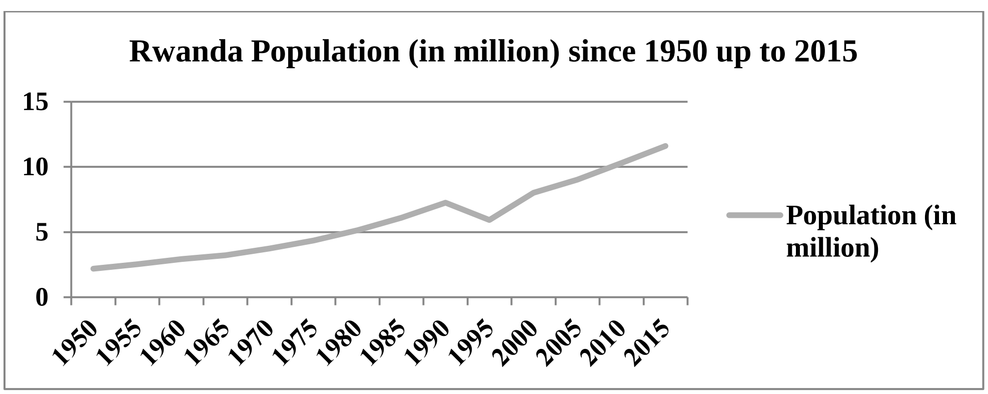

Figure 13: Rwanda population growth trend since 1950

Source: (Madewulf, 2015)

Referring to the graph above, before 1990 Rwandan population was increasing moderately. There was an abrupt drop in population from 1990 to 1995 due to Rwandan Genocide of Tutsi in 1994. After 1995 the population got a high increase rate more than before 1994.

The high increase of population constitutes a challenge to the welfare of the population; and has led to degradation of the environment and scarcity of enough land for cultivation and suitable land for habitation.

The figure below shows how much the land per capita in Rwanda has reduced and how it will keep reducing if nothing is done to reduce the birth rate.

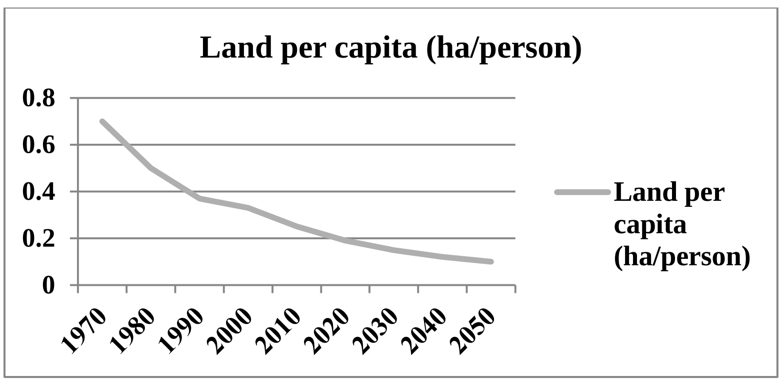

Figure 14: Shrinking land base scenario due to population pressure according to UN

Source: (REMA, 2011)

Rwanda's land is small, hilly and mountainous which does not favor the habitation and development of agriculture (REMA, 2011). The total arable land covers 52% of the whole country area, almost corresponding to 1,380,000 ha (IPAR, 2009) with a population of almost twelve million.

The rapid growth of population intensified the over cultivation of land, deforestation and the occupation of high risk zones (Habiyambere & et al., 2009). Deforestation has resulted in a decline of mountainous forests and rainforests mainly affected by their use in generating charcoal and wood fuels, exploration of land for both farming and human settlement (Nyandwi & Mukashema, 2011).

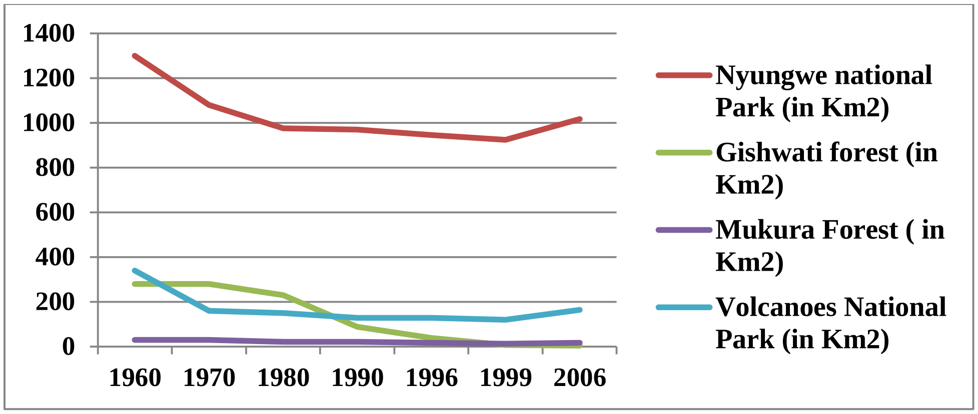

Figure 15: Rwanda's trends of some natural forests size

Source: (Nyandwi & Mukashema, 2011)

Until the year of 2006, Nyungwe, Volcanoes National Park and Gishwati forests reduced significantly due to high deforestation rate. But it was worse for Gishwati which had almost disappeared as shown in the graph above.

Figure 16: Rwanda's Mountainous and rain forests lost area in percentage

Forests	1960	2006	Lost area in percentage
Nyungwe National Park	130000	101725	21.75
Gishwati	28000	316	98.87
Mukura	3000	1600	46.67
Volcanoes National Park	34000	16334	51.96

Source: (Nyandwi & Mukashema, 2011)

From 1960 to 2006 there has been a huge loss in forests as it is seen in the table above. Nyungwe national park forest is the one that at least declined a little with a lost area of 21.75% of its area of 1960. Mukura and Volcanoes national park forests reduced of 46.67% and 51.96% respectively of their total area of 1960. Gishwati forest seems to almost disappear with a total loss of 98.87% of its area in 1960

2.4.1.2. Rwanda's main economic activity, Agriculture

Rwanda's population is classified into four economic classes which are; severely poor, moderately poor, slightly poor, and non-poor; and 37% of the total population is classified under the moderately poor group (MIDIMAR, 2015). According to Ubudehe survey 2005, lack of land, soil infertility, weather conditions, lack of livestock mostly related to soil infertility and ignorance are the main causes of poverty in Rwanda (Habiyambere & et al., 2009). Ubudehe is one of the approaches used by the government of Rwanda to reduce the poverty by working collectively to support each other in solving the community problems. The latter is mainly based on the traditional Rwandan culture, where people were working together to dig their field so every household may get ready for the planting season (RGB, 2016).

Despite all the mentioned challenges to agriculture and land in terms of quality and availability, agriculture is the fundamental economic pillar in Rwanda. It contributes up to 32.6% to the national GDP (REMA, 2011), provides 70% of revenues from export and generates 91% of the consumed national food (IPAR, 2009). As in all developing countries, Rwanda's industrial sector is still at its early growth stage with only 14% input to GDP (REMA, 2011).

2.4.1.3. Main cause of vulnerability of natural disasters in Rwanda

Considering that 90% of the population lives on subsistence agriculture (Nyandwi & Mukashema, 2011), an increase of the population has put pressure on the land use through over cultivation to meet the food demand. However, over cultivation and deforestation has depleted the quality of the soil (Habiyambere & et al., 2009). Therefore, the combination of an elevated surface land and low soil quality makes the land delicate and the whole country more vulnerable to natural hazards.

2.4.2. Climate change in Rwanda

Generally, GHG emissions are recognized as the main engine to global warming and consequently to climate change. Despite its low input to GHG emissions, Rwanda has experienced some indicators that prove changes in its climate. According to the analysis done in 30 years ago, the country is experiencing changes in climate patterns: the average temperature has increased and there has been shift in season (Habiyambere & et al., 2009).

2.4.2.1. Rwanda's climate and seasons

Normally, Rwanda has a tropical climate moderated by its altitude (Mutabazi, 2011). The climate is made of four seasons, which are short rainy season, short dry season, long rainy season and long dry season. These seasons had consistent duration in the time that were well distributed in the whole year as shown in the table below (MIDIMAR, 2015).

Table 1: Rwanda seasons and their normal duration

Climate seasons	The duration
Short rainy season – Umuhindo	From September to November
Short dry season - Urugaryi	From December to February
Long rainy season - Itumba	From March to end of May
Long dry season - Impeshyi	From June to August

Source: (Habiyambere & et al., 2009)

However, according to Sascha M. Henninger's research based on data of Rwanda weather from different stations located in the country, this information seems to be relevant only for the period of 1931 to 1960. After that period, changes in temperature and precipitation have been remarkable (Henninger, 2012). Actually, the climate is fluctuating, precipitation is not well distributed in the year which goes with an increase in extreme heavy precipitation (Mutabazi, 2011). The climate has become warmer with extended dry seasons; while rainy seasons became shorter in some regions. The rain onsets before the normal time or with lateness and ceases early, and the rate of heavy rain within a short period have increased. Currently, the number of rainy days has reduced while annual precipitation is almost constant and it often causes erosion, flood and landslide (Mutabazi, 2011). See temperature and precipitation trends of Rwanda in section 4.

2.4.2.2. Impact of climate change in Rwanda and mitigation strategy

These changes in climate have affected the whole country in economic, social and environmental spheres, since Rwandan economy depends on climate sensitive sectors including agriculture, where more than 80% of the population relies on agriculture (Habiyambere & et al., 2009). These changes in climate have caused disastrous events, especially flood and drought, that led to poor agricultural production (Habiyambere & et al., 2009).

Due to inevitable effects of climate change, manifested in form of extreme weather events experienced in Rwanda; the government of Rwanda has adopted different policy approaches that would enable it to cope with changes and enhance the development of a green economy. Green growth and climate resilience are parts of the policy, and is concerned with national strategy for climate change and low carbon development. The aim of that policy is to put effort in climate change mitigation and resilience, and economic development (Mossel, 2015).

2.4.3. Natural disasters in Rwanda

Natural disasters occurred in Rwanda in the past years but at a moderate rate. The number of victims was high due to use of outdated technology and development at that time. Currently, technology and development have improved, however the rate of these disasters has increased and they have become more intense.

As mentioned, rapid population growth, limited land resource and poor cultivation practices of the land have exacerbated the vulnerability and occurrence of natural disasters in Rwanda.

Drought, earthquake, torrential rains, flood, landslide, epidemic and storms are the most predominant hazards that occur in Rwanda (MIDIMAR, 2015). By considering the fact that majority of Rwandese depends on agriculture; drought and flood affect a lot the well-being of the population and cause to extreme famine and poverty.

❖ Droughts

The Eastern and South-Eastern parts of the country, see figure below, are the places experiencing rigorous drought. Most of the time, drought arises from deficit of rainfall, late onset or early ending of rainfall in those areas (Habiyambere & et al., 2009).

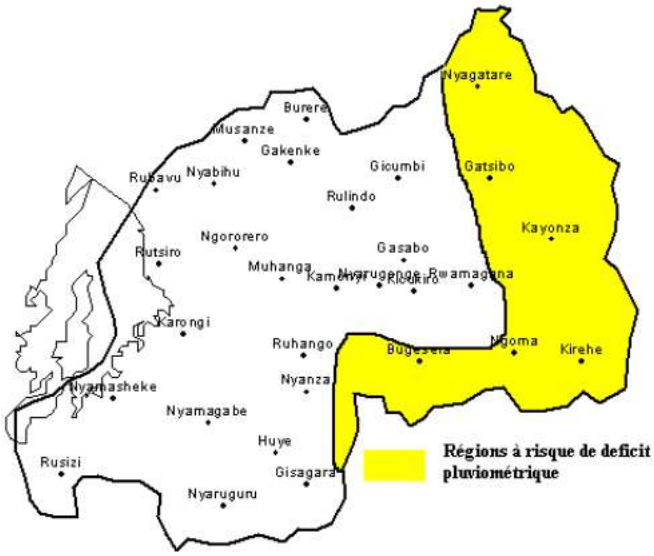

Figure 17: Zone with rainfall scarcity in Rwanda

Source: (Habiyambere & et al., 2009)

Drought results in reduction of plant and animal species, food shortage, displacement of people looking for food (Habiyambere & et al., 2009) and it enhances the development of warm weather related diseases such as malaria (Mutabazi, 2011). Looking from the agriculture point of view, the absence of irrigating systems aggravates the impacts of the event on the population. See record of drought event and damages in Rwanda in the appendix section.

❖ Floods and Landslides

The high altitude relief boosts flash flooding and landslides in many parts of the country. Southern, Northern and Western Provinces are the regions most affected by flood and landslide; and both events in the stated regions are mainly caused by deforestation, heavy rains and poor soil quality. Floods and landslides impacts do not only affect infrastructures, agricultural or induce humans' loss; but also they create a conductive environment for the spread of water borne diseases: such as malaria, diarrhea, cholera and viral infections (Habiyambere & et al., 2009). See historical records of landslide and flood events in the appendix section.

- **Earthquakes**

Due to its location on the volcanic zone and along the East African Great Rift Valley, Rwanda experiences tectonic movement and the resulting damages are not lesser. The most affected areas are the North-Western and South-Western parts of the country due to their location closed to the chain of volcanoes. Note that some of volcanoes are still seismically active, such as Nyiragongo and Nyamuragira located in the Democratic Republic of Congo - DRC near Rwanda and DRC boarder (Habiyambere & et al., 2009). According to the assessment done based on two scenarios from many years in the past, in the 2475-year and 475-year return periods, the intensity in earthquakes in Rwanda varies between MMI V (moderate intensity) to MMI VII (very strong intensity). And the resulting damages vary from very light, light to moderate damages (MIDIMAR, 2015). See earthquake event records and its effects in appendix.

- **Storm**

Storm often occurs in form of windstorm or in form of windy rain. The involved turbulent winds destroy roofs of buildings, crops especially banana plantations, sorghum and maize which are more vulnerable to storm. The poor are much affected by storm due to fragile unsuitable materials used to make their houses while they stay in zones with risk (MIDIMAR, 2015). See in the appendix section the record storm event that occurred in Rwanda.

- **Epidemic**

Flood, erosion and rise of temperature have boosted the spread and development of extreme weather related diseases such as malaria, as well as water borne diseases that pose a threat to humans' life as well as animals and plants. See records of epidemic diseases of plants that occurred in Rwanda in the appendix.

All the stated disasters above have devastated a number of population and goods, see details in the appendix section, and the worst is that they have increased in terms of frequency and atrocity, which affects the development of the whole country.

SECTION 3: RESEARCH METHODOLOGY

Outline:

3.0. Introduction

Climate Change and Natural Disasters in Africa, case study of Rwanda, consists of assessing influence climate change may have exerted on current abnormal occurrence of natural disasters in Africa in general, and specifically in Rwanda, in terms of frequency. Therefore, various parameters and methods have been used in this research study in order to accomplish well the objectives of this work.

This section of the report introduces all the considered parameters for the study analysis and the corresponding data records, as well as the methods used for the processing of those data records.

3.1. The Data

Climate change and natural disasters in Rwanda were analyzed basing on two points of view. First, there has been an assessment of whether climate change was also experienced in Rwanda by considering two main weather parameters, which are the land temperature and rainfall. The second point of view was done by using the records of natural disasters events starting from 1974 until 2015.

3.1.1. Temperature and rainfall data

Rwanda Meteorological Agency, RMA, is the main Rwandan institution with different meteorological stations around the country and it provides weather and climate information services. All the used temperature and rainfall's data in this report were obtained from some of RMA stations records. Some of the used data starts from the colonial period in 1929 until 2015.

Rwanda's weather, despite its geographical location in tropical zone, is made unique by the influence of its elevated surface land that provides it with a moderated tropical climate. As mentioned previously, Rwanda's geomorphology is distinguished into five different zones, and each zone has its own specific weather features a bit different from others. Those differences are mainly determined by the difference in altitude. Therefore, the weather in the country is specific due to the geomorphology of the concerned region. To make a more concrete analysis, temperature and precipitation data were analyzed per station.

In order to examine temperature and rainfall around the country and cover all different zones, data recorded from one meteorological station in each morph-climatic zone were gathered and processed, which helped to generally cover the whole country. From each morph-climatic zone, the chosen station was the one with as many data records as possible.

Below is shown a list of the used meteorological stations for temperature and precipitation parameters, their corresponding morph-climatic zones in which they are located.

Table 2: Climatic Geomorphologic zones and their representing rainfall and temperature meteorological stations

Morph-climatic zone	Altitude	Station for rainfall data	Station for temperature data
Eastern plains and bass plateau zone	1200 - 1700 m	Kigali Aero	Kigali Aero
Northern highlands and volcanic mountains zone	1800 - 3000 m	Ruhengeri Aero	Ruhengeri Aero
Central plateau zone	1400 – 1800 m	Byimana	Byimana
Zone along the lake Kivu	1500 – 1800 m	Kamembe Aero	Kamembe Aero

Source: (Sebazima & Mutabazi, 2001)

3.1.2. Natural disasters data

The used data records for natural disasters were obtained from the historical records of the Centre of Research on the Epidemiology of Disasters (CRED) database called EM-Data, Emergency Events Database in full words. All the natural disasters occurred in Rwanda starting in 1974 until 2015 that suit to EM-Data’s criteria, were registered in EM-Data database. Noting that for any disaster to be registered into EM-DAT database it has to suit with one of the following four criteria (CRED, 2015):

- To have killed at least ten people

- The disaster should have reported to affect at least 100 people
- To might have been a declaration of the state of emergency
- There might have been a call for international assistance

Drought, earthquake, torrential rains, flood, landslide, epidemic and storms are the most predominant disasters experienced in Rwanda. But only the climate related disasters, which are droughts, epidemic, and floods and landslides, were considered in this study,.

3.2. Data Processing Methods

This study is both a quantitative and qualitative research. Therefore to collect and analyze the temperature and precipitation data, as well as natural disasters data records, the whole work was carried out using historical and correlation research methodologies (Clarke, 2005).

Climate Change and Natural Disasters in Africa, case study of Rwanda, is based on the assessment of historical records of all natural hazards occurred in Rwanda until now, and records of temperature and precipitation, recorded since the colonial period until today. All these historical records are used to make a clear trend of those parameters.

The study is also based on the assessment of the link between two different parameters which are natural disasters trends versus weather parameters trends. It is from assessment of the correlation between natural disasters records and weather parameters that the conclusion of whether or not climate change is impacting natural disasters events is made.

The plotting of trends for analysis was made using Microsoft excel.

SECTION 4: PRESENTATION, ANALYSIS AND INTERPRETATION OF FINDINGS

Outline:

4.0. Introduction

In this section, all the data to be used are processed with the purpose to find the trend for each considered parameter. The found results are analyzed and interpreted to assess if any increase or variability in temperature, rainfall and natural disasters, has occurred so far.

4.1. Historical records of Temperature and Precipitation in Rwanda

The processed data records for temperature and rainfall of Rwanda are presented in this part, as well as the resulting trends. Note that most of the stations around the country missed some records, especially during the period of revolution, civil war and genocide. Due to the period of rehabilitation after genocide due to huge losses and damaged equipment and buildings, as well as loss of experts in the field; recall that the whole country was under ruin which is the main reason of some gaps in the data.

4.1.1. Rainfall variability during the past decades

Generally, rainfalls in Rwanda have changed their usual frequency in the season, but still with almost same annual quantity of precipitation. Therefore, to make a much more clearer analysis, monthly average of rainfalls were calculated for each chosen station and those monthly average were grouped into intervals of some years to assess changes in terms of monthly average precipitations and rainfall per seasons. The processed monthly average and per season data for precipitation are presented per station for each morph-climatic zone as shown below.

a) Rainfall data at Kigali Aero station since 1964 to 2014

Kigali Aero station is the best station with consecutive data and less gaps. The rainfall data start from 1964 to 2014, and those data were grouped into intervals of ten years. Note that data of 1994 are the only ones missing, due to the event of Genocide that was in Rwanda in that period.

Below are shown the processed monthly average rainfall data grouped into intervals of 10 years and their corresponding trends in the graph below.

Table 3: Monthly average rainfall at Kigali Aero station from 1964 – 2014

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1964-1973	61.01	135.93	125.78	168.82	94	24.83	7.33	28.51	62.79	89.29	139.58	73.19
1974-1983	71.12	90.72	102.97	169.95	83.4	27.83	9.33	32.41	89.33	91.77	113.49	113.65
1984-1993	78.37	93.29	102.86	190.64	98.11	11.25	8.87	32.62	66.75	103.53	118.18	76.6
1995-2004	82.59	70.48	138.03	131.38	81.41	21.68	17.22	35.04	70.5	113.81	120.5	80.65
2005-2014	65.75	117	117.84	133.01	92.64	24.85	10.15	30.58	65.51	113.48	128.15	73.61

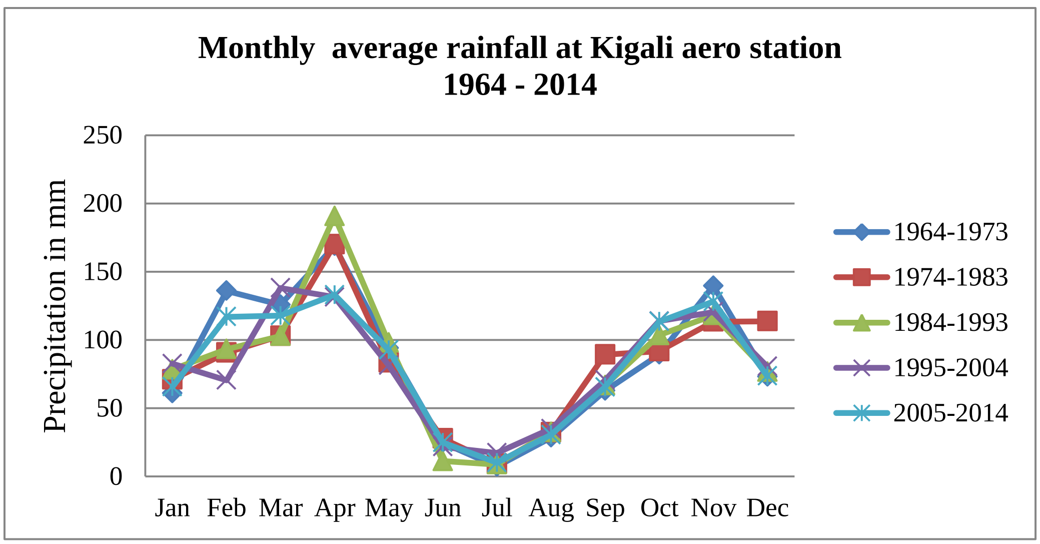

Figure 18: Monthly average precipitation trend at Kigali Aero station

As shown in the graph above, both rhythm and quantity of precipitation have been varying especially during the rainy seasons and short dry season. The quantity of rainfall has not much fluctuated during the long dry season compared to other seasons' fluctuation.

Below are shown the average of precipitation per season during the same considered stated interval of years.

Table 4: Rainfall per season at Kigali Aero station

	Short Dry Season	Long Rainy Season	Long Dry Season	Short Rainy Season
1964-1973	270.13	388.6	60.67	291.66
1974-1983	275.49	356.32	69.57	294.59
1984-1993	248.26	391.61	52.74	288.46
1995-2004	233.72	350.82	73.94	304.81
2005-2014	256.36	343.49	65.58	307.14

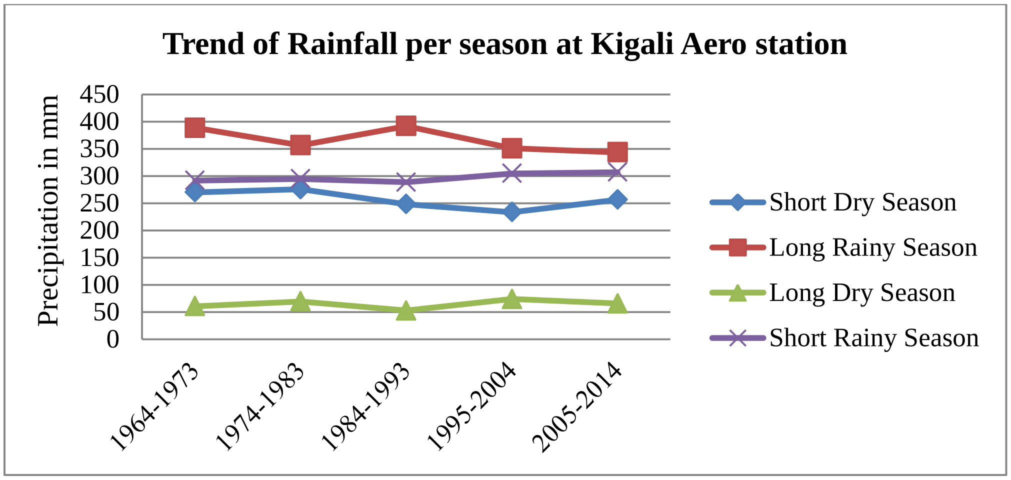

Figure 19: Per season rainfall trends at Kigali Aero station

Precipitations at Kigali Aero station have reduced in the long rainy season (from March to May), and have increased a bit in the short rainy season; while it is normally supposed to be the opposite. In dry seasons, the usual quantity of rainfalls has been decreasing in the past, but recently, it was somehow slightly increasing.

b) Rainfall data at Ruhengeri Aero station from 1976 to 2015

The used rainfall data from Ruhengeri Aero station starts from 1978 up to 2014. The data were grouped into intervals of 2, 5 and 7 years depending on the available data for the successive years. Some years in middle of the intervals were missing the data.

The processed monthly average rainfall data grouped into intervals of 2, 5 and 7 years are presented in the table below, as well as the resulting trends are in the graph below.

Table 5: Monthly average rainfall at Ruhengeri Aero station since 1978 - 2014

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978-1984	70.31	85.3	127.87	191.24	135.81	45.23	20.529	66.529	117.657	171.414	141.543	85.743
1985-1991	62.01	91.4	143.11	176.94	170.11	37.56	15.457	42.257	135.557	184.557	159.843	81.5
2003-2004	96.7	98.1	126.6	189.8	156.05	20.9	31.6	50.3	112.45	114	117.6	65.75
2010-2014	62.16	107.46	186.88	208.96	173.78	40.78	20.52	88.32	158.02	169.08	171.72	130.04

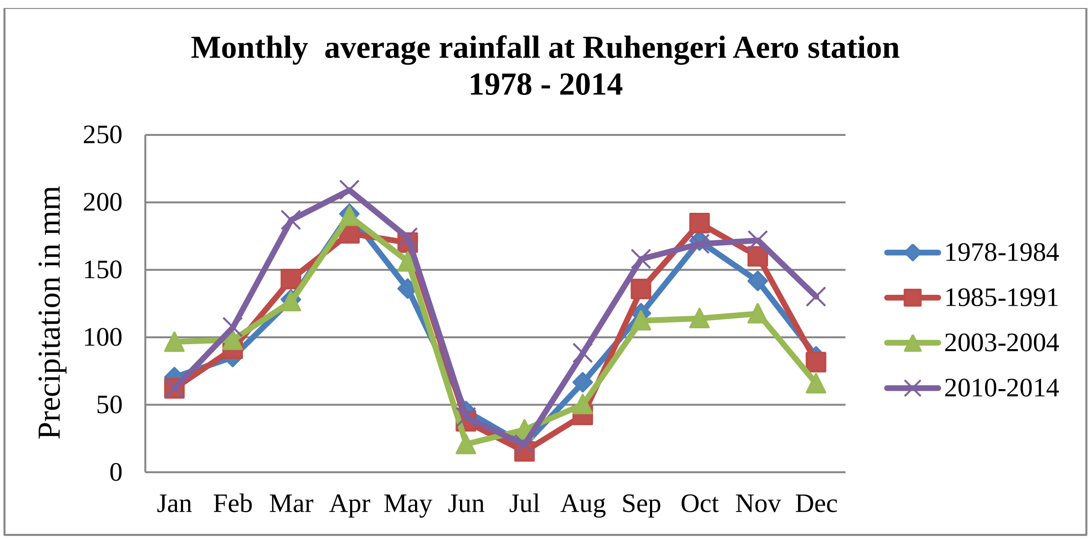

Figure 20: Monthly average precipitation trends at Ruhengeri Aero station

As demonstrated in the graphs above, the rhythm and quantity of precipitations at Ruhengeri Aero station have varied in all months. But generally the quantity of precipitation has increased and extended.

Seasonal average precipitations at Ruhengeri Aero station during the stated interval of years are shown in the table below, as well as their corresponding graphs.

Table 6: Rainfall per season at Ruhengeri Aero station

	Short Dry Season	Long Rainy Season	Long Dry Season	Short Rainy Season
1978-1984	241.357	454.93	132.29	430.61
1985-1991	234.914	490.17	95.27	479.96
2003-2004	260.55	472.45	102.8	344.05
2010-2014	299.66	569.62	149.62	498.82

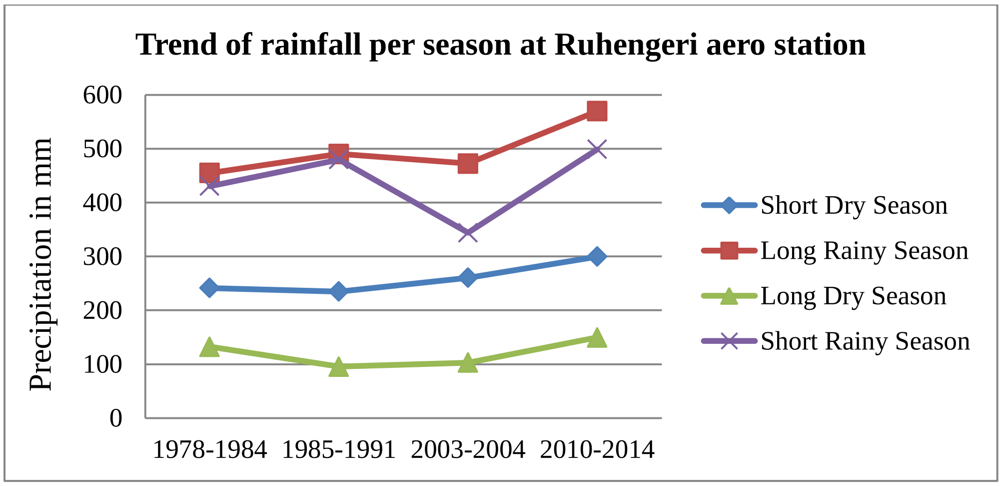

Figure 21: Per season precipitation trends at Ruhengeri Aero station

From the graph above, precipitations at Ruhengeri Aero station have generally increased. But the quantity of rainfall during the short rainy season has much dropped in the period of 2003 to 2004.

c) Rainfall data at Byimana station from 1959 to 2013

Available rainfall data records from Byimana station start from 1959 to 2013, but with many gaps within the period. The data were grouped into intervals of 8, 10 and 3 years due to its available data in that period for successive years.

The processed data of monthly average precipitation at Byimana station grouped into intervals of 8, 10 and 3 years are presented in the table below and the resulting trends are as well presented in the following graph.

Table 7: Monthly average rainfall at Byimana station since 1959 - 2013

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1959-1966	101.75	103.79	127.075	197.88	149.99	18.25	11.86	44.88	87.25	130.48	148.78	124.79
1967-1974	105.53	120.9	141.088	177.54	162.85	45.05	19.39	33.75	85.288	68.025	154.99	91.463
1975-1982	110.66	94.338	106.038	198.15	163.29	20.213	7.238	48.54	92.263	91.35	122.98	128.73
1983-1992	104.33	147.36	153.41	223.98	116.43	37.36	12.23	35.76	80.45	125.56	139.9	116.97
2011-2013	85.667	62.733	133.6	176.1	117.17	70.233	6.567	48.3	101.03	100.83	152.3	144.43

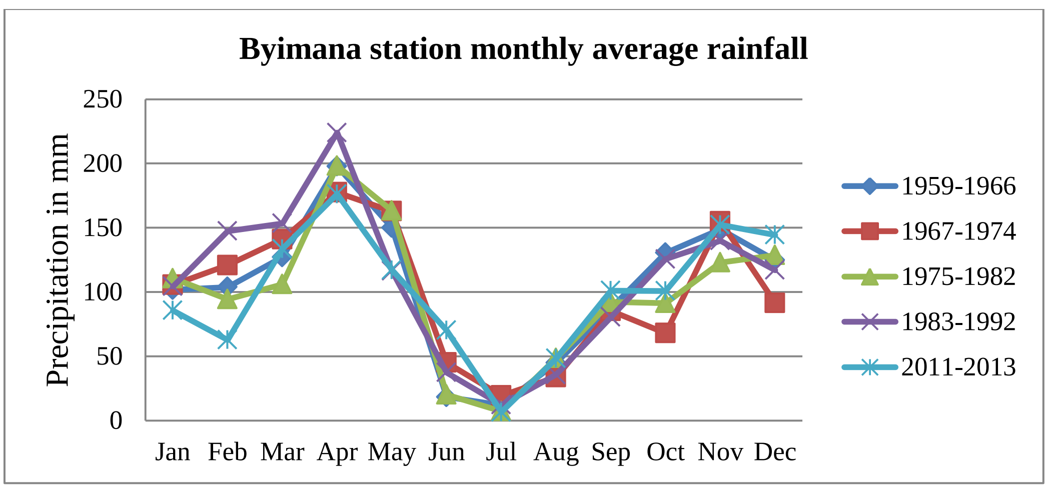

Table 8: Monthly average precipitation trends at Byimana

The rainfalls at Byimana station have varied in rhythm and quantity especially during both rainy seasons and short dry season. The trends present too much fluctuation.

Below are presented the seasonal average precipitations at Byimana station during the stated interval of years in the table, and the resulting trends are presented in the following graph.

Table 9: Rainfall per season at Byimana station

	Short Dry Season	Long Rainy Season	Long Dry Season	Short Rainy Season
1959-1966	330.325	474.9375	74.9875	366.5
1967-1974	317.8875	481.475	98.1875	308.3
1975-1982	333.725	467.475	75.9875	306.5875
1983-1992	368.66	493.82	85.35	345.91
2011-2013	292.83	426.867	125.1	354.167

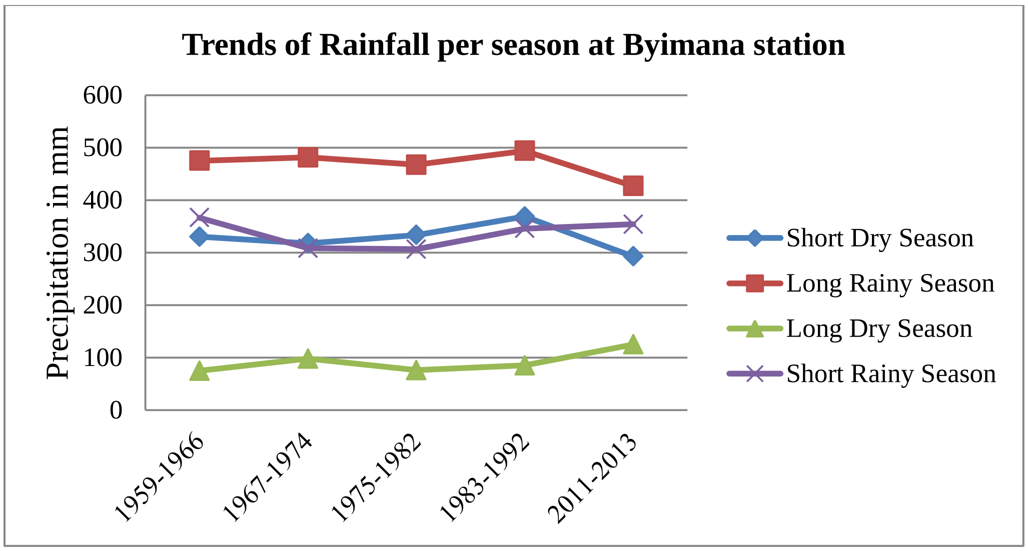

Figure 22: Per season precipitation trends at Byimana station

The quantity of precipitations in long rainy season has reduced and the one in short rainy season was reducing in the past but recently it has increased a bit much. Precipitations in long dry season have a bit increased, while recently they have decreased in short dry season.

d) Rainfall data at Kamembe aero station from 1958-2013

The used data were continual from 1958 to 1993, and records for the following period were most probably interrupted by the event of Genocide, thus the reason of gaps in the last used class of 1999-2013. The used data were grouped using intervals of 12 years for each class, and start from 1958 to 2013.

The processed monthly average data of precipitation at Kamembe Aero station grouped into intervals of 12 years are presented in the table below and the resulting trends are as well presented in the following graph.

Table 10: Monthly average rainfall at Kamembe Aero since 1958 to 2013

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1958-1969	142.1	153.14	177.83	182.32	115.53	21.42	2.48	31.25	114.22	170.45	176.56	147.19
1970-1981	139.35	133.6	154.86	162.1	107.8	37.5	16.4	51.87	127.25	150.33	190.9	142.13
1982-1993	149.025	157.26	207.18	176.12	83.458	27.19	6.88	41.78	108.73	182.67	178.8	125.11
1999-2013	136.508	131.21	179.58	134.56	104.23	29.97	14	50.49	117.11	157.55	162.98	142.74

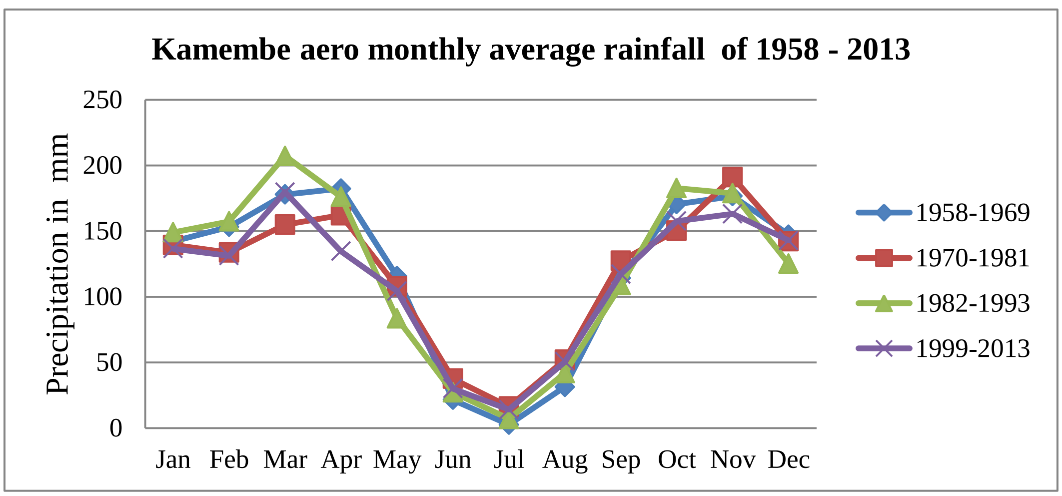

Figure 23: Monthly average precipitation trends at Kamembe Aero station

The precipitations at Kamembe Aero station have fluctuated during the whole year, but more fluctuation occurred especially during the period of January to May and September to December.

Below are presented the seasonal average precipitations of Kamembe Aero station during the stated interval of years in the table, and the resulting trends are presented in the following graph.

Table 11: Rainfall per season at Kamembe Aero stations

	Short Rainy Season	Long Rainy Season	Long Dry Season	Short Rainy Season
1958-1969	442.43	475.675	55.15	461.225
1970-1981	415.075	424.7583	105.7167	468.483
1982-1993	431.39167	466.75	75.85	470.19167
1999-2013	410.4583	418.3583	94.475	437.64167

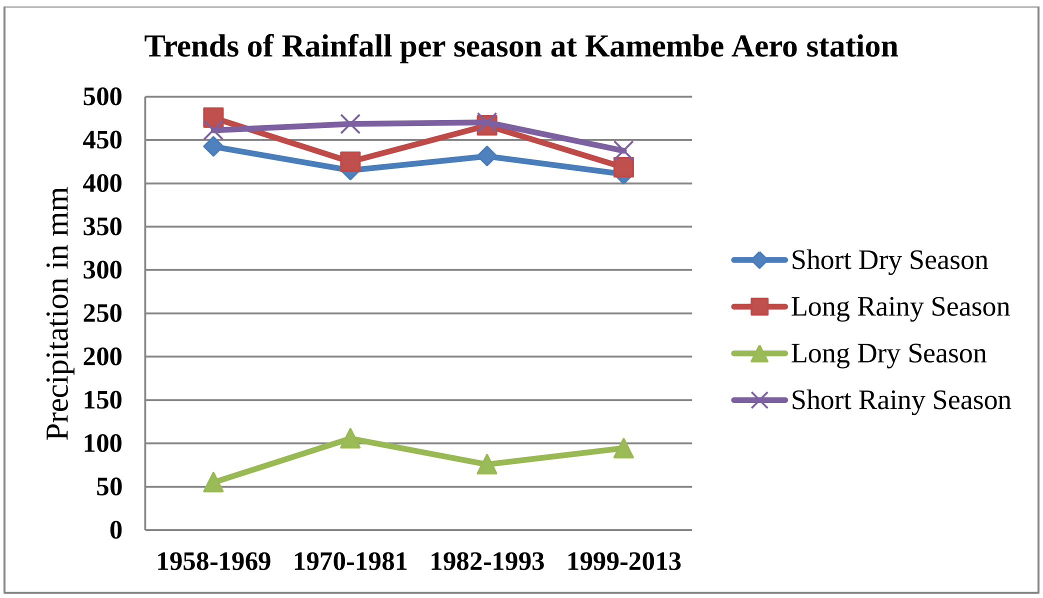

Figure 24: Per season precipitation trends at Kamembe Aero station

There is much precipitation during all the seasons at Kamembe Aero station than elsewhere in the considered stations. The short rainy season seems to dominate the long rainy season; and also the short dry season has considerable quantity of precipitations.

4.1.2. Temperature variability and trends

Temperature trend was analyzed and assessed per morph-climatic zones, due to differences in weather from one zone to another. Each zone is represented by one meteorological station. As the given data records from RMA were daily maximum and minimum data; annual average data were calculated for each station. Therefore, the analysis was done based on annual average temperature. The trends of the mean annual temperature for each used stations are presented in the graphs below.

a) Temperature trend at Kigali Aero station from 1971 - 2015

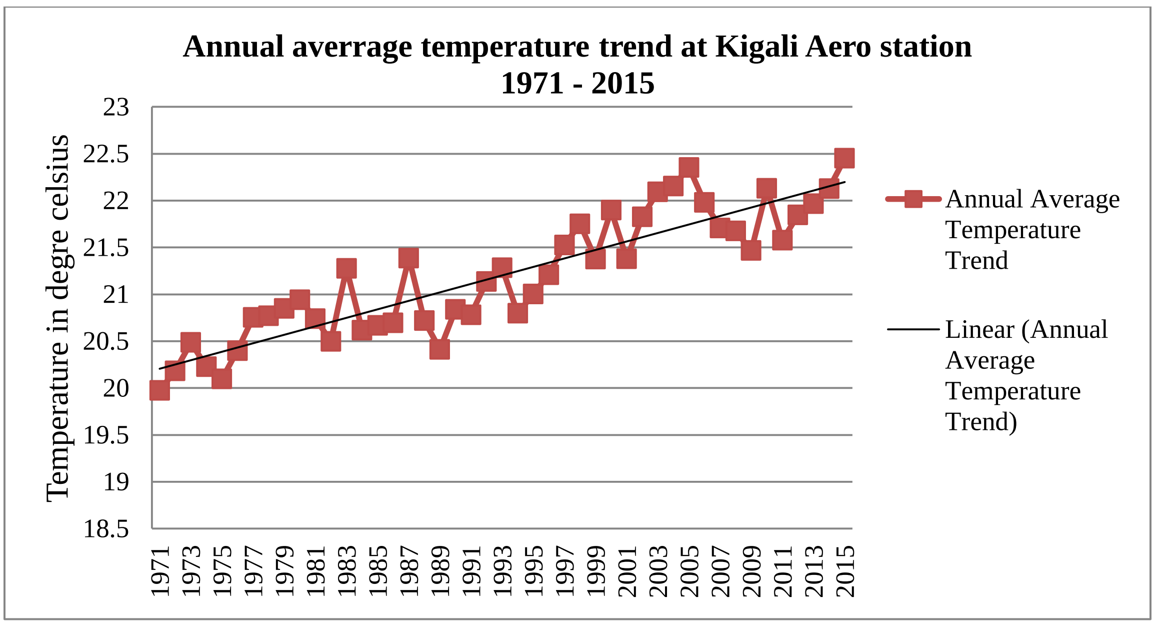

Figure 25: Temperature trend at Kigali Aero Station

b) Temperature trend at Ruhengeri Aero station from 1977 – 2015

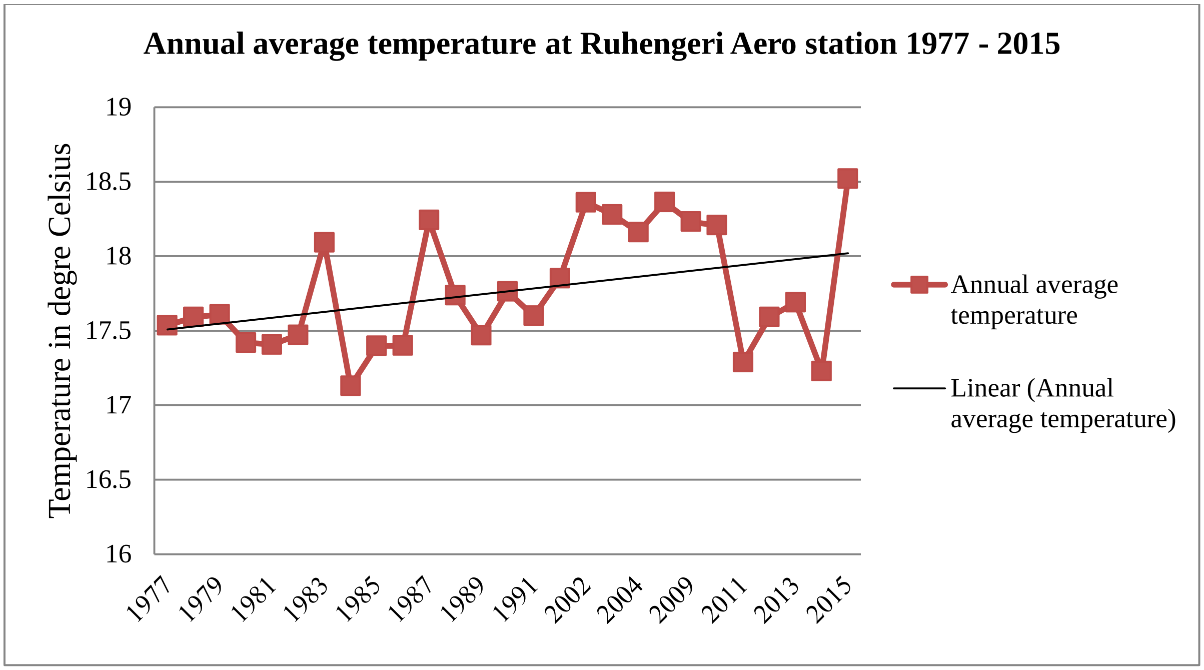

Figure 26: Temperature trend at Ruhengeri Aero Station

c) Temperature trend at Byimana station

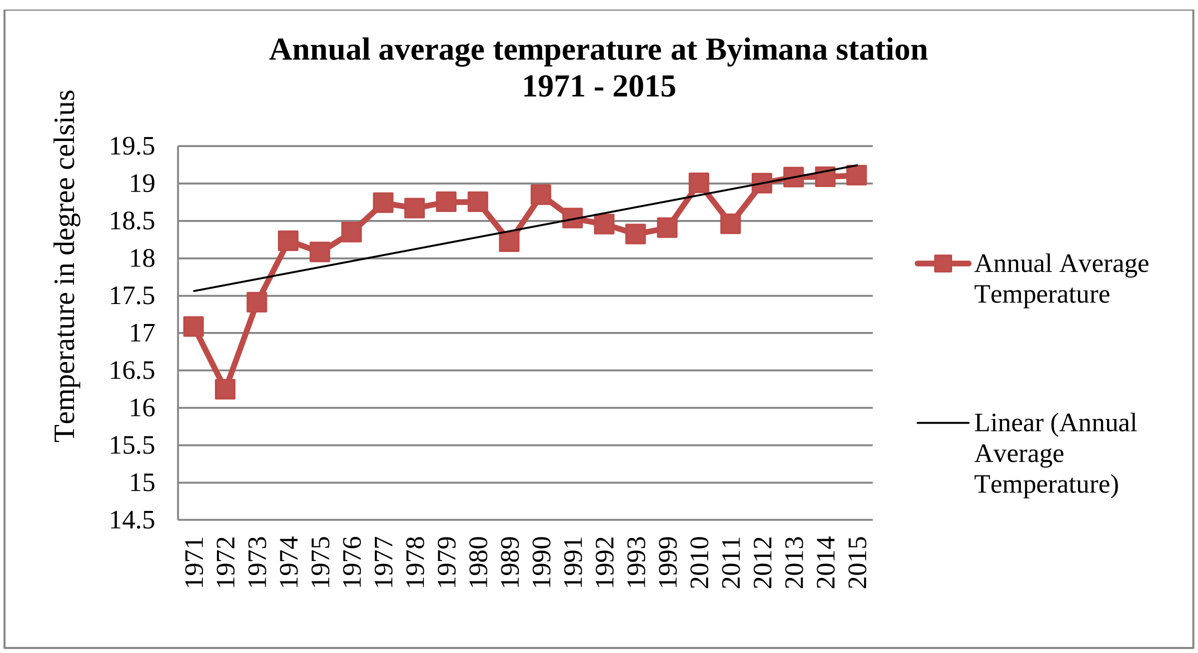

Figure 27: Temperature trend at Byimana Station

d) Temperature trend at Kamembe Aero station

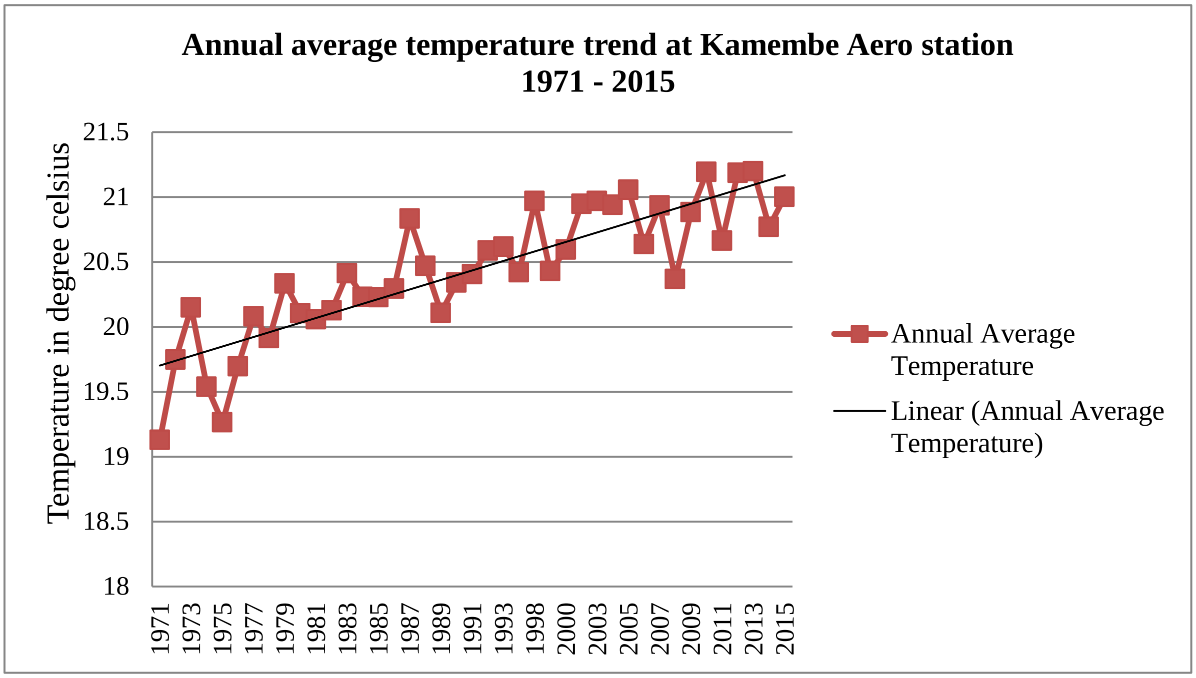

Figure 28: Temperature trend at Kamembe Aero Station

Obviously, all the temperatures have been increasing in all the considered stations, but at different rates of increase. In some places the temperature increased a lot, while in other places it has increased a bit. But generally it has considerably increased.

4.1.3. Annual average temperature linear trends equations for each considered station

The annual average temperature linear trends equations were obtained by using the method of least square. The least square method consists of the procedure used to calculate the best straight line that fit well to data.

The line equation is of the following form: **Y = ax + b** Equation 4. 1

Where $a = \frac{\sum_{i=1}^{n}(Xi - X_{mean})(Yi - Y_{mean})}{\sum_{i=1}^{n}(Xi - X_{mean})^2}$ Equation 4.2

$b = Y_{mean} - a * X_{mean}$ Equation 4.3

Note that on X-axis there were the years and annual average temperature on Y-axis.

Table 12: Annual average temperature's linear trend equation per station

Station	a value	b value	Annual average temperature's Linear trend equation
Kigali Aero	0.0453	-69.083	0.0453x – 69.083
Kamembe Aero	0.0319	-43.109	0.0319x – 43.109
Ruhengeri Aero	0.0126	-7.459	0.0126x – 7.459
Byimana	0.0282	-37.803	0.0282x – 37.803

4.1.4. Temperature increase

The temperature increase was calculated by from the linear trend using the least square method. Then, the temperature increase was calculated by taking the difference of the corresponding temperatures to the extreme points of the linear trend. The equations of the linear trends are shown in the appendix.

The temperature increase was calculated for each considered station, as well as the annual average temperature increase.

Table 13: Detailed variability in temperature

Meteorological station	Period of data	Number of years	Yearly mean temperature variation	Temperature increase
Kigali Aero	1971 - 2015	45	0.044 °C	1.993°C
Ruhengeri Aero	1977 - 2015	39	0.012 °C	0.481 °C
Byimana	1971 - 2015	45	0.028 °C	1.243 °C
Kamembe Aero	1971 - 2015	45	0.0312 °C	1.403 °C

From the table above, it is obvious that Rwanda's weather is getting warmer as the years are passing. The yearly average of temperature variation changes from 0.012 °C to 0.044 °C, with a temperature increase varying from 0.481 °C to 1.993 °C within periods of 39 years to 45 years, while the global temperature increase is 0.85 °C and it occurred within 132 years.

4.2. Trend of Natural Disasters in Rwanda

Since 1974 until now, Rwanda has been experiencing a number of natural disasters, most of which were climate related, that devastated a huge amount of goods and caused many losses. Even though the number of victims resulting from those disasters has really reduced due to the development and improved strategies for both resilience and mitigation systems, however the frequency of occurrence of those disasters has recently increased a lot.

Below is the graph of the natural disasters occurrence repeatability of all climate related natural disasters events found in Rwanda until 2015, obtained from EM-Data database. Those disasters include; drought, flood and landslide, storm and epidemic events.

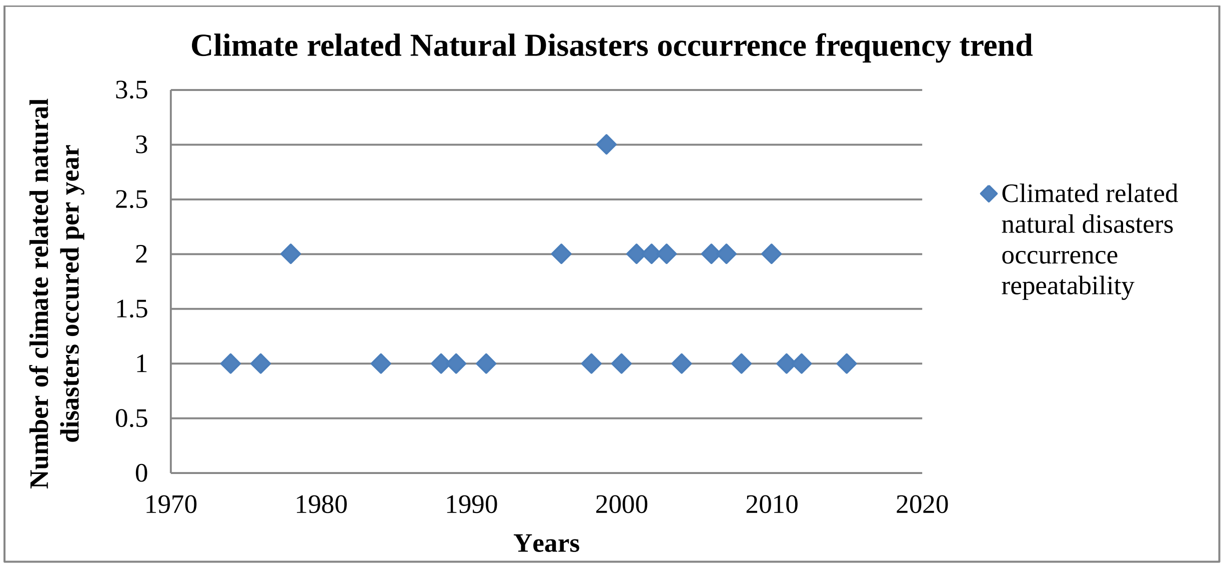

Figure 29: Natural disasters trend in Rwanda

Source: (EM-DAT, 2015)

The earliest climate related disaster event that was recorded in Rwanda occurred in 1974, and the latest presented in the above graph took place in 2015. During the period of 1974 to 2015, the peak in climate related natural disasters occurred in 1999.

Table 14: Distribution of climate related natural disasters events over the past years

Period	Number of climate related natural disasters in the period	Number of disasters in percentage	Increase rate
1974 – 1987	5	15.6%	31.25%
1988 – 2001	12	37.5%	
2002 – 2015	15	46.87%	

By taking an interval of 14 years, it is obvious that natural disasters have been increasing in number, from five disasters in the past to 15 disasters that occurred in the most recent period of 14 years. From the period of 1974 – 1987 to the period of 2002 – 2015 there has been an increase rate of 31.25% in climate driven disasters

4.3. Assessment of the correlation between Temperature Trends and Climate Related Natural Disasters Trend

The main objective of this study is to assess the influence climate change would have exerted on the occurrence of natural disasters. To assess that correlation, only annual average temperatures of the considered stations have been used as well as the occurrence frequency of natural disasters. Note that the used natural disasters data records were obtained from EM-Data database. Therefore, only the disasters events that have been declared to the Centre of Research on the Epidemiology of Disasters (CRED) database were the only ones to be used. Most probably, some disasters events may have occurred but if they have not been declared to CRED, this means that they were not available in the database and they have not been used in this report.

The used data on natural disasters were on the national scale, while the used temperature data were per station scale. It was not possible to obtain the temperature data on the national scale, hence the reason why used data were from some meteorological stations that cover some regions which were the only available data. Also, as it was demonstrated previously, the temperature increase were not the same in all stations. They were changing from one region to another region, thus the reason why the correlation was assessed using temperature data per station to take as well into consideration the differences in temperature increase of those different regions.

To assess the level of relationship between temperature rise in Rwanda and the occurrence of natural disasters in Rwanda, statistical calculations were used to calculate the correlation coefficient. Statistical Package for the Social Sciences – SPSS version 16 was used to calculate that correlation coefficient between the temperature trends and natural disasters trend. Below are shown in the table the obtained correlation coefficient for each station, its interpretation and he temperature increase to each station.

Table 15: Results of the correlation between temperature and natural disasters

Meteorological station	**Correlation coefficient and level**		**Period of years**	**Temperature increase**
Kigali Aero	0.341	Low positive correlation	1971 – 2015	1.993 °C
Kamembe Aero	0.312	Low positive correlation	1971 - 2015	1.403 °C
Ruhengeri Aero	0.273	Low positive correlation	1977 - 2015	0.481 °C
Byimana	0.227	Low positive correlation	1971 - 2015	1.243 °C

All the correlation coefficients in the four considered stations mean a low positive correlation. And stations with higher temperature increase have a higher correlation coefficient as well, except for the case of Byimana station.

4.4. General Interpretation of the Findings

❖ **Rainfall variability**

Rainfall trends, both per season and monthly average trends present too much instability in their rhythms and quantity. Rise in temperature would be the main cause of those disturbances in rainfall in Rwanda which can lead as well to non-expected hazards.

❖ **Temperature variability and trends**

All the plotted temperature trends testify the rise of the temperature in each considered station. As shown in table 12, all the three temperature increase at Kigali Aero, Kamembe Aero and Byimana stations during the period of 45 years, are higher than the global temperature increase during 180 past years. Therefore, Rwanda is tending to warmer climate at a high rate.

❖ **Occurrence trend of natural disasters**

The occurrence of natural disasters, as shown in figure 36, has been more repetitive during the last two decades than it was in the preceding periods of 1974 to 1991. From that graph, climate related disasters events started to increase in number and to occur more frequently from the year of 1996.

❖ **Correlation between climate change and climate related natural disasters**

Since it was not easy to assess climate change by analyzing changes in rainfalls' rhythm and quantity, in the end, the only used parameter to assess climate change in Rwanda was the temperature, specifically land temperature. All the obtained correlation coefficients were low positive correlations, which means that the rise in temperature has exerted a certain effect on the occurrence of climate related natural disasters but those effects are small. Then, there would be other factors that would have made climate related natural disasters occurrence more frequent; or those factors would have inevitably made usual natural hazards to be qualified of natural disasters, due to the increased vulnerability to those hazards.

4.5. Achievement

Basing on the analysis of available temperature and precipitation's data obtained from the RMA, the rate of climate change in Rwanda has been evaluated. Using those data records annual temperature trends, and seasonal and monthly rainfall trends have all been plotted. Different from what was planned at the beginning, only the annual average temperature trends were the only considered parameter in the end. Rainfall trends were left due to much fluctuation in rainfall rhythm that gave trends with much irregularity. This was a bit difficult to analyze.

Climate related natural disasters events; droughts, epidemic, floods and landslides; were plotted in terms of their annual occurrence frequency to obtain their occurrence trend.

The correlation between temperature trend and climate related disasters events was evaluated by using annual average temperature trends from four different meteorological stations in the country versus disasters events trends. Temperature trends were processed per station due to the fact that available data were given per station. Recalling that Rwanda geomorphology is subdivided into four to five types corresponding to a specific weather of the concerned region, the chosen stations each was from one a specific geomorphological region. Then by using statistical calculations the correlation coefficient of annual average temperature per station with annual rate of occurrence of climate related natural disasters on the national scale was calculated. Those calculations were done for each meteorological station's data.

Noting that each region's temperature increase is different from others, such calculation of the correlation coefficient using temperature parameter on a station scale with disasters data on a national scale helped to evaluate how much the temperature has increased in each region. It also helped to evaluate how much that temperature increase has affected the rate of climate related natural disasters events in that concerned region.

SECTION 5: CONCLUSION AND RECOMMENDATIONS

Outline:

5.0. Introduction

The current section contains the general conclusion on the topic and some recommendations on the concerned issue to be sorted out and other on the things to be improved so the study may be well achieved with more consistent results.

5.1. Encountered difficulties and solutions

Any achievement cannot be reached without encountering any problem. That has been the same case while conduction this research. Commonly in all developing countries, due to lack of financial capability, lack of necessary skills and periods of insecurity, wars and genocide; all those facts have influenced non continuous records of data. Thus, this is the main reason for many gaps in the available used data of Rwanda. Most probably, some events may not have been registered to the consulted database while they really occurred, which explains the reason why they may have not been considered in this study.

0n temperature and rainfall records, there were a lot of gaps. Apart from Kigali Aero station that presented data in a continuous way, the rest of stations were missing a lot of data that may have more or less influenced the obtained results.

Despite all these encountered issues, the research has been achieved as it was expected; even the results were obtained by using all the available and possible data and methods.

5.2. Conclusion

Nowadays, there is common agreement among scientists and policy makers that climate change is one of the greatest challenges that face humanity in the 21st century. In that same century, the climate related natural disasters events have become more frequent and they mostly devastate developing countries. The research study on Climate Change and Natural Disasters in Africa, case study of Rwanda focused first to point out evidence of climate change in Rwanda, and secondly to identify the link between climate change and occurrence of climate related natural disasters in Rwanda. For this study, historical records of the climate related natural disasters in Rwanda since 1974 until 2015 were considered, together with weather indicators that include temperature and rainfall. The data of these weather indicators collected and analyzed are from four different morph-climatic zones of Rwanda.

After processing the temperature and rainfall's data records, the climate change was clearly manifested in terms of a much rise of the temperature and changes in usual rainfalls. The temperature increases differ from one station to others. The temperatures in all the stations have increased from 0.48 degree Celsius to 1.99 degree Celsius. The analysis of rainfall manifested much disturbance in rainfall's rhythm at all the considered stations. Climate related Natural Disasters occurrence frequency trend was obtained using the scatter diagram. The obtained trend showed a high increase in those disasters events in the period of 1988 to 2015 and the total increase rate in climate related disasters events is 31.25%.

The analysis of precipitation's data collected in four different meteorological stations indicate much fluctuation in rainfall rhythm. In this study, it was generally assumed that these disturbances in rainfall rhythm during the last six decades are associated with climate change as it is defined by the rise in temperature. Thus the reason why the temperature was in the end the only used indicator to assess the correlation between the climate change and climate related natural disasters events in Rwanda.

In brief, the results of this study indicate that the observed climate change in Rwanda has led to the increase in occurrence of climate related natural disasters in the country. It is important to note that climate change driven natural disasters events in Rwanda have been also amplified on the other hand by the geomorphological structure of the land (made with many mountains and hills) and by high density of the population that survive on agriculture.

5.3. Recommendations

In order to ensure the safety of its population and its future generation, Rwanda's policy makers should join the global effort and initiative for sustainable development that aim to reduce effects of climate change. In Rwanda, efforts in this regard are currently under the supervision of REMA and should be improved in regard to environment protection and climate change mitigation. It should be noticed that all the nations are concerned with the harmful impacts of climate change.

The government of Rwanda has to improve the land management and urban planning programs. They have to be incorporated with disasters resilience strategies to minimize settlement of the population in high risk zones and to ensure the well use of land to reduce vulnerability land exposure to natural disasters.

The overpopulation is among the main important issues that have made the country more vulnerable to natural disasters, therefore, the government should sensitize the population in reducing the number of birth and providing them with all the possible means to regulate the births, since the land and resources are limited to fit a fast growing population.

In order to reduce the impacts of shift in season and extreme weather events on the agriculture production, modern techniques of agriculture such as affordable irrigation using renewable energies, drainage in wetter land, crop rotation and intercropping, and protected production (using greenhouses), have to be taught and sensitized to the population and make a follow up of their implementation.

The current initiated study can serve as a basis for more extensive study that can be improved by incorporating more weather indicators such as; pressure, humidity, winds and the 27 indices of extreme temperature and pressure. A further and deep research is therefore encouraged and recommended.

EXECUTIVE SUMMARY

In the framework to obtain a Master's degree in Energy Engineering Track, the report on the thesis entitled "Climate Change and Natural Disasters in Africa, case study of Rwanda" has been done as a partial fulfillment of the requirements for the award of a Master's degree from the Pan African University Institute of Water and Energy Sciences, including climate change, during the academic year 2015 – 2016.

The main aim of this research was to assess the influence the climate change would have exerted and still exerts on the recent abnormal rate of climate related natural disasters events in Rwanda. Besides that aim, the objectives of this research were; to assess the rate of climate change in Rwanda by analyzing both temperature and rainfall's data records, to collect and plot all the available climate related natural disasters events data records to evaluate the rate of climate related natural disasters events in Rwanda, and to assess the rate of correlation between climate parameters, either temperature or rainfall with the rate of climate related natural disasters events in Rwanda.

In this report, four main disasters events that are climate related, which are drought, epidemic, flood and landslide were the main considered disasters events found in Rwanda. To assess the rate of climate change, temperature was the main parameter used due to the availability of its data and as well the provision of a clear trend with less instability. Even precipitation parameter was planned to be used together with temperature to assess the rate of climate change in Rwanda. However, the obtained rainfall trends on Rwanda presented too much fluctuation. And that was qualified to be one of some indirect consequences of climate change on precipitation in Rwanda.

Microsoft Excel and SPSS version 16 were the used program and software to process and analyze the used data. Recall that historical records of climate related natural disasters obtained from EM-Dat database were used to analyze natural disasters events in Rwanda relatively to climate. To analyze the temperature and assess the temperature increase, the chosen meteorological stations were located in four different morph-climatic zones found in the country. This was done in order to generally cover the whole country. Those stations are; Byimana, Kamembe Aero, Kigali Aero and Ruhengeri Aero stations from the following

respective morph-climatic ones; Central plateau zone, zone along the Lake Kivu, Eastern plains and bass plateau zone, and volcanic mountains zone. Recall that the above stated geomorphological zones are the main ones found in the country and does each correspond to a specific weather condition.

After plotting annual average temperature trends for each station and plotting disasters events' scatter diagram using Microsoft Excel, the correlation between annual average temperature for each station versus the rate of climate related natural disasters events records was calculated using SPSS v16. Basing from the obtained trends, there has been increase in temperatures to each station that ranges from 0.48 °C to 1.99 °C during the past 39 to 45 years. This is a bit higher than global temperature increase of 0.85 degree Celsius that has occurred from 1880 to 2012. The temperature increase was calculated using the method of least square. From the results obtained in SPSS, the correlation between temperature trends and rate of climate related natural disasters events varies from 22.7% to 34.1%. Therefore, it was concluded that climate change is not the only engine that is boosting the rate of climate related natural disasters events in Rwanda. There are other factors that are playing a considerable important role in enhancing the occurrence of climate relate natural disasters at a high rate.

Recall that Rwandan population has been increasing at a very fast rate while the land is not growing, and that the main economic activity to most Rwandese is the rain fed agriculture where more than 80% of Rwandese lives on subsistence agriculture. The above facts emphasize degradation of the soil's quality due to over cultivation and decline of habitable land caused by overpopulation which had led as well the population to occupy zones with high risk. Note that Rwanda's land is hilly and mountainous. All these facts have made the whole country vulnerable to any least hazard and extreme weather event. Therefore, it was recommended to the Rwandan government to improve the policy of habitation so to manage well that small land of 26,338 square kilometers and reduce as well the risk of vulnerability enhanced by occupying risky zones. The incorporation of disasters resilience strategies in the urban planning programs would help in reducing damages and loss caused by disasters events. Seeing that the economy of Rwanda is mostly driven by the agriculture and that the latter is much affected by climate change and natural disasters events; implementation of protected production (greenhouses use) has to be increased and sensitized to the population, as well as irrigation in dry places using available renewable energies in the place and drainage in wetter areas. All these would help to alleviate the effects of shift in seasons on the agriculture yield. Crops rotation and intercropping methods have to be enhanced in order to prevent the only available small arable land from becoming infertile.

There would be improvement on the vulnerability to climate change and climate related natural disasters events in case the above stated recommendations were to be implemented.

RESUME

Dans le cadre d'obtention de diplôme de maîtrise en génie énergétique, le rapport sur la thèse intitulée «Le changement climatique et les catastrophes naturelles en Afrique, cas de l'étude du Rwanda" a été fait comme un accomplissement partiel des exigences relatives à l'attribution d'un diplôme de maîtrise de l'Institut Universitaire Panafricaine des Sciences de l'Eau et de l'Energie, y compris le changement climatique, au cours de l'année scolaire 2015-2016.

Le but principal de cette recherche était d'évaluer l'influence que le changement climatique aurait exercée et exerce encore sur la fréquence anormale des faits des catastrophes naturelles liées au climat au Rwanda. Outre ce but principal, les objectifs de cette recherche étaient premièrement d'évaluer le taux de changement climatique au Rwanda en analysant l'historique des données des températures et des précipitations qui ont eu lieu au Rwanda. Deuxièmement l'objectif était de collectionner tous les enregistrements disponible sur le déroulement des catastrophes naturelles induites par le climat et d'en déduire le taux de déroulement de ces catastrophes naturelles. Et enfin le troisième objectif était d'évaluer la corrélation entre les paramètres climatique utilises, soit la température ou les précipitations, avec le taux de déroulement des catastrophes naturelles induites par le climat trouvée au Rwanda.

Dans ce rapport, quatre catastrophes naturelles qui sont liés au climat tel que ; la sécheresse, épidémies, inondations et glissements de terrain ont été considérés comme les principales catastrophes naturelles induites par le climat trouvés au Rwanda. Pour évaluer le taux de changement climatique, la température était le seul principal paramètre utilisé en raison de la disponibilité de ses données qui ont été ainsi fourni pour une tendance claire avec moins d'instabilité. Même le paramètre de précipitation était prévu pour être utilisé conjointement avec la température pour évaluer le taux de changement climatique au Rwanda. Cependant, les tendances des précipitations obtenues sur le Rwanda ont présenté trop de fluctuation. Et cela a été qualifié pour être l'un des quelques conséquences indirectes du changement climatique sur les précipitations au Rwanda.

Microsoft Excel et SPSS version 16 sont le programme et logiciel utilisés pour traiter et analyser les données utilisées. Rappelons que l'historique des données sur les catastrophes naturelles induites par le climat qui ont été utilisés pour analyser les catastrophes naturelles survenus au Rwanda a été obtenu à partir de la base des données d'EM-Dat. Pour analyser la température et d'évaluer l'augmentation de cette dernière, les stations météorologiques choisis sont situés dans quatre zones morpho-climatiques différentes trouvées dans le pays. Cela a été fait afin de couvrir l'ensemble du pays d'une manière générale. Ces stations sont: Byimana, Kamembe Aero, Aero Kigali et la station de Ruhengeri Aero. Elles sont toutes localisées dans les zones morpho-climatiques respective suivantes ; la zone des plateaux centrales, la zone au long du lac Kivu, la zone des plaines de l'Est et de bas plateau, et la zone des montagnes volcaniques. Rappelons que les zones géomorphologiques mentionnées ci-dessus sont les principales trouvées dans le pays et correspondent chacun à des conditions de temps spécifique.

Après avoir tracé la tendance de l'évolution des températures moyennes annuelles pour chaque station et le diagramme de dispersion des différentes événements de catastrophes naturelles relative au climat en utilisant Microsoft Excel, la corrélation entre la température moyenne annuelle pour chaque station par rapport au taux de déroulement de ces événements cités ci-haut a été calculé en utilisant SPSS v16. En se basant sur des tendances obtenues, une augmentation de la température e été remarquée à chaque station. Chaque station présente une augmentation de température différente de celles des autres, et elles varient de 0,48 ° C à 1,99 ° C au cours des 39 à 45 dernières années. Ceci est un peu plus élevé que l'augmentation de la température globale de 0.85 degré Celsius qui a eu lieu de 1880 jusqu' à 2012. L'augmentation de la température a été calculée selon la méthode des moindres carrés. A partir des résultats obtenus dans SPSS, la corrélation entre les tendances de la température et le taux des événements de catastrophes naturelles relative au climat varie de 22,7% à 34,1%. Et finalement il a été conclu que le changement climatique n'est pas le seul moteur qui stimule l'augmentation du taux des événements de catastrophes naturelles liées au climat au Rwanda. En effet, il existe d'autres facteurs qui jouent un rôle important dans l'augmentation considérable de la survenance de catastrophes naturelles climatiques à un taux élevé.

Rappelons que la population rwandaise a augmenté à un rythme rapide alors que la terre ne se développe pas, et que la principale activité économique de la plupart des Rwandais est l'agriculture pluviale où plus de 80% de Rwandais vivent de l'agriculture d'auto subsistance.

Ces facteurs cités en haut soulignent les faits conséquences d'une population galopante sur l'environnement, et plus précisément dégradation de la qualité du sol cultivable causée par la sur-cultivation du terrain. Ainsi que le déclin des terres habitables avec moins de risques, ce qui a poussé la population à occuper des espaces a grandes risques ; vue que la terre au Rwanda est accidentée et montagneuse. Tous ces faits ont fait que l'ensemble du pays devienne vulnérable à tout danger et au moindre condition météorologique extrême. Par conséquent, il a été recommandé au gouvernement rwandais d'améliorer la politique d'habitation afin de bien gérer cette petite terre de 26.338 kilomètres carrés et ainsi de réduire le risque de vulnérabilité accrue en occupant des zones à grande risque. L'intégration des stratégies de résilience aux catastrophes dans les programmes de planification urbaine contribuerait à réduire les dommages et les pertes causées par des phénomènes de ces catastrophes. Vue que l'économie du Rwanda est principalement tirée par l'agriculture, et que cette dernière est beaucoup plus affectée par le changement climatique et les événements des catastrophes naturelles; la mise en œuvre de la production protégée par l'utilisation des maisons de serres doit être augmenté et sensibilisé à la population. Ainsi que l'irrigation dans des endroits secs en utilisant les énergies renouvelables disponibles dans le lieu et le drainage dans les zones humides. Tout cela contribuerait à atténuer les effets du changement de saisons sur le rendement de l'agriculture. Les cultures de la rotation, et les méthodes de cultures intercalaires doivent être renforcées afin d'empêcher que la seule disponible petite terres arables devienne infertiles.

Il y aurait une amélioration sur la vulnérabilité aux changements climatiques liés aux événements des catastrophes naturelles climatique en cas où les recommandations énoncées ci-haut sont mises en œuvre.

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APPENDICES

APPENDIX 1: LIST OF ALL CLIMATE RELATED NATURAL DISASTERS EVENTS AROUND THE WORLD FROM 1980–2015

Table 16: Rate of occurrence of climate related disasters

Years	Drought	Flood	Extreme temperature	Storm
1980	14	39	3	42
1981	13	43	2	50
1982	13	48	3	52
1983	32	49	2	59
1984	8	47	1	57
1985	3	58	8	51
1986	4	50	2	56
1987	15	68	6	58
1988	17	76	6	60
1989	7	46	5	73
1990	12	60	13	137
1991	18	77	8	66
1992	12	59	7	76
1993	9	84	4	108
1994	13	88	9	81
1995	6	94	13	81
1996	6	92	5	77
1997	18	95	13	79
1998	20	94	12	88
1999	23	122	8	106
2000	27	158	31	101
2001	22	157	23	107

2002	25	172	15	123
2003	14	158	25	86
2004	11	129	16	123
2005	22	193	29	131
2006	9	226	24	76
2007	11	218	25	105
2008	16	165	9	111
2009	18	151	24	87
2010	16	184	29	95
2011	17	156	16	84
2012	19	135	51	90
2013	9	149	14	105
2014	18	135	18	102
2015	25	148	10	90
Total	**542**	**4023**	**489**	**3073**

Source: (EM-DAT, 2015)

APPENDIX 2: LIST OF ALL NATURAL DISASTERS EVENTS OCCURRED IN RWANDA

❖ **Table 17: Rwanda's Records of all the disasters and resulting damages**

Year	Disaster type	Occurrence	Total deaths	Affected	Injured	Homeless	Total affected	Total damage
1974	Flood	1	0	1900000	0	0	1900000	0
1976	Drought	1	0	1700000	0	0	1700000	0
1978	Epidemic	2	17	2000	0	0	2000	0
1984	Drought	1	0	420000	0	0	420000	0
1988	Flood	1	48	21628	50	0	21678	0
1989	Drought	1	237	60000	0	0	60000	0
1991	Epidemic	1	32	214	0	0	214	0
1996	Drought	1	0	82000	0	0	82000	0
1996	Epidemic	1	10	106	0	0	106	0
1998	Epidemic	1	55	2951	0	0	2951	0
1999	Drought	1	0	894545	0	0	894545	0
1999	Epidemic	3	76	488	0	0	488	0
2000	Epidemic	1	10	164	0	0	164	0
2001	Flood	2	12	3000	0	0	3000	0
2002	Earthquake	1	45	1535	108	0	1643	0
2002	Epidemic	1	83	636	0	0	636	0
2002	Flood	1	69	20000	0	0	20000	0
2003	Drought	1	0	1000000	0	0	1000000	0
2003	Flood	1	0	0	16	7000	7016	0
2004	Epidemic	1	4	540	0	0	540	0
2006	Epidemic	1	35	300	0	0	300	0
2006	Landslide	1	24	2000	0	0	2000	0
2007	Flood	2	30	4500	0	0	4500	9
2008	Earthquake	1	36	0	643	0	643	0
2008	Flood	1	0	11295	51	0	11346	0
2010	Landslide	2	21	0	17	5920	5937	0
2011	Flood	1	14	3588	20	0	3608	0
2012	Flood	1	5	11160	0	0	11160	0
2015	Flood	1	2	3425	6	0	3431	0

Source: **(EM-DAT, 2015)**

- **The occurrence:** The rate at which the event has happened in a given period
- **Total deaths:** Total number of killed people, including as well the number of missing people due to the event
- **Affected people:** Number of people who due to the disaster event require immediate assistance during that emergent period of the event, including as well evacuated people due to that event
- **Injured people:** number of people that got injuries, trauma or diseases caused by the occurrence of the disaster and that require urgent assistance
- **Homeless people:** number of people whose houses get completely devastated or heavily damaged by the disaster event and those people need accommodation after the event
- **Total affected people:** Total number of the affected and the injured and homeless people
- **Total damage:** Equivalent in US dollars of the total damages resulting from the disaster event, it is considered as the cost of the economic impact of the disaster event covered by direct consequences on the local economy and indirect consequences.

Noting that the used disaster reference year was the start date of that event.

APPENDIX 3: MINIMUM, MAXIMUM, ANNUAL AVERAGE TEMPERATURE IN THE FOUR CONSIDERED METEOROLOGICAL STATIONS

Table 18: Kigali aero station temperature records in degree Celsius

Year	Minimum Annual average temperature (Tmin)	Maximum annual average temperature (Tmax)	Annual Average Temperature [(Tmin + Tmax)/2]
1971	14.21	25.74	**19.97**
1972	14.3	26.07	**20.18**
1973	14.54	26.43	**20.49**
1974	14.5	25.95	**20.23**
1975	14.5	25.69	**20.1**
1976	14.57	26.23	**20.4**
1977	15.29	26.22	**20.75**
1978	15.22	26.32	**20.77**
1979	15.33	26.36	**20.85**
1980	15.19	26.69	**20.94**
1981	14.91	26.57	**20.74**
1982	14.55	26.44	**20.5**
1983	15.65	26.91	**21.28**
1984	14.97	26.26	**20.62**
1985	15.22	26.11	**20.67**
1986	15.2	26.19	**20.7**
1987	15.76	27.01	**21.39**
1988	15.49	25.96	**20.72**
1989	15.1	25.73	**20.41**
1990	15.42	26.26	**20.84**
1991	15.38	26.18	**20.78**
1992	15.68	26.59	**21.14**
1993	15.77	26.8	**21.29**
1994	15.43	26.17	**20.8**
1995	15.4	26.61	**21**
1996	15.35	27.07	**21.21**
1997	15.78	27.27	**21.53**
1998	16.14	27.37	**21.75**
1999	15.61	27.14	**21.38**
2000	16.05	27.74	**21.9**
2001	15.9	26.86	**21.38**
2002	16.21	27.44	**21.83**
2003	16.29	27.9	**22.09**
2004	16.33	27.98	**22.16**

2005	16.52	28.18	**22.35**
2006	16.45	27.51	**21.98**
2007	16.18	27.24	**21.71**
2008	16.07	27.28	**21.68**
2009	16.18	26.76	**21.47**
2010	16.57	27.7	**22.13**
2011	16.21	26.94	**21.58**
2012	16.39	27.3	**21.85**
2013	16.48	27.45	**21.97**
2014	16.76	27.5	**22.13**
2015	16.82	28.08	**22.45**

Table 19: Ruhengeri aero station temperature records in degree Celsius

Year	Minimum Annual average temperature (Tmin)	Maximum annual average temperature (Tmax)	Annual Average Temperature [(Tmin + Tmax)/2]
1977	11.352	23.72	17.535
1978	11.381	23.8	17.591
1979	11.324	23.89	17.609
1980	10.651	24.19	17.42
1981	10.743	24.07	17.407
1982	10.992	23.95	17.472
1983	11.509	24.67	18.092
1984	10.451	23.81	17.128
1985	10.98	23.82	17.398
1986	10.896	23.9	17.399
1987	11.897	24.59	18.242
1988	11.694	23.78	17.736
1989	11.496	23.44	17.468
1990	11.625	23.9	17.762
1991	11.377	23.82	17.599
1992	11.66	24.04	17.851
2002	13.455	23.27	18.361
2003	12.298	24.26	18.28
2004	12.117	24.21	18.161
2005	12.321	24.4	18.362
2009	11.897	24.57	18.231
2010	12.319	24.1	18.207
2011	11.222	23.36	17.289
2012	11.585	23.6	17.591
2013	11.513	23.87	17.689
2014	10.888	23.57	17.228
2015	12.189	24.85	18.52

Table 20: Byimana station temperature records in degree Celsius

Year	Minimum Annual average temperature (Tmin)	Maximum annual average temperature (Tmax)	Annual Average Temperature [(Tmin + Tmax)/2]
1971	11.11	23.05	17.08
1972	11.09	21.4	16.25
1973	10.99	23.83	17.41
1974	13.05	23.42	18.23
1975	12.97	23.19	18.08
1976	13.14	23.55	18.35
1977	13.85	23.63	18.74
1978	13.67	23.67	18.67
1979	13.53	23.98	18.75
1980	13.5	24.01	18.75
1989	12.93	23.51	18.22
1990	13.69	24	18.85
1991	13.42	23.65	18.53
1992	13.52	23.39	18.46
1993	13.13	23.51	18.32
1999	13.02	23.79	18.41
2010	13.76	24.25	19.01
2011	13.17	23.75	18.46
2012	13.95	24.06	19
2013	13.78	24.39	19.09
2014	14.24	23.94	19.09
2015	14.13	24.08	19.11

Table 21: Kamembe aero station temperature records in degree Celsius

Year	Minimum Annual average temperature (Tmin)	Maximum annual average temperature (Tmax)	Annual Average Temperature [(Tmin + Tmax)/2]
1971	14.25	24	19.13
1972	14.85	24.64	19.75
1973	15.04	25.26	20.15
1974	14.15	24.93	19.54
1975	13.81	24.72	19.26
1976	14.69	24.7	19.7
1977	15.15	25.01	20.08
1978	14.72	25.1	19.91
1979	15.26	25.41	20.33
1980	14.79	25.42	20.1
1981	15.15	24.96	20.06
1982	15.14	25.11	20.13
1983	15.5	25.32	20.41
1984	15.46	25	20.23
1985			20.23
1986			20.29
1987	16.11	25.56	20.83
1988	15.88	25.05	20.47
1989	15.43	24.78	20.11
1990			20.34
1991			20.4
1992	15.81	25.37	20.59
1993	15.79	25.44	20.62
1994	15.64	25.2	20.42
1998	16.05	25.89	20.97
1999	15.57	25.28	20.43
2000	15.68	25.51	20.59
2002	15.87	26.02	20.95
2003	15.82	26.11	20.97
2004	15.69	26.19	20.94
2005	15.63	26.47	21.05
2006	15.13	26.14	20.63
2007	14.84	27.03	20.93
2008	14.36	26.37	20.37
2009	15.22	26.54	20.88
2010	16.01	26.37	21.19
2011	15.53	25.79	20.66

2012	15.91	26.46	21.18
2013	15.95	26.45	21.2
2014	15.95	25.59	20.77
2015	15.83	26.17	21

APPENDIX 4: MONTHLY AVERAGE PRECIPITATION IN THE FOUR CONSIDERED METEOROLOGICAL STATIONS

Table 22: Kigali aero station precipitation records in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1964	47.2	208.6	116.1	286.9	34.2	42.1	27.7	23.7	5	109.2	75.9	112.8
1965	30.4	91.8	262.3	255.4	79.2	11.3	0	36.2	90.6	128.5	167.7	62.5
1966	85.1	85.3	118.4	141.9	33.8	20.9	0	33.7	61.8	75.7	91.8	40.1
1967	30.1	47.9	102.1	100.5	112.8	72.6	0.1	5.4	104.2	138.8	135.3	100.5
1968	59.3	327.4	130	148.9	99.3	38.8	22.9	0.5	8.4	81.1	176.4	54.4
1969	74.2	136.1	83	145.5	134.5	0	0	6.5	32.5	53.2	110.1	24.2
1970	159.8	74.8	150.7	188.8	83.6	3.3	4.7	55.5	29.7	51.5	166.7	84.3
1971	35.4	65.8	84.9	165.4	129	0	17.9	56.1	79.4	56.6	125.3	92.8
1972	62.2	193.7	110.8	92.5	111.7	58.8	0	35.7	88.7	111.2	219.7	69.2
1973	26.4	127.9	99.5	162.4	121.9	0.5	0	31.8	127.6	87.1	126.9	91.1
1974	20	76.8	139.5	114.7	80.9	102.4	28.9	1.9	68.9	49.3	101.1	80.5
1975	43.1	45.3	67.3	124.6	80.7	1.7	54.6	4.7	149.8	165.6	43.6	117.2
1976	94	89.6	77.5	102.6	56.9	29.1	0.4	60.8	82.2	29.8	79.8	153.9
1977	59.4	67.5	115.4	189.6	91.4	17	3.2	29.4	82.6	45.1	158.6	148.3
1978	84.1	145.7	175.5	168.3	97	11.2	0	23.3	57.6	86.6	82.8	137
1979	135.1	93	107.6	234.7	73.3	24.7	0.4	31.1	25.4	99.9	168.9	123.9
1980	68	133.4	96.9	130.7	131.5	14.1	1.2	5.7	193.7	74.9	151.9	71.9
1981	113.1	136.6	142	220.1	63.9	0.3	0	135.5	86.2	100	93.7	75
1982	63.9	40.6	47.9	211.9	133	17.5	3.3	3.9	101.4	126.8	111.9	125.9
1983	30.5	78.7	60.1	202.3	25.4	60.3	1.3	27.8	45.5	139.7	142.6	102.9
1984	59.8	112.2	97.3	201.3	28.6	0.4	59.1	55.6	39.1	130.3	130.8	82.7
1985	60.7	60.9	98.2	317.1	48.5	1.6	1	4.4	101.5	113.3	190.2	37.7
1986	66.6	103.6	90.2	273.5	81.3	8.3	0	0.4	12.1	87.6	109	120.8
1987	75.5	103.8	98.7	158.9	213.9	25	0	11.3	101.3	98.5	212	33.5
1988	120.3	117.4	174.8	122.9	149.2	0	15.1	97.1	77	126.5	126.8	70.9
1989	84.8	62.4	91	272.8	77.3	21.4	1.7	48.6	49	103.7	90.5	133.2
1990	74.6	139.3	136.3	190.9	39.1	0	0	13.7	155.4	108.3	80.3	121.1
1991	67	95.2	82.5	139.8	180.1	18.4	10.5	27	51.6	146	67.2	52.5
1992	46.4	48.9	94.1	140.6	43.2	28.7	1.3	1	57.8	86.7	53.7	84.8
1993	128	89.2	65.5	88.6	119.9	8.7	0	67.1	22.7	34.4	121.3	28.8
1994												
1995	76.4	57.7	119.8	155.2	114	63.9	0	1.1	74.7	131.1	139.7	46
1996	42.2	97.1	136.4	124.9	42.4	45.6	36.5	95	80.3	52	67.6	28.3
1997	116.3	45.4	98.8	171.1	59.8	67.3	6.2	40.6	11.7	166.8	147	134.1
1998	141.9	200	161.3	93.3	222.7	35.8	8.7	41.7	85.1	107.1	122.1	54.6
1999	64.4	18.3	218.2	121.8	43.9	0	0	64.4	77.8	48.9	106	104.3

2000	22.1	58.2	100.7	84.1	51.3	0	0	5.4	32.6	129.2	144.2	76.3
2001	80.3	60.8	257.3	84.3	61.4	0.2	120.8	21.8	86.1	225.9	185	98.9
2002	155	65.7	98.9	156	145.6	0	0	0.2	34.6	99.7	116.5	131.7
2003	60.3	29.8	74.6	121.7	49.9	0	0	65.1	147.5	106.7	101.1	49.5
2004	67	71.8	114.3	201.4	23.1	4	0	15.1	74.6	70.7	75.8	82.8
2005	64.6	41.8	134.3	91.6	88	10.3	0	41.6	112.4	128.2	55.3	30
2006	22.7	90.6	112.2	218	117.8	5.3	14.5	25.1	35.4	57.4	210.2	141.4
2007	53.1	161	40.6	134.7	124.5	39.5	65	21.2	68	163.9	125.3	50.9
2008	76.7	73.5	154.8	115	63	58.9	7.4	13.3	34.5	64.8	55.5	39
2009	103.6	183.5	97.4	116.9	99.4	0	0.8	14	21.1	132.1	122.7	69.1
2010	133.3	315.7	120.6	135.1	88.6	40.8	0	4.3	87	128.1	79.6	87.7
2011	71.5	60.4	115.8	123.8	55.3	50.7	1.8	61.7	83.9	137.1	112.6	51.6
2012	28.3	70	109.7	184.4	222.3	13.9	0	47.2	61.3	97.9	170.6	74.3
2013	63.2	72.4	213.5	137.3	35.4	0	0	6.7	97.2	98.6	231.9	115.2
2014	40.5	101.1	79.5	73.3	32.1	29.1	12	70.7	54.3	126.7	117.8	76.9

Table 23: Ruhengeri Aero station precipitation records in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	88.9	124.6	171.5	187.4	143.8	37.8	0.4	48.3	119.4	185	134.5	106.6
1979	158	87.5	117.8	151.4	145	71.7	7.4	55	79.7	169.5	141.4	105
1980	38.7	118.2	75	132.3	253	37.3	0.7	71.9	141.7	171.3	161.8	70.5
1981	73.4	52.6	156.5	133.9	188	29.7	18.7	81.5	125.6	144.6	110.2	79.3
1982	84.5	57.1	111.9	311.5	136.9	108.2	1.3	75.6	139.7	147.5	95	106.7
1983	6	65.1	129.5	256.9	58.7	31	26.2	75.3	164.6	208.7	175.4	64.5
1984	42.7	92	132.9	165.3	25.3	0.9	89	58.1	52.9	173.3	172.5	67.6
1985	84.1	34.4	104.2	191.3	156.8	43.7	16.2	19	144.5	151.1	176.2	70.5
1986	66.5	95.3	161.3	161.3	132.8	56.7	0	8.7	74.5	154.1	172.2	72.6
1987	79	56.6	162.8	162.9	238.3	57.4	0.1	66.7	136.6	230.5	269.8	87.2
1988	62.9	114.5	195.9	215.7	242.4	5.2	49.4	83.6	167.5	218.6	107.7	66.6
1989	23.6	75.7	169.1	111.6	158.6	62.4	15.2	45.8	131.3	159.5	123.1	98.9
1990	40.8	144.3	94.9	256	119.7	1.9	0	69.2	160.4	136.4	135.8	126.6
1991	77.2	119	113.6	139.8	142.2	35.6	27.3	2.8	134.1	241.7	134.1	48.1
1992												
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003	82.4	36.4	99	205.9	192.8	41	26.8	71.9	120.3	139.7	126	64.9
2004	111	159.8	154.2	173.7	119.3	0.8	36.4	28.7	104.6	88.3	109.2	66.6
2005												
2006												
2007												
2008												
2009												
2010	77.5	177.8	279.9	193.3	196.6	82.4	13.5	20.9	180.4	159.9	200.5	119.4
2011	109.3	84.9	150.7	172.5	192.4	63.2	43.7	118.4	176	184.8	151.2	100.7
2012	11.2	127.1	102.5	285.4	257.4	14.3	4	115.2	201.9	188.5	131.8	166.1
2013	64.5	75.4	226.9	224.6	147.9	3.2	0.6	45.5	125.4	99.9	163.2	164
2014	48.3	72.1	174.4	169	74.6	40.8	40.8	141.6	106.4	212.3	211.9	100

Table 24: Byimana station precipitation records in mm

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1959	84.6	84.2	145.9	149.2	188.4	6.3	0	30.4	53.3	171.4	233.9	203.1
1960	112.2	97.6	137.3	273.7	39	1.6	3.5	25.2	52.5	110.2	71.7	45.2
1961	69.3	121.2	150.9	96.5	99.2	2.1	7	0.8	120.7	144.6	222.2	199.3
1962	168.5	31.4	130.4	123.2	199.3	15.5	18.4	93.4	104.4	272.4	124.2	131.1
1963	167.4	99.9	80.2	205.7	402.4	47.5	0	43.8	146.7	33.7	110.8	205.9
1964	93.4	162.5	106.5	272	68.7	42.3	66	22.1	44.5	134.8	144.6	70.4
1965	87.9	69	102.4	282.9	141	8	0	42.5	103.7	111.5	146.4	78.1
1966	30.7	164.5	163	179.8	61.9	22.7	0	100.8	72.2	65.2	136.4	65.2
1967	40	63	111.3	169.3	283.6	49.4	24	7.8	130	30.9	143.4	193.9
1968	128.1	171.5	213.8	187.8	91.6	67.8	8.8	0.2	36.7	55.4	170.6	96.1
1969	88.9	85.7	123.1	121.7	135.4	1.4	0.3	0	65.5	65.3	106.9	44.2
1970	265.2	152.7	170.9	232	56.3	19.7	17.3	56.2	56.8	103	169.2	64.4
1971	103.7	132.3	80.8	193.3	197.6	0	16.8	126.6	51.6	42.9	115.2	121.2
1972	63.3	225.2	68.3	84	103.2	111.5	0	35	52.2	106.9	223.4	83.4
1973	85.5	104.2	84	258.9	232.7	4.7	0	36.4	204.8	105.3	189.5	73.1
1974	69.5	32.6	276.5	173.3	202.4	105.9	87.9	7.8	84.7	34.5	121.7	55.4
1975	136.5	82.6	73.9	231.8	142.7	3.4	52.4	14.6	135.2	151.1	92	160.5
1976	84.9	99.6	113.9	118.5	143.6	31.5	0	82.6	90	94.6	74.3	82.5
1977	116.3	87.2	105.4	237.4	98.6	7.2	5.5	66.3	119.3	121.7	161.6	109.2
1978	125.2	85.1	237.1	173	127.8	22	0	39.5	37.1	55.4	106.1	106.9
1979	210.1	150.3	36.3	185.6	234.7	52.3	0	21.5	5.5	28.8	140.9	129.9
1980	81.9	96.9	86.2	204.5	160.1	3.8	0	8.9	153.6	110.4	182.9	122.5
1981	62.2	69.7	150.2	186.9	174.2	0.2	0	148.8	107.5	79.7	62.4	77.4
1982	68.2	83.3	45.3	247.5	224.6	41.3	0	6.1	89.9	89.1	163.6	240.9
1983	12	200.7	131.4	283.7	70.5	3.3	18.6	36.7	46.4	124.7	177.4	151.4
1984	78	88	97.5	181.5	26	0.2	65.9	42.2	24.9	171.6	149.1	68.9
1985	83	126.7	163.7	263.9	65.8	30.6	0	0.2	181.8	116.5	157.9	143.3
1986	169.6	155.4	128	412.8	183.6	51.2	0	25.1	43.1	145.5	97.5	130.1
1987	153.1	222.6	111.5	190.5	220.7	87.4	0	32.8	167.7	163.3	344.3	80.8
1988	90.3	172.3	216.6	218.4	113.1	4.6	0.3	105.4	91.7	97.4	102.9	56.1
1989	143.5	160.5	190.5	220.4	153.5	53.9	21.1	57.9	38.9	76.9	65.2	143.4
1990	65.9	120.9	191.3	187.2	59.2	0	0	24.4	88.9	90.8	136.5	110.3
1991	140.1	140	125.1	120.3	152.9	53	14.5	31.2	37.9	99.6	64.9	135.5
1992	107.8	86.5	178.5	161.1	119	89.4	1.9	1.7	83.2	169.3	103.3	149.9
1993												
1994												
1995												
1996												
1997												

1998												
1999												
2000												
2001												
2002												
2003												
2004												
2005												
2006												
2007												
2008												
2009												
2010												
2011	157.5	86.4	69.8	76.2	57.2	193.7	13	31	75.2	114.1	240.4	120.5
2012	11.7	74.8	70.2	281.3	168.9	16.6	6.5	54.4	63	123.1	138.5	108.1
2013	87.8	27	260.8	170.8	125.4	0.4	0.2	59.5	164.9	65.3	78	204.7

Table 25: Kamembe Aero station precipitation records in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1958	55.9	117.1	204.4	135.8	131.3	20.1	1.7	116.8	86	113	185.7	139.8
1959	192	111.8	153.7	215.6	83.8	6.1	2.3	43.9	133.5	180.2	202.8	155.3
1960	108.8	206.6	263.6	167.6	105.9	4.5	0	28.1	87	198.9	170.9	87.9
1961	97.5	262.3	145.5	268.3	51.3	5.1	5.8	0.8	179.5	192.4	169.7	152.6
1962	80.6	112.8	179.2	226.4	170.5	56.2	3.6	55	120.3	206.2	148.1	181.8
1963	278.9	128.5	157.8	255.4	189.3	10.8	2.6	7.5	120.3	91.3	178.4	236.1
1964	141.4	158.6	102.5	177.8	110.9	19.4	1.6	54.3	33.9	170.4	195.1	104.4
1965	28	155	229	199.3	59.1	34.3	0.4	8.2	134.7	161.5	186	134.7
1966	170	200.4	169.1	184.4	83.6	12.6	0	51.6	116.1	152.5	96.1	160
1967	176.9	110.5	191.4	140.1	196.7	45.1	1.6	0.9	191.6	166.6	234.7	120
1968	115	151.2	157.4	110.3	88.8	40.9	2.3	0	82.2	237.7	219.2	167.2
1969	260.2	122.9	180.3	106.8	115.2	1.9	7.9	7.9	85.5	174.7	132	126.5
1970	139.8	172.7	200.3	190.8	82.3	12	50.8	74.6	54	82.1	179.8	126.2
1971	192	102.6	126.6	172.5	122.2	0.4	22.1	65.5	101.6	150.1	219.3	166.4
1972	103.3	145	165	93.6	105.1	79.5	0.2	43.6	183.1	197.4	189.7	210.4
1973	193.7	119.6	91.1	176.4	112.7	23.6	0.1	0.8	250.1	109.6	148.4	109.1
1974	98.4	81.9	140.2	114.7	112.7	52.1	55.7	6.5	73.6	134.6	239	84.6
1975	199.6	211.8	113.2	264.2	75	31.3	30.8	11.3	133.1	204.9	178.2	144.9
1976	81.7	125.8	147.6	292.5	79.1	40.6	0.3	79.2	145.6	148.8	142.6	162.8
1977	173.8	157.3	123.8	170.8	89.7	33.2	14.6	110.2	93.3	120	238.5	80.5
1978	91.3	97.3	253.4	124.2	87	44.9	1.2	113	117.2	175.6	238.5	167.3
1979	73.5	109.5	164	137.9	144.6	44.3	14.4	14.8	120.1	130.5	167.3	144.9
1980	129.5	75.2	165	110.3	177.5	40.1	3.7	2.4	133.2	171.9	204.8	175.8
1981	195.6	204.5	168.1	97.3	105.7	48	2.3	100.5	122.1	178.5	144.7	132.6
1982	179	101.6	108.1	159.9	86.1	44.1	0	34.9	148	236	224.2	113.2
1983	67.1	140.7	296.7	245.1	81.5	24.2	2.6	120.1	69.6	190.9	182.3	186.6
1984	139.3	159.5	179.3	189.7	19.6	0.4	33.1	52.9	62	112.3	254.9	127.8
1985	106	136.5	221.1	252.5	48.1	60.2	1.8	3.5	115.5	159.3	165.3	152.8
1986	121.1	129.5	215.6	232.8	63.3	20.3	0.2	0.8	94.1	211.6	114	125.6
1987	113.9	184.1	213.8	142.9	179	47.5	0.2	29.4	128.3	143.6	202	49.6
1988	124.3	215	218.1	177.9	91.4	23.3	15.7	121	149.4	162.7	168.2	94
1989	313.7	169.8	303.9	87.5	89.7	9.8	14.5	57.3	136.7	262.3	191.4	140.8
1990	150	221.7	208.1	137.4	81.8	8.5	0	41.4	159.6	148	155.1	105.8
1991	198.1	166.2	228.9	161.7	117.5	33.4	14.5	2	77.7	237	187.5	110.5
1992	92.8	138.9	174.5	129.7	66.8	33.3	0	0	55.6	236.2	166.6	106.2
1993	183	123.6	118	196.3	76.7	21.3	0	38	108.2	92.1	134.1	188.4
1994												
1995												
1996												

1997												
1998												
1999	125.7	64.3	191	126.2	36.2	0	0.3	96.8	119.1	178.4	147.2	95.4
2000												
2001												
2002												
2003	107.6	100.8	98.3	117	166.5	18.1	3.7	57.9	93.1	97	187.7	107.8
2004	142.3	102.7	97.6	167.8	25.3	0	8.1	30	116.9	122.1	169.5	170.7
2005	183.2	94.2	180.1	65.6	148.2	68.2	0	25.2	85.9	126.4	127.6	108.5
2006	131.6	164.4	195.7	110.5	175	7.4	41.5	57.4	87.6	101.3	206.5	123.8
2007	170.5	142.6	120.6	125.5	52	38.1	4.3	35.1	85.5	197.4	157.7	153.9
2008	98.8	166.9	238.9	90.1	97.6	75.4	17.6	95.3	63.8	216.4	162.9	158
2009	135.4	174	168.7	160.7	137.3	10.1	9.8	31.6	166.1	224.8	201.4	130.9
2010	136.3	141.4	149.8	146.2	104.3	24	1.5	21.5	116.6	102.3	82.8	96
2011	214.7	190.4	185.8	162	77.1	81.4	81.4	56.9	113.7	210	113.6	257
2012	54.2	98.9	230.2	281.4	125.7	36.3	0	76.9	163.5	222.5	151	165
2013	137.8	133.9	298.2	61.7	105.5	0.6	0	21.3	193.5	92	247.9	145.9