INTER-ANNUAL TEMPERATURE VARIABILITY AND PROJECTIONS ON ITS IRISH POTATOES PRODUCTION IN RWANDA

(Case study: MUSANZE and NYABIHU Districts)

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A thesis submitted in partial fulfillment for the award of the degree of Master of Science in the School of Science and Technology of University of Rwanda

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DECLARATION

I **Rukundo Emmanuel** declare that, this thesis is my original work and has not been Presented/submitted for a degree in any other University or any other award.

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Signature.. Date..

I confirm that the work reported in this thesis was carried out by the Student under my supervision.

Prof. Bonfils Safari

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Signature... Date..

DEDICATION

I dedicate this thesis to my parents who educated and taught me that there is no other way leading to the richness except to converge to school together with obeying God.

ACKNOWLEDGEMENT

Foremost, this thesis is a result of the contribution of many peoples to whom I express my deepest gratitude. I am forever indebted to all of you who made my master's journey possible.

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LIST OF ABBREVIATIONS

GDP: Gross Domestic Product

SOND: September-October-November-December

MAM: March-April-May

GCM: Global Climate Model

CDT: Climate Data Tool.

DRC: Democratic Republic of Congo

VNP: Virunga National Park

MAGICC: Model for the assessment of Greenhouse gas induced Climate Change

RCPs: Representative Concentration Pathways

Tmax: Maximum Temperature

Tmin: Minimum Temperature

DRC: Democratic Republic of Congo

VNP: through Virunga National Park

IBM SPSS 23: Statistical Package for the Social Sciences

GCM: Global Climate Model

RAB: Rwanda Agricultural Board

MINAGRI: Rwanda Ministry of agriculture and Animal resources.

IPCC: Intergovernmental panel for climate Change

MT: Metric tones

SRES: Special Report Emission Scenarios

GHGs: Green House Gases

NISR: National Institute of Statistics Rwanda

ABSTRACT

This study analyzed the inter-annual Temperature variability on potato production in Rwanda especially in Nyabihu and Musanze districts, the overall objective was to investigate the annual Temperature variability, projections and impacts on production volumes of Irish Potatoes to assess the information gaps that should otherwise be tailored for general famers**.** Specific objectives were to assess the annual Temperature variability and trends factors of temperature and Irish potato production volumes per district of the area of study, to identify the correlation of Irish potato production associated with temperature variability and to identify how the future will unfold based on the past behaviors

Primary data on daily Tmax and Tmin from 2007 to 2017 was collected from Rwanda Meteorological Agency' stations, where the respective stations which are Bigogwe, Jenda, Mukamira representative of Nyabihu district, Busogo, Musanze and Rwaza representative of Musanze District was sampled, Secondary data on annual potato production for both long and short rain season comprised between 2007 and 2017 were collected from RAB and NSRI. For the consistency of the good results the long rain season production was added to the short rain season production to get the annual yields in each year, again online Marksim simulated monthly present day climate data (Tertiary) were extracted and compared with the observed data to Assess the performance of Marksim model in simulating present day temperature, monthly projected data from 2010 to 2039 with the help of seventeen models were also extracted and projected with the help of RCPs to evaluate the future unfolding. The data collected were analyzed using Python, R, IBM SPSS statistics 23, CDT and Excel; the results were presented using trend lines and bar graphs, curves, radar with makers, tables and pie charts. The findings were that annual Tmax and Tmin shown an increasing trend between 2007 and 2017 and Annual potato production increase and decline in mid 2012 for both Districts, but to some extend the two variables exhibited weak negative correlation between them. Pearson's r= -0.366 for Tmax and r= -0.369 for Tmin is close to 0 followed by the P value of 0.94 for TMax and 0.91 for Tmin which bigger than 0.05 (>5% significance interval), showing that there is a weak negative correlation between the *two* variables and that change in one variable are weak correlated with changes in the second variable, meanwhile there is weak statistical correlation between annual temperature and annual potato production. the projected annual maximum and minimum temperature from 2010 up 2039 with the help of RCP 2.6, RCP 4.5 and RCP 8.5 in the studied areas shows that an increase of Tmax and Tmin will be between 1-1.3^{o}C and 0.2 -1.3 ^{o}C respectively within both Districts and this will lead to the decline of future potato production with no futher adaptation. The study recommends that Farmers should be encouraged to enhance crop diversification to caution them from temperature variability, to be focused of forecasting and to adopt cultivars that can be withstand ever to the increasing temperatures.

Key words: Correlation and projection between climate and Agriculture variables

CHAPITER I: GENERAL INTRODUCTION

1.1 Background to the study

Agriculture is at the heart of Rwanda's economy. The sector occupies 79.5 percent of the labor force, contributes one-third of GDP (Gross Domestic Product) and generates more than 45.0 percent of the country's export revenues Agriculture is also important for national food self-sufficiency, accounting for well over 90.0 percent of all food consumed in the country [1]**,** Rwandan agriculture has made major advances in the last decade. Productivity and production for a number of crops have sharply increased and improved rural incomes [2]**;** the climate variability of Rwanda is one of the most significant factors influencing year to year crop production. Even in high-technology agricultural areas, that factor remains one of the most important [3]; Rwanda is located in a tropical temperate climate due to its high altitude. The average annual temperature ranges between 16°C and 20°C, without significant variations [3] and has been experienced a temperature increase of 1.4°C since 1970, higher than the global average, and can expect an increase in temperature of up to 2.0°C by the 2030s from 1970 [4], Temperature is central to how climate influences the growth and yield of crops. The rate of many growth and development processes of crop plants is controlled by air or soil temperature. Over the last decade or so, the interests of the scientific community in the response of crops to temperature has been renewed as the evidence of a warming of global mean temperatures due to human activities becomes more persuasive. [5].

Potato was first cultivated in the Andean highlands in South America and by the end of the 16th century potatoes were brought to Spain and in the following centuries the crop spread throughout Europe, It spread to most other parts of the world from Europe, rather than directly from South America. Missionaries and colonists introduced the crop into many tropical and subtropical areas from the 17th century onwards, where it was mostly eaten by Europeans. However, food shortages often encouraged local people to include potatoes in their diet as well [6] Irish potato was introduced into Nigeria early in the 20th Century by European miners in Jos Plateau. Jos Plateau has high altitude and thus, cool climate, which is favorable for the development of the crop [7], In Rwanda Potatoes was introduced around the end of 19th century by German missionaries and latter was adapted by colonial administration as a food crop among other roots and tubers. In Rwanda, potatoes are usually grown above 2000 m, and in two growing seasons every year corresponding to the two rainy seasons of September to December (SOND) and March to May (MAM) popularly known among the farming communities as season A and season B respectively. The region where this crop is being grown is cool and moist throughout the year, save for June to August dry interval. The Potato crop when compared to other traditional crops usually grown in the same regions of Rwanda, has a relatively short vegetative cycle and exhibits high yield potential and this has made it the most suiting crop to the farming systems in those agro-ecological zones favorable to its production [8].It is a lover of cool climate and therefore requires a cool growing season with a moderate and well distributed rainfall of about 800mm during growing seasons with no prolonged dry weather. It could be grown under rain-fed condition or irrigated, but waterlogged areas are unsuitable. Temperatures higher than 27.0 C are unfavorable for the production of economic size tubers. Observations have shown that temperature ranges of 21.0C – 26.0C is required for sprouting of the tubers [9]

Temperature in Rwanda varies throughout the year with two maxima and two minima. The low maximum temperature occurs in February while the high maximum temperature occurs in August. The two minima occur respectively in June and in November. As the average temperature for Rwanda is around 20˚C, varies with the topography. The warmest annual average temperatures are found in the eastern plateau (20˚C - 21˚C) and south-eastern valley of Rusizi (23˚C - 24˚C), and cooler temperatures are found in higher elevations of the central plateau (17.5˚C - 19˚C) and high-lands (<17˚C) [10]. Although the increases in temperature patterns have been reported in past centuries, more variability and changes are projected in coming years [11]. Recent progressive increase in temperature results from global warming caused by rapid increase of greenhouse gases concentrations in the atmosphere since the industrial era [12].

An increase in atmospheric concentrations of greenhouse gases equivalent to a doubling of carbon dioxide (CO2) would force a rise in global average surface temperature of 2 °C to 4 °C by 2100, In addition, the atmospheric concentration of nitrous oxide (N2O) and methane (CH4) in 2010 was about 323.2 ppb and 1808 ppb or 20% and 158% of the pre-industrial level respectively. The impact of nitrous oxide (N2O) on climate, over a 100-year period, is 298 times greater than equal emissions of carbon dioxide. This shows the degree to which the world is exposed to more warming in future leading to rise in temperatures. This phenomenon is bound to continue in the coming years though Gerald argued that the world faced the stagnation of temperature for the period 2000-2010 [12]

The projection of temperature trends over Rwanda especially in the studied area both Musanze and Nyabihu Districts is important as it helps refine an understanding the expected changes in temperatures, with a view to predicting their impacts on expected changes on exhibited potatoes yields. The results can also be used in further exploration of the impacts of projected climatic conditions on both natural environment and human activities.

1.2. Statement of the problem

Temperature variability affect the ability to increase food production as required by the growing populations in Rwanda, creating a need to assess the Temperature characteristics that affect potato yields. It is not clear how these variations in potato yields are correlated to Temperature variations. Temperature variability is expected to be responsible cause of the variations in the potato yield in Northern Province especially Musanze and Nyabihu Districts. It is against this background that the study investigated the relationship between Temperature variability and Irish potato production volume

1.3. Study objectives

1.1.1. General objective

The overall objective of this research was to investigate the annual Temperature variability, projections on the yield and the impacts on production volumes of Irish Potatoes in NYABIHU and MUSANZE districts and to assess the information gaps that should otherwise be tailored for general farmers**.**

1.3.2. Specific Objectives

(i) To assess the annual Temperature variability and trends factors of temperature and Irish potato production volumes per district of the area of study.

(ii) To identify the correlation of Irish potato production associated with temperature variability.

(iii) To identify how the future will unfold based on the past behaviors/approaches.

1.4. Research questions

The study addressed the following questions:

(i) What have been the annual potato production, Temperature trends and variability between 2007and 2017 in Musanze and Nyabihu District?

(ii). How much of this effect (Temperature variability) is to the agricultural sector globally is largely unknown?

(iii).How does the past climate reflect the impacts based on the recent views?

1.5. Research hypothesis

Using different programming language and Statistical analysis, the study will be guided by the following hypotheses:

H0: Potato production has not varied annually between 2007 and 2017 in Musanze and Nyabihu Districts Trends Analysis.)

H1: Potato production varied annually between 2007 and 2017 in Musanze and Nyabihu Districts (Trends Analysis.)

H0: There is no significant relationship between annual Temperature variability and potato Production in Musanze and Nyabihu Districts.

H1: There is significant relationship between annual Temperature variability and potato Production in Musanze and Nyabihu Districts.

The null hypothesis shall be rejected if Pearson correlation test computed a P- value less than the significant level alpha (α) =0.05.

1.6. Justification and significance.

Musanze and Nyabihu were selected because they are major Irish potato growing divisions in Rwanda County; MUSANZE District population is occupied by agriculture production activities at an average of 91%. Three quarter of its population are in rural area and are generally farmers. The main crops available in Musanze are Irish potatoes, beans, maize, wheat, bananas, sorghum and various vegetables. [13]**.**

Also the economy of NYABIHU district is heavily dependent on subsistence agriculture, where the majority of households are smallholders, approximately 74%, or 105,672 people in 143 000 of the population of the district, derive their income from the exploitation of the soil (This done in 2013). For food, there are Irish potatoes, corn, beans, wheat and banana and vegetables as well. Irish potatoes, maize and beans are cultivated by 76.6% of households on average is 51,000 households**.** Irish potatoes are most cultivated with 83.7% followed by maize (74.3%) and beans (71.9%). Maize production represents 47.3% of the agricultural production in the district against 8.9% wheat [14]**.**Recently, there are some indications that Rwanda has been subject to climate change. Observations from the National Meteorological Service have indicated that during the last 30 years minimum temperature has risen up to two degrees (2^0C). The year 2005 was the hottest year for many years in Rwanda. Minimum temperature climbed to 20.4˚C in August and maximum temperature climbed to 35˚C in the Capital City, Kigali [15] **.**

Therefore this study will provide an understanding of the relationship between Temperature characteristics, it variability in both Districts. The study will significantly benefit the Ministry of Agriculture, Districts Agriculture Officers and Rwanda Agricultural Research Institute, Agricultural Extension Officers, Farmers Training Centre, farmers' policy makers and policy implementers in trying to mitigate seasonal variations of Temperature in the entire country**.**

1.7. Scope and limitation of the study

The study considered Temperature as the most critical element that influences Irish potato production. The study was limited to ten years data because the present names of districts is just ten years old and thus data available and arranged or collected by the present districts is only from 2007. Means of reaching to people for survey was limited by financial resources and it was expected to use both yield and production data but the yield data was found to have many gaps except production data which found with no missing value from 2007 to 2017.

1.8 Study area

Musanze and Nyabihu Districts located in Northwest Rwanda are two areas selected for this research as indicated significant level of cultivation of Irish potatoes compared to other Districts in the region (Rwanda), the Irish potato is the preliminary fed of almost inhabitants of these Districts.

1.9 Geographical information

Musanze and Nyabihu Districts are both located on Latitude and Longitude of 1^0 30' S, 29^0 36' E and 1^0 37'S, 29^0 33'E Respectively. The area is dominated by Virunga volcanic mountain ranges, a home to almost one third of the world's remaining Mountain Gorillas in the world (Volcanoes National Park Rwanda).

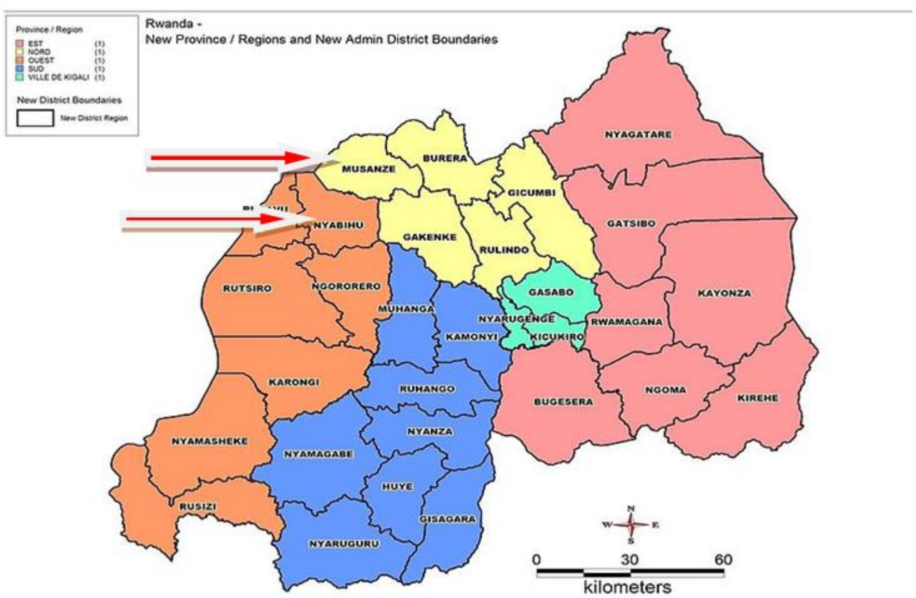


Figure 1: Country Administrative Map

1.10. Musanze geographical situation

Musanze District is one of the 5 Districts of the Northern Province boarded by: North: Uganda & Democratic Republic of Congo (DRC) through Virunga National Park (VNP), South: Gakenke District, East: Burera District, West: Nyabihu District, Virunga Park: (60 km2), Lake Ruhondo: (28 Km2) in the south west. Musanze district is divided into 15 sectors which are Busogo, Cyuve, Gacaca, Gashaki, Gataraga, Kimonyi, Kinigi, Muhoza, Muko, Musanze, Nkotsi, Nyange, Remera, Rwaza and Shingiro. These sectors are split into 68 cells (with an average of 5 cells per Sectors) and 432 villages (average of 29 villages per sector). The current population is 368, 267 with a density of 694 habitant/Km2 (2012) [16]

Figure 2 : Musanze Administrative Map

1.11. Nyabihu geographical situation

Located in the Western Province of Rwanda and in the west part of the country, Nyabihu District has 12 sectors that are Bigogwe, Jenda, Jomba, Kabatwa, Karago, Kintobo, Mukamira, Mulinga, Rambura, Rugera, Rurembo, and Shyira. These areas are themselves divided into 73 cells and 473 villages. Taking into account its administrative limits, in the north there is Musanze district and the Virunga National Park, which separates it with the DRC. In the South, there 6 is Ngororero and Rutsiro Districts, and in the East there is Gakenke and Musanze Districts. The characteristic of the soil is sandy and clay, laterite and volcanic. It is very fertile. Precipitation is almost uniformly over every month and close to 1400 mm per year. It has a temperate climate with an average temperature of 15^0 C favorable for the growth of the agro-pastoral products throughout the year with less risk of development of bacteria and diseases [17]

Figure 3: Nyabihu Administrative

Map Source: www.nyabihu.gov.rw

CHAPITER II. REVIEW OF CLIMATE VARIABILITY AND THEIR IMPACT ON CROPS PRODUCTIVITY

2.0. Introduction

In this review we emphasize on relevant study on climate variability in the past periods and their impacts had on the agriculture whether dwindled the crops production or not especially on the Irish potatoes. Many studies have investigated how the warmer temperatures and elevated atmospheric CO2 concentrations expected under climate change scenarios affect crop plants In general, an increase in mean seasonal temperature of 2–4◦C reduces the yield of annual crops of determinate growth habit, such as grown in well-watered conditions. Much of this decline in yield is due to shorter crop durations at these warmer temperatures. Nevertheless, this decline is expected to be countered by the enhancement of the rate of photosynthesis under future conditions of elevated atmospheric CO2 concentrations [5, p. 159]

2.1. Climate and weather variability

2.1.1. Does the climate change differ from climate variability?

There is a fundamental difference between climate change and climate variability. Climate change constitutes a shift in meteorological conditions that last for a long period of time while climate variability is short-term fluctuations happening from year to year or seasonally. Climate change, resulting from the effects of increased greenhouse gas emissions, poses greater threats by combining higher temperature, less available water in regions where it is most needed and more frequent and intense extreme weather events [18]

2.1.2 Climate variability (temperature) on potato yield

According to the studies done on effects of temperature, using some climate model, the assumptions, predicted that an increase in global average temperature was estimated to increase between 1.2 and 1.8^{o}C during the period 2010-2039. This range of temperature increase predicted is relatively higher than the predicted temperature change weighted by potato area, which is between 1.6 and 3.0^{o}C during the period between 2040 and 69 [19]. Further studies have shown that the yield when no adaptation is allowed, overall simulated global potato yield would decrease between 10% and 19%. [20]. If there is no adaptation considered, this increase of temperature will be perspective to the potential reduction of the annual yield.

2.1.3 Climate variability on production volume

Development and growth are related processes in plants. However they are also independent processes and may not occur simultaneously. Growth refers to an irreversible increase in organ mass, area, volume, height or diameter. Development refers to meristematic cell differentiation, organ initiation and appearance, and extends to crop senescence; it comprises morphological and phonological aspects. Morphology refers to the beginning and ending of various plant organs with the plant life cycle, it involves the appearance, expansion and duration of organs (i.e. leaf, stem, branches and tubers) [21].

Because of increases in temperature, future potato yields could decrease in many regions as predicted, in some regions, mainly in temperate regions(**The temperatures in these regions are generally relatively moderate, rather than extremely hot or cold, and the changes between summer and winter are also usually moderate**), yield decline can partly be avoided through adaptation. Yields may even go up at high latitudes because of a lengthening of the growing season. There is no much scope for adaptation of Irish potato production in the tropics, where there is little temperature variation during the year, and in the warmer parts of the subtropics, where potatoes are already grown in the coolest season. In much of the tropical highlands of Africa, temperature is relatively high and stable throughout the year. [20].

2.1.4 Temperature trends and potato yield.

Potato yields depend on soil, cultivation practices, and weather, in particular temperature and precipitation [22], because potatoes are grown mainly on light soils, their yielding depends on evenly distributed precipitation. A combined effect of temperature and precipitation is crucial [23], High temperature can decrease yield due to physiological and biochemical changes occurring in the plant, such as photosynthesis, respiration and water status. A negative impact of too high temperature can, however, is partially reduced by evenly distributed optimum precipitation. The optimum precipitation for early potato ranges from 250 mm to 350 mm Precipitation higher than this optimum leads to yield loss as it prolongs germination and sprouting, and increases disease incidence [22], As climate is changing all the time, studying the effect of weather on potato yield is gaining more and more importance in terms of potato adaptation to environmental conditions. According to various studies, potato responds to improved moisture conditions [24].

2.1.5 None weather variables

Cash constraints and small land sizes are the two most important factors that inhibit realization of higher farm incomes and optimal production at farm level [25]

2.1.6 Factors driving Irish potato crop development

Temperature has been described as the primarily factor driving plant morphological and phonological development, other factors including day length and water stress may delay development in some plants. In potato, phonological development is mainly driven by accumulated temperature and modified by photoperiod [21]

2.2 Challenges facing potato yields

2.2.1 Price fluctuation

Volatility of price will depend on multiple factors. Rwanda cities which are major trading markets daily place, price will depend on the demand of its. Prices will also depend on high fragility of the harvested crop, road conditions among others. Climate factors have their share of the market prices since they are key determinants in the quantity of the potato harvested and available for sale. A combination of these aforementioned factors generate large price fluctuations at the farm level thereby increasing the risks of a farmer entering into loses from his potato produce and reducing incentives/motivation to invest in yield-increasing technologies [8] , also we can mention Diseases and insect pests are another major constraint, Lack of efficient seed systems, Limited access to higher value markets, Inefficiency of local markets Potato prices, Lack of support to farmer organizations and entrepreneurs [26]

2.3 Conceptual framework

Weather variables and their variability affect potato growth and consequently potato yields [26] even though my study is limited to Temperature, also rainfall constitutes the main water source for crops. Rainfall characteristics such as rainfall amount, onset and cessation of rainfall, number of rain days, rainfall distribution and rainfall intensity affect potato production. to organize an appropriate time of planting and harvesting adaptation of rainfall characteristics is applied where the methods of farming and sustainable land management practices such as mulching, digging trenches and irrigation to be put in place in a growing season, There is dependency of various factors which are the application of fertilizers, application of weather forecast, scientific method, introduction of qualified seed (seeds quality) etc. The intervening aforementioned factors inform farmers on the time of planting, nature of seed to be planted and the possible threats such as pest and diseases which affect potato yields, so that they may overcame from every confusion related to the threats encountered the unharvested crops

CHAPITER III. RESEARCH METHODOLOGY

3.1 Introduction

This chapter described/structured the nature of the research since in it starting up to the end, the used methods to analyze or assess the variability of temperature endorsed by the outcomes of the real climate known in the area of study, information given by the researchers and other relevant specialists in this field of agriculture, Then source of data relevant to the study either from individual researchers, institutions of government or non- government.

3.2 Study design

Ideally, below flow diagram shows the route network structure of activities undertaken during the research period.

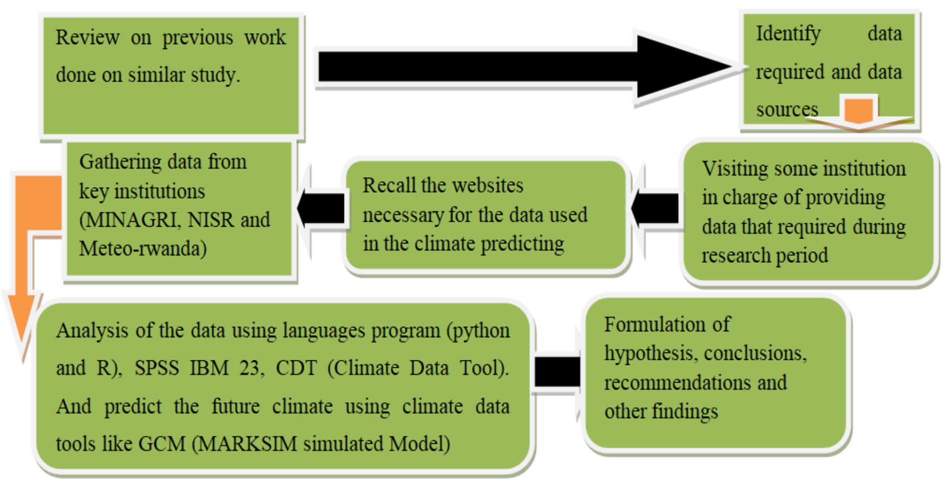


Figure 4: Study design

3.3 Data Collection Procedures

3.3.1 Primary Data

Primary data on daily Maximum and Minimum Temperature was collected from Rwanda Meteorological Agency' station (Meteo-rwanda) where the representative station which are **Bigogwe, Jenda, Mukamira** representative of Nyabihu district**, Busogo, Musanze and Rwaza** representative of Musanze District was sampled, and then were aggregated from daily to Annual with the Help of CDT for Further analysis.

3.3.2 Secondary Data

Annual Potato production datasets for both long rain season and short rain season comprised between 2007 and 2017 were collected from RAB and NSRI for both District musanze and

Nyabihu. For the consistency of the good results the long rain season production was added to the short rain season production to get the annual yields in each year**.**

3.3.3 Tertiary data

Based on past and present days analysis, The data was projected in the coming years to evaluate how the future will unfold and reflect the similar and/or different features, so that we might formulate the measures to mitigate the issue accordingly, therefore online Marksim simulated monthly climatic data from 1983-2010 were extracted and Compared them with the observed data and Marksim simulated temperature climatology of the area studied to Assess the performance of Marksim model in simulating present day temperature and projected data from 2010 to 2039 were extracted with the help of seventeen models which are BCC-CSM1-1, BCC-CSM1-1-M, CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MRI-CGCM3, NorESM1-M and projected with the help RCPs (RCP 2.5, RCP 4.5 RCP 8.5)

3.3.4 Instrumentation

Below method illustrated the fully way used for good achievement of the purposes of the study.

1. Consulting institutions such as Rwanda Meteorology Agency (Meteo-Rwanda), Rwanda Agricultural Board (RAB), among others Like MINAGRI etc...

2. Consult authoritative documents such as policy documents and project documents geared towards improving growing and export of Irish potato crop in Rwanda.

3. Consult district agronomists for information related to agronomy.

3.3.5 Quality of the data

Production of high quality statistics depends on the assessment of data quality**.** [27] By Definition Contrary to popular belief, quality is not necessarily zero defects. Quality is conformance to valid requirements. In defining quality, we must determine who sets the requirements, Determine how the requirements are set and determine the degree of conformance that is needed [28].

Figure 5 : Six core data Quality Dimension [29].

3.3 6 Degree of Conformance

The degree of conformance must then be set. The degree of conformance represents the tolerance level for errors. Data quality is then established by knowing whether or not the target has been achieved. [28].

3.3.7 Verification and validation of data

Verification mean assessing data accuracy, completeness, consistency, availability and internal control practices that serve to determine the overall reliability of the data collected, whereas Validation is assessing whether data collected and measured are a true reflection of the performance being measured and having a clear relationship to the mission of the case studied [30]

3.4 Data analysis procedures

Trend, Correlation, Temperature variability, comparative trends were drawn Using IBM SPSS statistics 23, python, R and CDT, trend test were carried out on annual maximum and minimum temperature basis and annual potato production data between 2007 and 2017 in both Districts. Simple line graphs on annual Maximum and minimum temperature and potato production was generated and the trend line was drawn to determine the significance of the trend. Trend analysis aimed at determination of the relationship/correction of temperature and potato production data in the District of study. Also Marksim simulated model were used for Tertiary data during Temperature projected data extraction but the analysis was also done with python.

CHAPTER IV: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter aimed to discuss the results of the findings and interpret data gathered in the study, the findings will be based on the objectives of the study. The first section discusses the Annual Trends and variability of Maximum and minimum Temperature and potato production. The second section discusses the comparative trends analysis, Temperature characteristic analysis and the correlation of annual Maximum and minimum Temperature with the Irish potato production, finally the third section covered the outputs from projection on climate variables compared to agriculture variables and then come up with outputs, findings and conclusions.

4.2 Annual temperature trends

4.2.1. Annual Trend of Maximum Temperature

Although the trend did not statistically show significant changes, nonetheless, the results showed a general increase in Maximum Temperature over the years, the results in (*Figure 6*, see addendum), shows that annual maximum Temperature amount has increased between 2007 and 2017 in Musanze and Nyabihu Districts as shown by the trend line. Generally Peaks are noticed in 2010, 2015 and 2016 within the entire Districts (all Rwaza Stations) while dips are noticed in 2009, 2011 and 2014 in similarly to all stations .referenced to the linear trends Nyabihu shown an increase of Maximum temperature of 0.4^0C/year while Musaze shown an increase of 0.2^0C/year. Note that Bigogwe**,** Jenda and Mukamira stations represent Nyabihu District and Busogo, Musanze and Rwaza stations represent Musanze District. The argument to support this increase of Temperature, Hijmans According to the climate scenarios considered in his study, he concluded that the increase in global average temperature will be between 1.2 and 1.8^0C in the 2010-39, and this increase is higher than the predicted temperature this argument is supported by Robert J. change weighted by potato area, which is between 0.9 and 1.7^0C for 2010-39. [20]. The argument from the IPCC report reviewed they concluded that the earth's climate temperature is increasing and the temperature change is a natural, cyclic occurrence driven by solar activity, where controlling anthropogenic greenhouse gases, including CO2, will not stop temperature change, if the temperature change is due to solar activity [31]

4.2.2. Annual Trend of Minimum Temperature

It is clear that the annual minimum Temperature reflect the similar features as those of maximum Temperature as both shown general increase in trends through the years (*Figure 7*, see addendum). It is clear that generally the significant peaks occurred in 2010 and 2016 for all stations and dips occurred in 2011 for the entire stations. Generally as Musanze and Nyabihu are neighboring Districts each other, there is no significance difference in the level of minimum Temperature increase as Musanze shown an increase of 0.5^0C/year similarly to Nyabihu with an increase of 0.5^0C/year the reason of this increase can also be supported by Hijimans argument in his scenarios as aforementioned in section 4.1.1 [20].note that Both Districts are dominated by Virunga volcanic mountain ranges [13] with a cool climate through the year where this increase in minimum temperature cannot be expected.

4.3. Trend of potato production

4.3.1. Musanze and Nyabihu Annual Trend of potato production in MT

The studies as shown on (*Figure 8*, see addendum) found that Potato production have increased between 2007 and 2012 in Musanze followed by decline in the rest of years as shown by the variation curve, for Nyabihu Peaks are noticed in mid of 2013 constantly up to 2014 in , while dips are noticed in 2015 in both Districts. The peaks in 2011 and the mid 2013-2014 are due to favorable maximum and minimum Temperature as shown on both figures. The dips in 2015 in both Districts where the fall of production started in 2014 can be explained by the unfavorable Tmax and Tmin or others adverse effects where in the same year both Maximum and Minimum started to rise at the significant level; we can mention Diseases and insect pests are another major constraint, lack cleen seed [26]. The observations have shown that temperature ranges between 21.0C – 23.0C is required for sprouting of the tubers [9], thus this increase is clear and significant.

4.3.2 Musanze and Nyabihu seasonal Trends of potato production in MT during long rain season

From the findings shown in the (*Fig 9*, see addendum) Musanze and Nyabihu shown both significant increase and dwindling of potato production during FMAM season, In Musanze Peaks were noticed in 2012 followed by a significant decline in the rest of the years and the dips were noticed in 2010, In Nyabihu, the peaks were noticed in 2012, 2013 and 2014 while dips were noticed in 2011. Generally the peaks can be explained as the results of favorable maximum temperature and The dips Among reasons of production decline can be suggested by the unfavorable weather as a big determining factor, water logged as it was in long rain season, pests and diseases, lack organic manure, mineral fertilizers, Quality of seed, timely planting, crop rotation can also be mentioned as among those factors that impact on yield as well, [26].

4.3.3. Musanze and Nyabihu seasonal Trend of Potato production in MT during short rain season.

From the findings shown in the (*Fig 10*, see addendum) during SOND Musanze, shown an increase of Potato productions between 2007 and 2012 followed by constants between 2012-2014 and then decline from 2014 to 2017. Peaks were noticed in 2012, while Nyabihu shown an increase from 2007 to 2011 followed by a decline through the rest of the years. Dips are noticed in 2015 in both Districts and the peaks in 2012 and 2011 as the results of favorable maximum temperature while the dips in 2015 were the results of unfavorable temperature and pests and diseases, lack organic manure, mineral fertilizers, Quality of seed, timely planting, crop rotation can also be mentioned as among those factors that impact on yield as well, [26].

According to the Annual trend analysis done on potato production, H_0 cannot be rejected as the annual Tmax and Tmin varied between 2007 and 2017 and the trend line shown the positive trends for both Districts but contrary to the potato production which shown a significant decline in the mid of decade (2007-2017), where there is no need of drawing the trends line because the increase and decrease were clear with naked eye.

4.4. Temperature variability (Using Temperature variability index)

Climate extremes can be defined as climatologically rare events (infrequent) but also based on how they affect the society and the environment. There are climatologically rare (i.e. extreme) events that have little impact on society (e.g. high air pressure), and climatologically not so rare events that still may have considerable impacts (e.g. heavy snowfall, freezing rain, or windstorms). It is therefore important to know the limitations to ability for society and environment to cope with climate extremes without serious stress [32]. Table 1 and table 2 in addendum illustrated the important indices in this study, to list most but not necessarily.

Musanze is exposed to more risk compared to Nyabihu *(Fig 11, see addendum*), all extreme indices (**SCDI, DRT, GSL, TNn, TNx, TXn, TXx and WSDI)** are counted on high rank, 2017 was not computed because of the datasets ended in June 2017 and 2012 was found to be the one shown the significant phenomena of extreme indices (7 consecutive days of dry spell, high TXx of 26.63^{o}C and 28.97 ^{o}C for Nyabihu and Musanze respectively among the years compared to others.)

4.5. Comparative trends analysis.

4.5.1. Nyabihu Annual mean maximum Temperature and Annual potato production

Nyabihu Temperature Climatology: Maximum daily average temperature is 20.1 ^{0}c, Absolute Maximum is 28^{0}c and minimum average is 10.5^{0}c, the temperature range is suitable for Irish Potato growing which is sharply inhibited below 10^{o}C and above 30^{o}C Absolute minimum temperature is 8.5^{0}c between June and July. Probability of below 10^{0}c stands at 31%, implying that frost could be a problem. Mean monthly variability attains maximum temperature in February. [33]

Generally from the findings on the (*fig 12.1 and 12.2, see addendum)* it is clear that sharp increase in maximum Temperature with R^2 =0.585 in 2014 lead to the decline of annual potato production in the same year, from the IPCC report, The earth's climate temperature is increasing and The temperature change is a natural, cyclic occurrence driven by solar activity, where Controlling anthropogenic greenhouse gases, including CO_2, will not stop temperature change, if the temperature change is due to solar activity [31], the increase in global average temperature will be between 1.2 and 1.8^{0}C in the 2010-39, and this increase is higher than the predicted temperature change weighted by potato area, which is between 0.9 and 1.7^{0}C for 2010-39. [20].but in the years between 2007 and 2014 variation of Tmax were favorable where SOND production has increased, rain fall distribution shall be among the factors that contributed to this increase.

4.5.2. Musanze Annual means maximum Temperature and Annual potato production

Musanze Temperature Climatology January is hot, and February is the hottest month of the year with maximum up to 23.1^{0}C. The coolest months are June and July about 20.5^{0}C; the temperature of the area is suitable for the Irish Potato growing which is sharply inhibited below 10^{o}C and above 30^{o}C Minimum average is about 12.3^{0}c with minimum absolute of about 10.1^{0}c. Probability of below 10^{0}C is nil. [33] The results in (*Figure 12 3 and 12 4, see addendum)* shows that variation of Maximum Temperature causes variation on potato production in Musanze District, even though a sharp increase in annual Maximum temperature appeared to decrease annual total production as it is clear in 2012 where variation curves of Tmax goes up with decline of potato production in the same year, even though the adverse effects are wide and many including factors that affect potato yields, such as lack of clean seed, lack of water and nutrients in the soil, damage from pest and diseases [34]

4.5.3. Nyabihu Annual mean minimum Temperature and Annual potato production

As referenced above on section 4.6.1**,** Nyabihu temperature climatology indicated that average Minimum Temperature of 10.5^{0}C is suitable for growing Irish potato in the region, back to *fig 12.5* and *fig 12 1***.**Increase in Minimum temperature lead to the decline in potato production but as it is clear in 2014 where the variation curve of Tmin goes up significantly and led to the productivity decline in the same years, obviously in the previous years the Tmin were in range and the potato productivity have been increased significantly. Because of increases in temperature, future potato yields could decrease in many regions. In some regions, mainly in temperate regions [35].

4.5.4. Musanze Annual means maximum Temperature and Annual potato production.

In section 4.6.2**,** Musanze temperature climatology indicated that average Minimum Temperature of 12.3^{0}C is suitable for growing Irish potato in the region and minimum absolute of about 10.1^0 C, between 2007-2011 where the average temperature is in the range this led to the increase of productivity within the nominated years, but from 2012 to 2017 there is significant sharp increase of minimum temperature but not beyond the threshold, declination of potato production within the entire range it may be the cause different factors as mentioned in section 5.5.2

4.6. TEMPERATURE CHARACTERISTIC ANALYSIS

4.6.1 Annual Maximum and Minimum Temperature characteristic analysis

The results in *Table 3 and fig 13.1 and 13.2* shown that the result are closest similar as the District are somehow twins. Long rain season shown a significant increase of production compared to short rain season among others where the production were counted on 414.869 and 402.346 MT/annum in Musanze for moth of February and Nyabihu for month of May respectively, (note that February and May are both inclusive in long rain season), where Warm spell duration indicator (Annual count of days with at least 6 consecutive days when TX<90th percentile indicator) was 7 in Musaze and zero in Nyabihu. And Cold spell duration indicator (Annual count of days with at least 6 consecutive days when TN < 10th percentile) was null in both Districts 2012 was the year of productivity compared to other years. The peaks month of Tmax observed were in August which represented by (18%) in Nyabihu and (20%) in Musanze and February represented by (27%) in Nyabihu and (30%) in Musanze whereas the peaks months in Tmin, May is represented by (46%) in Nyabihu and (40%) in Musanze and January represented by (18%) in Nyabihu.

4.7. Correlation of annual temperature trend and annual potato production

The annual maximum, minimum temperature trend and annual potato production from the findings in *Table 5 & 6* were correlated using IBM SPSS statistic 23 to determine the significance of their relationship. When Pearson’s r is close to 1, this means that there is a strong relationship between the two variables and that change in one variable are strongly correlated with changes in the second variable. When Pearson’s r is close to 0, this means that there is a weak relationship between the two variables and that change in one variable are not correlated with changes in the second variable The P value is defined as the probability under the assumption of no effect or no difference (null hypothesis), of obtaining a result equal to or more extreme than what was actually observed [36].

4.7.1. Correlation of annual maximum temperature trend and annual potato production

From the findings on *Table 6***,** Pearson’s r= -0.366 is close to 0 showing that there is a weak negative correlation between the *two* variables, as one variable decreases in value, the second variable Increases in value. From the findings the Sig. (2-Tailed) value 0.94 is bigger than 0.05 (>5% significance interval), meaning that there is weak correlation between Tmax and potato production.

Table 1: Correlations

Correlations

		Production	Tmax
Production	Pearson Correlation	1	-.366
	Sig. (2-tailed)		.094
	N	22	22
Tmax	Pearson Correlation	-.366	1
	Sig. (2-tailed)	.094	
	N	22	22

4.7.2. Correlation of annual minimum temperature trend and annual potato production

From the findings *on Table 7*, Pearson's r= -0.369 is close to 0 showing that there is weak negative correlation between the two variables and that change in one variable are negatively correlated with the second variable, as one variable decreases in value, the second variable Increases in value. From the findings the Sig. (2-Tailed) value 0.91 is bigger than 0.05 (>5% significance interval), meaning that there is weak statistical significant negative correlation between Tmin and potato production.

Table 2: correlations

Correlations

		Production	Tmin
Production	Pearson Correlation	1	-.369
	Sig. (2-tailed)		.091
	N	22	22
Tmin	Pearson Correlation	-.369	1
	Sig. (2-tailed)	.091	
	N	22	22

Therefore The null hypothesis were not rejected as Pearson trend test computed a P- value greater than the significant level alpha (α) =0.05. There is weak negative relationship between annual Temperature variability and potato Production in Musanze and Nyabihu Districts.

4.8 Projection on production

4.8.1. Introduction

The future climate is uncertain, as we move forward in the world of worth technology toward the significant development we are ahead converging to the world of stagnant, rising of GHGs and other pollutant which contribute to climate change and eventually to the sudden rising of global air temperature continue to become an unsolved issue, consequently This study also aimed to project the future temperature so that it can be correlated with Irish potato production to evaluate how this will impact the life of peoples inhabitant the region where Irish potato is growing especially in Musanze and Nyabihu**.** Note that RCP used during data extraction are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. [37] The pathways used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2 [38].

4.8.2. Performance of MarkSIM model in simulating present day maximum and Minimum Temperature Assessment

The Comparison between observed monthly maximum temperature climatology and Marksim simulated monthly maximum temperature climatology (*Figure 14 2, see addendum*) it can be seen that MarkSim has captured the monthly maximum temperature climatology distribution with slight difference in the magnitude. The comparison between observed monthly maximum temperature climatology and MarkSim simulated monthly maximum temperature climatology shows the bias between observation and MarkSim. The values of the bias of the months from January onward for all months are positive, so that the MarkSim over-estimate the Musanze Maximum temperature.

The Comparison between observed monthly minimum temperature climatology and Marksim simulated monthly minimum temperature climatology (*Figure 14 4, see addendum)* indicated a sliht differnce in magnitude in minimum temperature climatology distribution, The bias on the say figure may results from the number of duplication made during the extraction of the data or from the complexity in topography of the area.Therefore MarkSim do not deviate much from the station observation. The slight observed bias was registered in April, June and with May having the highest bias. Thus the MarkSim over-estimate the Musanze Minimum temperature.

The Comparison between observed monthly minimum temperature climatology and Marksim simulated monthly minimum temperature climatology (*Figure 14 6, see addendum)* indicated that MarkSim has captured well the monthly minimum temperature climatology distribution with the almost same pattern. the Bias between observed monthly minimum temperature climatology and Marksim simulated monthly minimum temperature climatology (*Figure 14 1*) shows that the values of the bias of the months from January, March, April,November and December are almost the same but the so the MarkSim is slightly under-estimating and stongly over-estimate the Nyabihu monthly minimum temperature.

The Comparison between observed monthly minimum temperature climatology and Marksim simulated monthly minimum temperature climatology (*Figure 14 9, see addendum*) it can be seen that MarkSim has captured the monthly minimum temperature climatology distribution with slight difference in the magnitude. The comparison between observed monthly minimum temperature climatology and MarkSim simulated monthly minimum temperature climatology shows the bias between observation and MarkSim. The values of the bias of the months from January onward for all months are positive, so that the MarkSim over-estimate the Nyabihu minimum temperature.

It can be seen that almost months of the monthly temperature climatology, the MarkSim over-estimate the Maximum and minimum temperature for the entire Districts.

4.8.3 Projected monthly temperature

Even though we re interested in inter-annual analysis before we go through Annual projection, firstly we did monthly analysis to evaluate if the months will be seasonaly behaved.

The projected monthly maximum temperature change from 2010 to 2039 using the three scenarios RCP8.5, RCP4.5 and RCP2.6 (*Figure 18.a and Figure 18.b, see addendum*) in both Districts indicates the projected monthly maximum temperature change. Findings From the figure, it can be observed that entire RCPs project a decreasing maximum temperature from February to May and from September to November while an increasing maximum temperature is projected from May to August. It can be seen that this increase and decrease is normal through the years as it will be corresponded to the Rwanda seasons (Long and short rain season), the increase from May to August is normal as it correspond to the long dry season and both decrease will be corresponded to the short and long rain seasons.RCP 8.5 shows a significant increase in maximum temperature than other RCPs, Note that The RCP 8.5 is characterised by increasing GHGs emissions over time. It is representative of scenarios that lead to high GHGs concentration levels. [39]

The change in maximum temperature (see *Figure 18 c and 18 d*) is almost ranged between (0.8-1.2^{0}C) throughout the entire months considering all RCPs except December in Musanze

Which shown a slight increase of 0.2 ^{0}C but generally maximum temperature will increase for entire projected months. Bellow Table summarized Musanze and Nyabihu projected Maximum Temperature and temperature change since 2010 to 2039 for all RCPs.

The projected monthly minimum temperature change from 2010 to 2039 using the three scenarios RCP8.5, RCP4.5 and RCP2.6 (*Figure 19 a*) in both Districts indicates the projected monthly minimum temperature change. Findings From the figure, The RCP8.5 projects highest Maximum temperature for all months followed by RCP 4.5. It can be observed that entire RCPs project a decreasing maximum temperature from February to June for Musanze and to July for Nyabihu whereas from June to end of August minimum temperature will increase and behave constant-like through the rest of month. It can be seen that this increase and decrease will be also normal through the years as it will be corresponded to the Rwanda seasons (Long and short rain season), the increase from May to August is normal as it correspond to the long dry season and both decrease will be corresponded to the short and long rain seasons. As aforementioned Note that The RCP 8.5 is characterised by increasing GHGs emissions over time. It is representative of scenarios that lead to high GHGs concentration levels. [39]

The change in minimum temperature is almost around 1-1.2^{0}C (*figure 19 b*) throughout the entire months considering all RCPs but generally maximum temperature will increase for entire projected months.

4.8.4 projected Musanze and Nyabihu Annual Maximum and minimum temperature

A 0.5-degree resolution over extended areas, the chances of WISE profiles coming from similar geologies and climates are high and were used, the current version of MarkSim sets 1985 as the 'present day climate'. The General Circulation Models (GCMs) it is derived from are usually run for about 50 or 100 years of past data to determine a baseline. The GCM differential is modeled pixel by pixel with a fifth-order polynomial regression. There is a data gap from 1985 to 2010 and the curves might not be stable, so it is decided best not to allow the user to specify years in this range. In practice, there is usually such an insignificant effect that it would not be worth including it**.** This is why MarkSim cannot generate weather data before 2010.

From the findings on the ***(figures** 20,see addendum)* the projected annual maximum and minimum temperature from 2010 up 2039 with the help of RCP 2.6, RCP 4.5 and RCP 8.5 in the studied districts shown an increase in both Tmax and Tmin in both Districts. The following figure further illustrates the global temperature change projected for RCP8.5 and RCP2.6 which can support the above projected increase. The solid lines represent the average values, with the shading representing the range of outcomes. The numbers within the graph indicate the number of model runs used to generate results. Note that the temperature baseline (0.0°C) was set to the average from 1986-2005, the temperature will continue to increase if there are no other measures and adaptations.

Because of these continuous increases in maximum and minimum temperature, future potato production could decrease in many regions. In some regions, mainly in temperate regions, production decline can partly be avoided through adaptation. Yields may even go up at high latitudes because of a lengthening of the growing season [19]Therefore referenced to the obtained projected results (*see fig 16 2***,** this increase will lead to the decrease of potato production if there is no adaptation taken into account as there is no significant relationship between annual Temperature variability and annual potato Production in Musanze and Nyabihu Districts (*see section 4.7, see also fig 5 and fig 7)* and this can be endorsed by weak negative correlation between the *two* variables where change in one variable are not correlated with changes in the second variable, as one variable decreases in value, the second variable Increases in value.

4.9. Linear regression between simulated observed and marksim data

During data extraction from marksim model, some errors, bias or outliers in data might occur for a numbers of reasons; it could happen either to the replication made during data extraction or it depends on the topography of the studied areas. The reason why liner regression was drawn intended to reduce the bias in datasets so that the projection can be easily understood and show a clear outlook and this eventually lead to the generation of new datasets. From the new generated datasets, figures 17 indicated the monthly projection maximum and minimum from 2010 until 2039.

V. SUMMARY OF FINDINGS AND RECOMMENDATIONS

5.1. Conclusions

The analyses of decade data from six reference stations representing the study area shown a significant trends in maximum and minimum temperature during the period from 2007 up to 2007, the potato production shown a decline in the mid of decade (2007-2017), where there is no need of drawing the trends line because the increase and decrease in production were clear with naked eye. The correlation analyses of these decade datasets with time series of production exhibited weak negative correlation between climate and agriculture variables as one variable decreases in value, the second variable Increases in value, Pearson's r= -0.366 and -0.369 of Tmax and Tmin respectively is close to 0, and the P value of 0.94 and 0.91 of Tmax and Tmin respectively is bigger than alpha value of 0.05 (>5% significance interval) (see *Table 15*) which means that Tmax, Tmin and potato production were weak negatively correlated.

Annual temperatures are increasing as the projection manifested during analysis of projected temperature datasets and this increase point to increase in extreme weather events such as outbreaks of animal and crop diseases; however the drivers of climate change may continue to alter the trends towards more uncertain future. Globally warming is serious issue which can be studied further as the evidence shown the solar activity to be the major contributor followed by emissions of GHGs into space (see section *4.5.1***)**

5.2 Recommendations

Based on the findings from the study, recommendations was formulated to cope with climate variability impacts with a particular reference to the increase in temperature and related stresses in order to increase and sustain potato production in the region:

Famers should practice crop intensification to increase potato production.

Training of farmers on importance of timely planting should be intensified to utilize the available rains at their different stages of growth such as flowering and maturity.

They should also be focused on and aware of the forecast dissemination of Rwanda meteorological Agency for early warning before they start their time of seeding instead of using the analogous method where some of them predict fake information by saying tomorrow will like today.

They should also adopt cultivars (quality and type of potato variety) that can be withstand ever to the increasing of temperatures in the future.

Further funded research is needed in the days to come to mitigate and implement adaptative solutions to temperature variability.

5.3. **REFERENCES**

[1] R. The World Bank, "Rwanda Economic Update ,SEEDS FOR HIGHER GROWTH," The World Bank, Kigali, 2011.

[2] M. o. A. a. A. Resources, "Strategic Plan for the Transformation of Agriculture in Rwanda phase III," Ministry of Agriculture and Animal Resources, Kigali Rwanda, July 2013.

[3] *. E. M. J. K. o. G. a. E. s. U. o. D. D. T. 2. R. M. U. R. A. B. K. R. Kseniia Mikova1, "Effect of Climate Change on Crop Production in Rwanda," *Earth Sciences,* Vols. Vol. 4, No. 3, 2015, no. Effect of Climate Change on Crop Production in Rwanda, p. 121, June 10, 2015.

[4] R. O. RWANDA, "INTENDED NATIONALLY DETERMINED CONTRIBUTION (INDC) FOR THE REPUBLIC OF RWANDA," REPUBLIC OF RWANDA, Kigali, November 2015.

[5] P. Q. C. R. H. E. J. R. P. a. P. V. P. Timothy R. Wheelera, "Temperature variability and the yield of annual crops," Department of Agricultural Sciences, The Royal Agricultural and Veterinary University, Taasuup, Denmark, 2000.

[6] D. Horton, Long-term trends in production of roots and tubers, USA: Winrock International Institute for Agricultural Development, 1988.

[7] S. Z. W. A. A. A. &. C. J. J. By Ambrose A. Zemba, "Growth and Yield Response of Irish Potato to Climate in Jos-South, Plateau State, Nigeria," *Global Journals Inc,* p. 13, Year 2013 .

[8] A. e. M. v. Munyemana, La pomme de Terre au Rwanda:une analyse d’une filière à hautes potentialités, Lima, Pérou : International Potato Center (CIP) et Universitat Hohenheim, 1999.

[9] G.-S. E. D. M. Global Journal of Human social science Geography, "Growth and Yield Response of Irish Potato to Climate in Jos-South, Plateau State, Nigeria," *Global Journals Inc. (USA),* p. 13, Year 2013.

[10] B. Safari, "Trend Analysis of the Mean Annual Temperature in Rwanda during the Last Fifty Two Years," *Journal of Environmental Protection, 2012, 3, 538-551 ,* p. 539, 2012.

[11] M. N. I. N. A. V. C. G. A. M. M. O.-E. B. T. R. a. Y. P. (. I. S. S. Q. D. M. M. C. Z. M. M. A. K. T. M. a. M. H. (. Boko, "Contribution of Working Group I to the Fourth Assessment Report of the Intergovermental Panel on Climate Change. IPCC report AR4,," Cambridge University Press, Cambridge, 2007.

[12] M. 1. 2. S. T. F. A. a. E. M. I., "Spatio-Temporal Trend Analysis of Projected Temperature over Rwanda," *IOSR Journal of Environmental Science, Toxicology and Food Technology,* p. 64, 2015.

[13] M. District, "Musanze District Plan to Eliminate malnutrion revised version," Mayor Mpembyemungu

Winfrida , Musanze, 2014-2015.

[14] N. District, "Distict Development Plan (2013-2018)," Twahirwa Abdulatif,The Mayor), Nyabihu, 2013.

[15] B. k.Safari, "Trend Analysis of the Mean Annual Temperature in Rwanda during the Last Fifty Two Years," *Journal of Environmental Protection, 2012, 3, 538-551 ,* p. 540, May 16th, 2012.

[16] M. District, "Musanze Disrtict Plan to Eliminate malnutrution 2014 - 2017," Musanze District, Musanze, 2014.

[17] t. M. TWAHIRWA Abdulatif, "Nyabihu District Development plan(2013-2018)," Nyabihu District, RUHENGERI, 2013.

[18] IPCC-AR5, " Summary for Policymakers," IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2007.

[19] R. J. Hijmans, "The Effect of Climate Change on Global Potato Production," Robert J. Hijmans , Peru, 2003.

[20] R. J. Hijmans, "The Effect of Climate Change on Global Potato Production," *AMERICAN JOURNAL OF POTATO RESEARCH,* p. 277, 17 April 2003.

[21] J. S. d. Oliveira, Artist, *Growth and development of potato (Solanum tuberosum L.) crops after different cool season storage.* [Art]. Lincoln University .

[22] E. R. 1. T. L. 2. Katarzyna Rymuza 1*, "Effect of weather conditions on early potato yields in eastcentral Poland," *INTERNATIONAL JOURNAL OF THE FACULTY OF AGRICULTURE AND BIOLOGY, WARSAW UNIVERSITY OF LIFE SCIENCES – SGGW, POLAND ,* Vols. VOL. 10, NO. 2, 2015, PP. 65–72 , no. Communications in Biometry and Crop Science , p. 65, 17 August 2015 .

[23] G. S. Borkowska H., " Changes of quality properties of spring wheat grain resulting from some agrotechnical factors.," *International Agrophysics,* p. 21, 2007.

[24] W. A. W. J. Mazurczyk W., "Influence of optimisation of irrigation and nitrogen fertilisation on some growth parameters and yield of early potato variety," in *Infrastructure and Ecology of Rural Areas*, Poland, Mazurczyk W., Wierzbicka A., Wroniak J, 2009, p. Infrastructure and Ecology of Rural Areas.

[25] A. M. K. (Be.d), ANALYSIS OF RAINFALL VARIABILITY ON IRISH POTATO, KENYA: Amon Mwangi Karanja (Be.d) , PRODUCTION IN OL-JORO-OROK DIVISION, NYANDARUA COUNTY, KENYA.

[26] A. M. K. B. (ARTS), ANALYSIS OF RAINFALL VARIABILITY ON IRISH POTATO PRODUCTION IN OL-JORO-OROK DIVISION, NYANDARUA COUNTY, KENYA, OR-JOR-OROK: AMON MWANGI KARANJA, NOVEMBER 2013.

[27] F. S. O. G. T. K. (. t. 6. F. S. O. G. M. B. S. S. E. E. S. S. E. F. H. C. S. O. A. K. Manfred Ehling (chair), Handbook on Data Quality Assessment Methods and Tools, Wiesbaden: COMMISION, EUROPIAN, 2007.

[28] I. S. I. B. C. Jonathan G. Geiger, "Data Quality Management The Most Critical Initiative You Can Implement," Jonathan G. Geiger, Intelligent Solutions, Inc., Boulder, CO, Boulder, None Defined.

[29] D. U. W. Group, "THE SIX PRIMARY DIMENSIONS FOR DATA QUALITY ASSESSMENT Defining Data Quality Dimensions," DAMA UK Working Group, United Kingdom, October 2013.

[30] J. Z. (. o. P. a. P. M. M. A. P. B. G. D. (. o. t. I. G. D. K. (. o. L. M. Norma Campbell, "DATA VALIDATION AND VERIFICATION ASSESSMENT MATRIX," U.S. DEPARTMENT OF THE INTERIOR , U.S, January,2013.

[31] P. P. B. A. L. F. George H. Holliday, "Global Temperature Change," George, 2010.

[32] L. B. E. K. Gunn Persson, "Climate indices for vulnerability assessments," Swedish Meteorological and Hydrological Institute, Sweden , Aug 2007.

[33] FAO, "The global potato economy. -International year of the Potato.," FAO, Rome, 2008,2009.

[34] O. M. W. A. A. O. O. K. Ogola, " Analysis of fertiliser use in potato production in Nakuru district, Kenya.," *Africa journal of Agriculture vol.6 (16):3672-3677 ,* p. 16, 2011.

[35] R. J. Hijmans, "The Effect of Climate Change on Global Potato Production," International Potato Center (CIP , Peru, 200.

[36] D. T. Dahiru, "P – VALUE, A TRUE TEST OF STATISTICAL SIGNIFICANCE? A CAUTIONARY NOTE," Dr. Tukur Dahiru, Nigeria., June, 2008.

[37] M. M. &. S. J. S. &. K. C. &. J. S. D. &. M. L. T. K. &. J.-F. L. &. K. M. &. S. A. M. &. S. C. B. R. &. K. R. &. A. T. &. G. J. M. V. &. D. P. v. Vuuren, "The RCP greenhouse gas concentrations and their extensions from 1765 to 2300," 09 August 2011.

[38] A. A. F. a. W. M. S. E.-D. M. A. Abdrabbo1, "Implementing of RCPs Scenarios for the Prediction of Evapotranspiration in Egypt," 2nd February 2015.

[39] I. p. o. C. change, "Special Report on Emissions Scenarios," PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE , United Kingdom, 2000.

[41] Department of Austrlian Government, "Representative Concentration Pathways (RCPs)," Australian Government, 2013. [Online]. Available: http://www.environment.gov.au/climate-change/publications/fact-sheet-rcps. [Accessed 23 08 2018].

[42] P.Camberlin and J. G. Wairoto, " Intraseasonal Wind Anomalies Related to Wet and Dry Spells during the "long" and "short" Rainy Seasons in Kenya," *Theor. Appl. Climatol. 58, 57-69,* 1997.

[43] E. K. Anyamba, " On the monthly mean lower tropospheric circulation, and the anomalous circulation during the 1961/62 floods in East Africa.," *M.Sc. thesis, University of Nairob,* p. 240 , 1983.

[44] L. J. Ogallo, " Climatology of rainfall in East Africa. In WAMEX related research and tropical meteorology in in Africa.," *WMO, TMRP, n ° 28,,* pp. 136-142, 1988.

[45] R. Camberlin, " Intraseasonal variations of June- September rainfall and upper-air circulation over Kenya.," *Theor. Appl. Climatol., 54, ,* pp. 107-116, 1996.

[46] G. Beltrando, " Space-time variability of rainfall in April and October-November over East Africa during the period 1932-1983.," *Int. J. Climatol., 10, ,* pp. 691-702., 1990.

[47] Alusa, A. L. and Gwage, E M.,, "The occurrence of dry spells during the East African long rains.," *KMD Research. Report n ° 2/78.,* 1978.

[48] B. S. Nyenzi, "Equatorial zonally moving disturbances which contributed to the East African long rains of March to May 1979.,," *In WAMEX related research and tropical meteorology in Africa. WMO, TMRP, n ° 28,,* pp. 270-271., 1988b.

[49] Camberlin.P and J. G. Wairoto, " Intraseasonal Wind Anomalies Related to Wet and Dry Spells during the "long" and "short" Rainy Seasons in Kenya.," *Theor. Appl. Climatol. 58, ,* pp. 57-69 , 1997.

[50] IPCC, "Climate Change," *Synthesis report, Cambridge University Press, Cambridge,* 2001.

[51] A. Omeny, East African rainfall variability associated with the Madden-Julian Oscillation., Kenya: Msc.thesis , Department of meteorology, University of Nairobi, 2006.

[52] R. Okoola, Space-time characteristics of ITCZ over equatorial East Africa during anomalous rainfall years., Kenya: Ph.D Thesis, Department of meteorology, University of Nairobi, 1996.

[53] Madden.R. and Julian.P, " Observations of the 40-50 day tropical oscillation.," *A review. Mon. Wea.Rev., 112-814-837,* 1994.

[54] Ogallo. L and Nyakwanda. W, " Spatial patterns of Outgoing Longwave Radiation over East Africa derived from rotational principal component.," 1994.

[55] Otieno F. O and Anyamba E.A, "42. OLR and SST characteristics during years of extreme rainfall over East Africa.," 1994.

[56] B. Safari, "iTrend Analysis of the Mean Annual Temperature in Rwanda during the Last Fifty Two

Years.," *Journal of Environmental Protection, Vol. 3 No. 6, 2012.,* pp. 538-551. doi: 10.4236/jep.2012.36065, 2012.

[57] J. Ndabarasa, "Characteristics of extreme rainfall events over Rwanda.," *Department of meteorology, University of Nairobi, Kenya.,* 2015.

[58] N. Sebaziga, " Association between Madden-Julian oscillations and wet and dry spells over Rwanda.," *Department of meteorology, University of Nairobi, Kenya ,* 2014.

[59] Jones, P.G.and Thornton, P.K.,, " The potential impacts of climate change in tropical agriculture: the case of maize in Africa and Latin America in 2055.," *Global Environmental Change 13,,* p. 51–59., 2003.

[60] Kowal, J.M. and Knabe, D.T., " An agro-climatic atlas of the northern states of Nigeria.," *Ahmadu Bello University Press, Zaria, Nigeria,* 1972.

[61] Alusa, A.L., and Mushi,M. T., " Study of the onset, duration and cessation of the rains in East Africa.," *International Tropical meeting, (preprints, part 1,133-140, Nairobi, Kenya),* 1974.

[62] P. Benoit, "The starts of the growing season in northern Nigeria.," *International Journal of Agricultural Meteorology 18,* p. 91–99, 1977.

[63] Mesay, " The Onset, Cessation and Dry Spells of the Small Rainy Season (Belg) of Ethiopia.," *Meteorological Research and Studies Department .National Meteorological Agency (Addis Ababa),* 2006.

[64] M. Sivakumar, " Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa.," *Agric. For. Meteorol. 42:295-305.,* 1988.

[65] R. E. Okoola, "A study of the characteristics of the ICTZ over equatorial Eastern Africa based on station rainfall records.," *J. African Meteor,soc. Vol. 3 No.1,* 1998.

[66] Camberlin .P and Okoola R. E , "15. The onset and cessation of the “long rains” in eastern Africa and their interannual variability.," *Theor. Appl. Climatol. 75 ,* pp. 43–54.DOI 10.1007/s00704-002-0721-5, 2003 .

[67] Tesfaye K. and Walker, S, "Matching of the crop and environment for optimal water use: the case of Ethiopia.," *Physics and Chemistry of the Earth 29:1061-1067.,* 2004.

[68] Segele, Z. T. and Lamb,P. J., " Characterization and variability of Kiremt rainy season over Ethiopia.," *Meteorology and Atmospheric Physics 89: 153–180,* 2005.

[69] J. Ayoade, " A statistical analysis of rainfall over Nigeria.," *Journal of Tropical Geography 29: 11–23.,* 1974.

[70] Zargina A.B, "Onset of effective rainfall and characteristics of dry spell in Nigeria savanna.," *Unpublished B.Sc. Project Report,Department of Geography, Ahmadu Bello University, Zaria, Nigeria,,* pp. 1-20, 1987.

[71] Tesfaye, K and Walker, S, "51. Matching of the crop and environment for optimal water use: the case of Ethiopia.," *Physics and Chemistry of the Earth 29:1061-1067.,* 2004.

[72] M. Sivakumar, " Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa.," *Agric. For. Meteorol. 42:295-305.,* 1988.

[73] J. Ayoade, "A statistical analysis of rainfall over Nigeria.," *Journal of Tropical Geography 29: 11–23.,* 1974.

[74] E. R. Team, "Evaluation Briefs," Department of Health and Human Services, 21 July 2010. [Online]. Available: http://www.cdc.gov/healthyyouth/evaluation/index.htm. . [Accessed 8 May 2018].

[75] A. M. K. B. (ARTS), ANALYSIS OF RAINFALL VARIABILITY ON IRISH POTATO, NYANDARUA COUNTY, : AMON MWANGI KARANJA B.ED, 2008.

[76] R. O. RWANDA, "MUSANZE DISTRICT PLAN TO ELIMINATE MALNUTRITION," Musanze District, Musanze, 2014 - 2017 .

[77] R. Faniriantisoas, Writer, *Climate data tool.* [Performance]. 2014.

5.4. ADDENDUM

Addendum 1: Figures

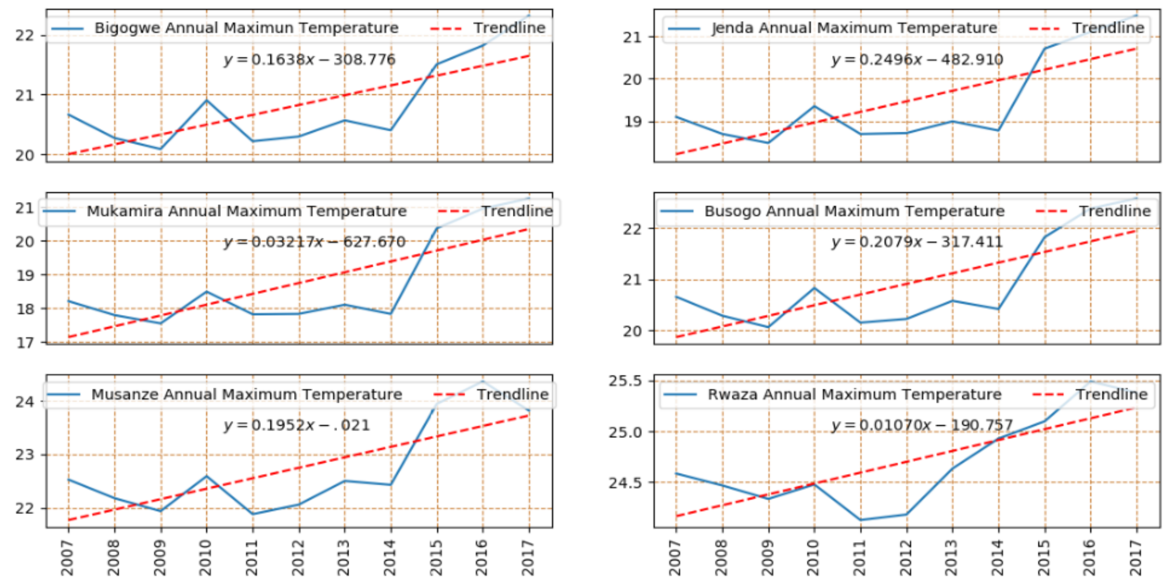


Figure 6: Trends of maximum Temperature

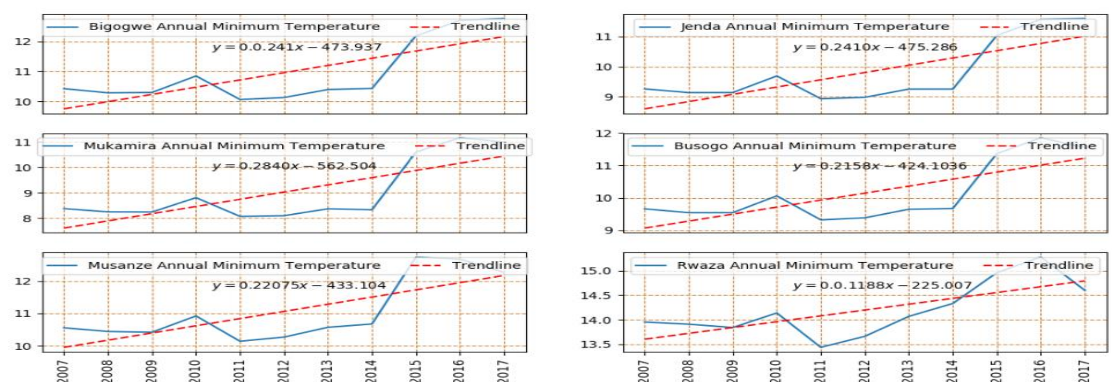


Figure 7: Trends of minimum Temperature

Figure 8: Annual Trends of potato production

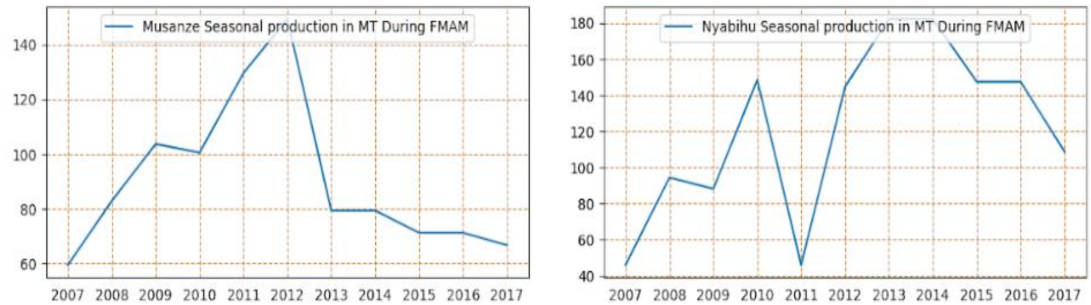


Figure 9: Seasonal Trends of potato production

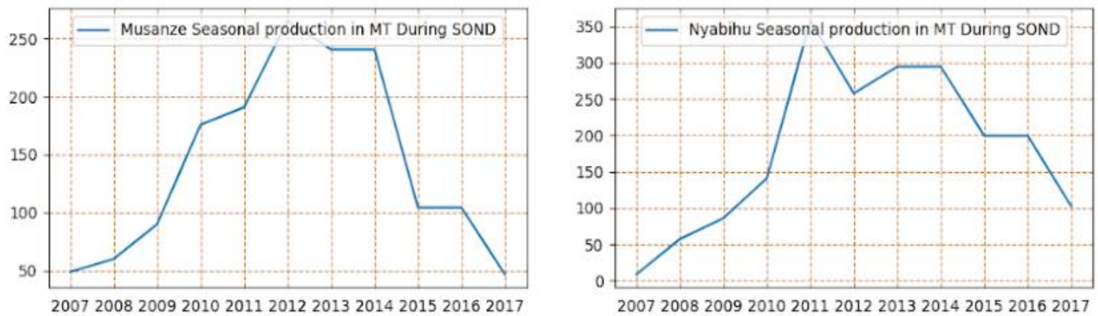
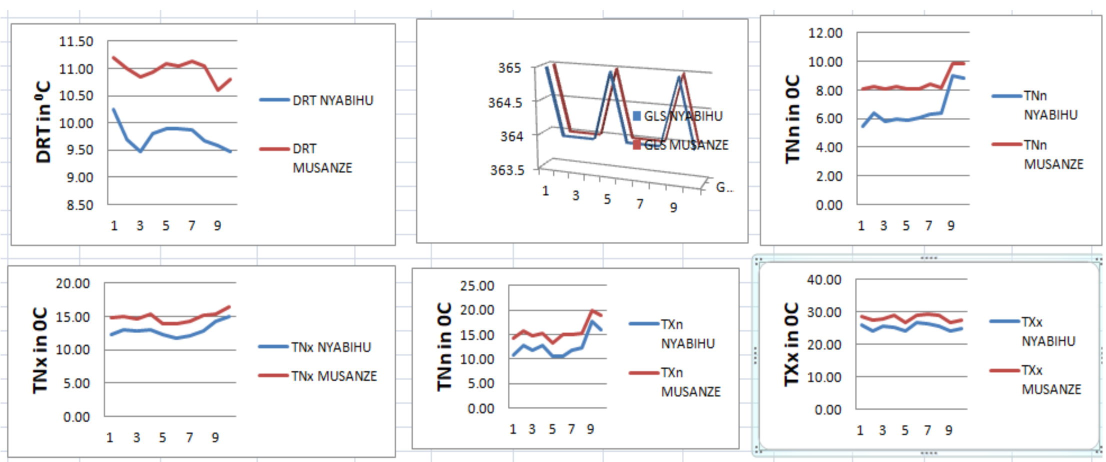


Figure 10: Seasonal Trends of potato production



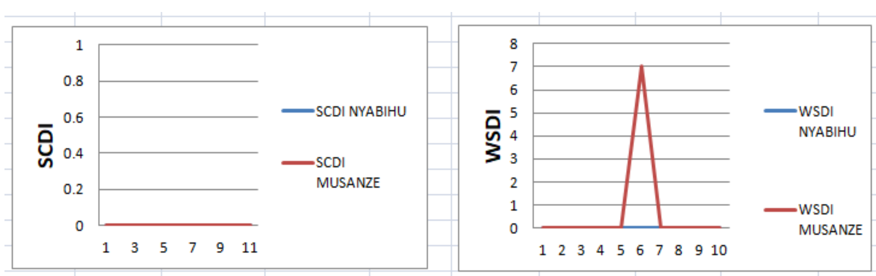
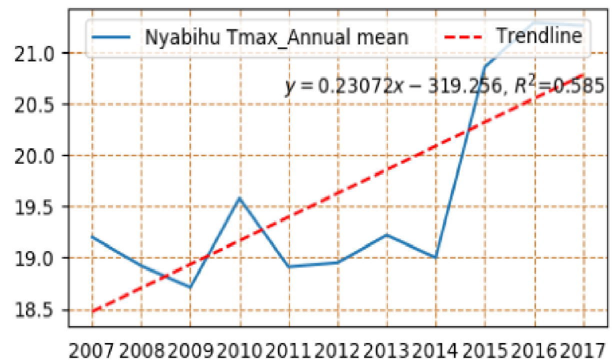


Figure 11: Musanze and Nyabihu extreme indices



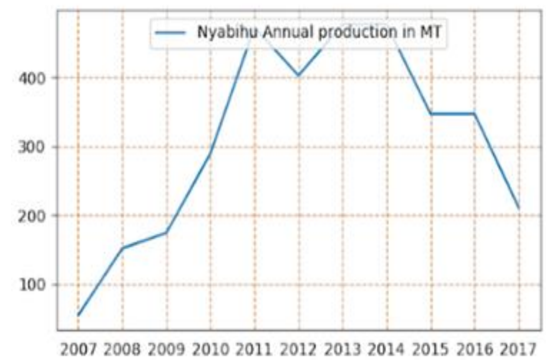
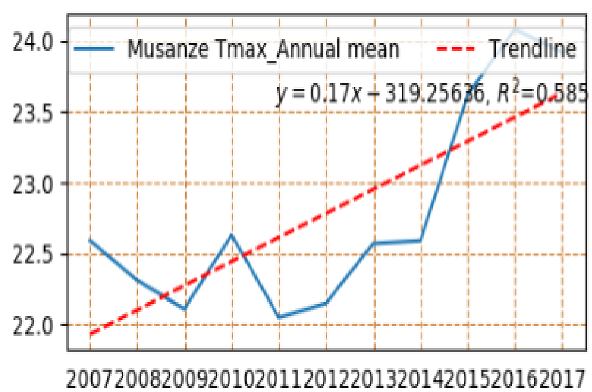


Figure 12 1: Nyabihu Annual mean Tmax

Figure 12 2 : Nyabihu Annual potato production in MT



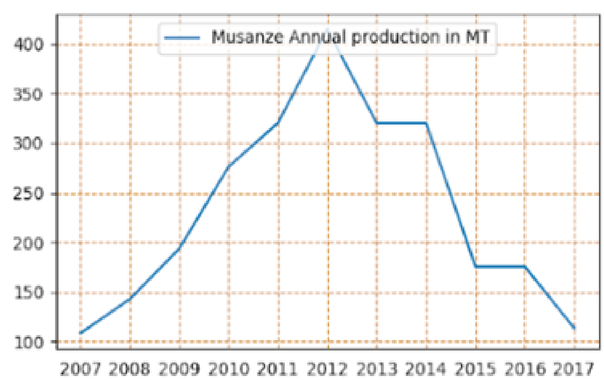
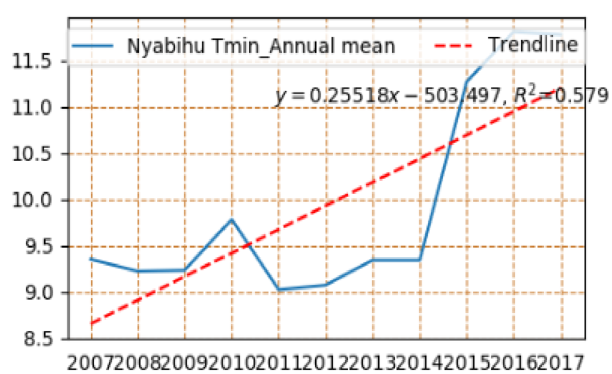


Figure 12 3: Musanze Annual mean Tmax

Figure 12 4 : Musanze Annual potato production in MT



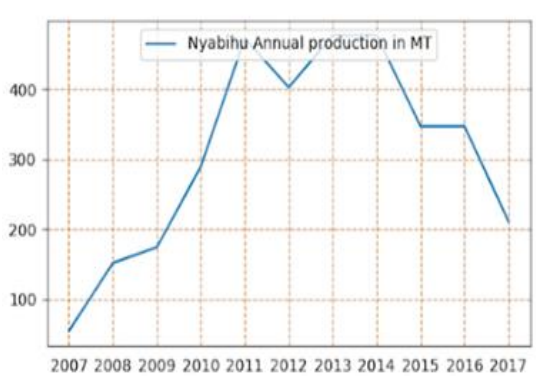
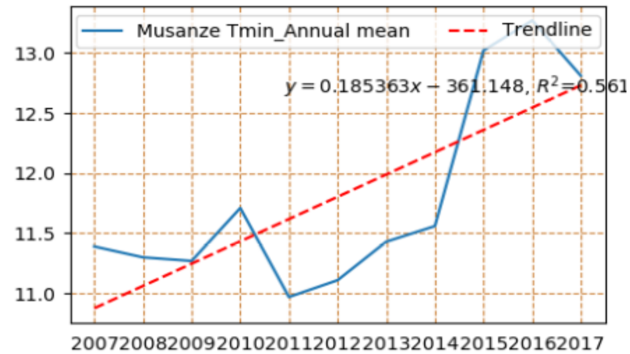


Figure 12 5: Nyabihu Annual mean Tmin in MT

Figure 12 1 Nyabihu Annual potato production



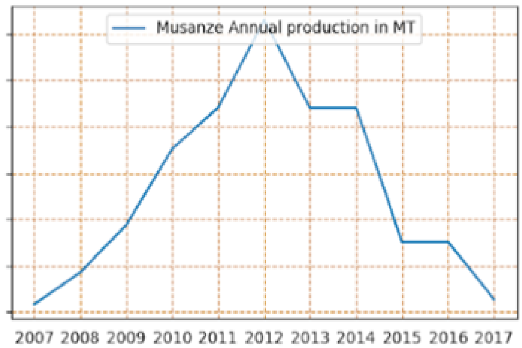


Figure 12 6: Musanze Annual mean Tmin production in MT

Figure 12 7 : Musanze Annual potato

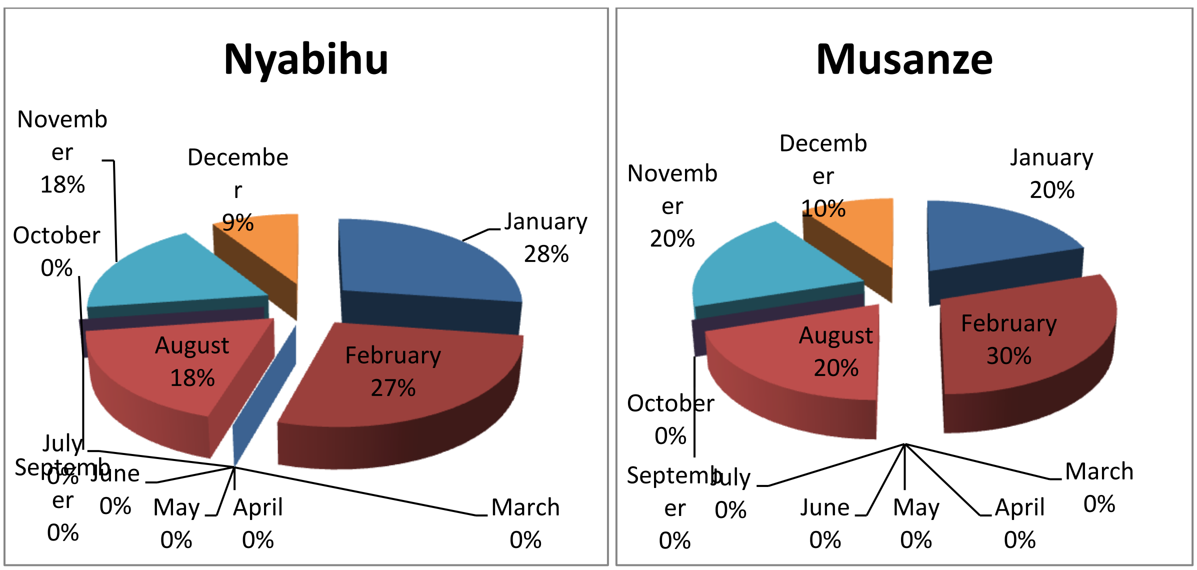


Figure 13 1: Distribution of Peak's month of Tmin

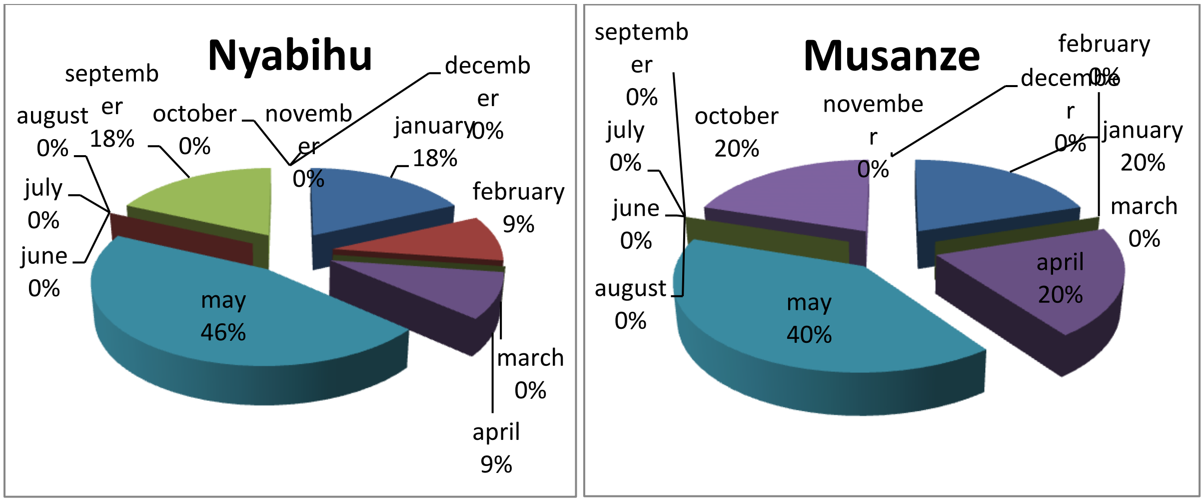


Figure 13 2: Distribution of Peak's month Tmax

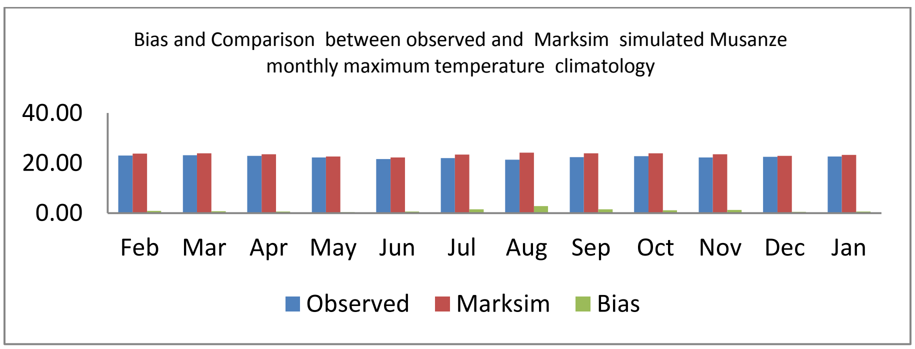


Figure 14 2: Bias and Comparison between observed and Marksim simulated Musanze monthly maximum temperature climatology

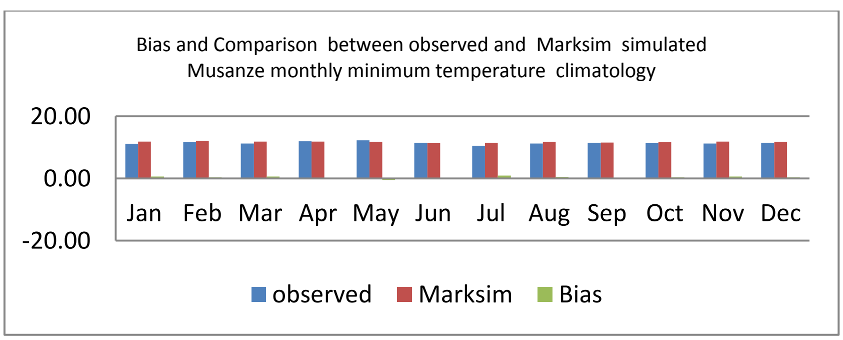


Figure 14 3. Bias and Comparison between observed and Marksim simulated Musanze monthly minimum temperature climatology

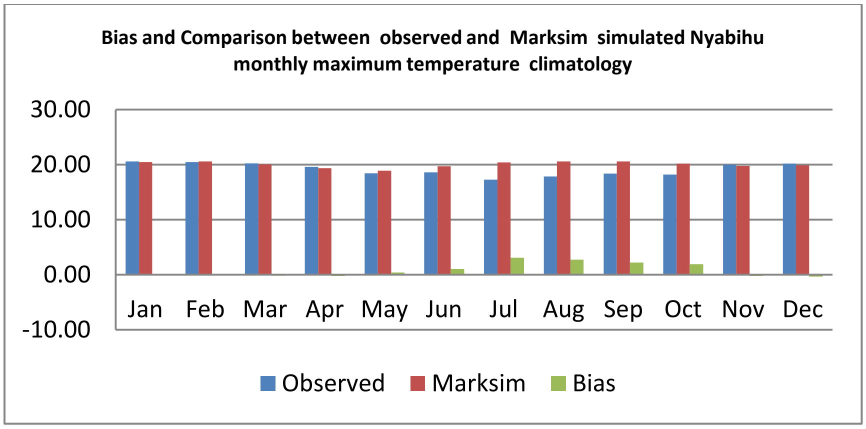


Figure 14 4. Bias and Comparison between observed and Marksim simulated Nyabihu monthly maximum temperature climatology

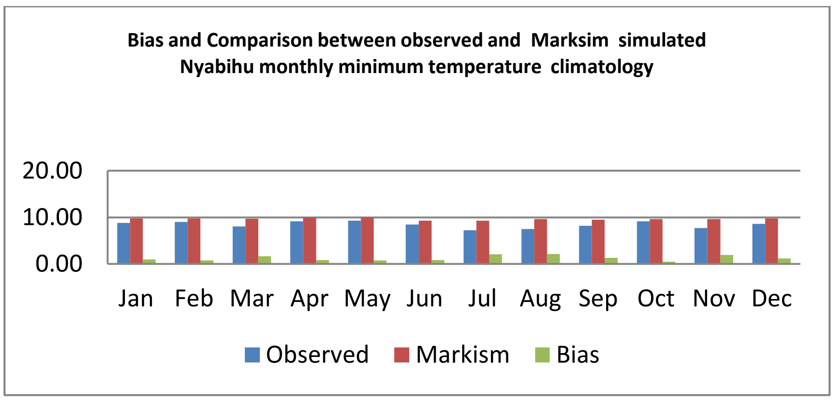


Figure 14 5. Bias and Comparison between observed and Marksim simulated Nyabihu monthly minimum temperature climatology

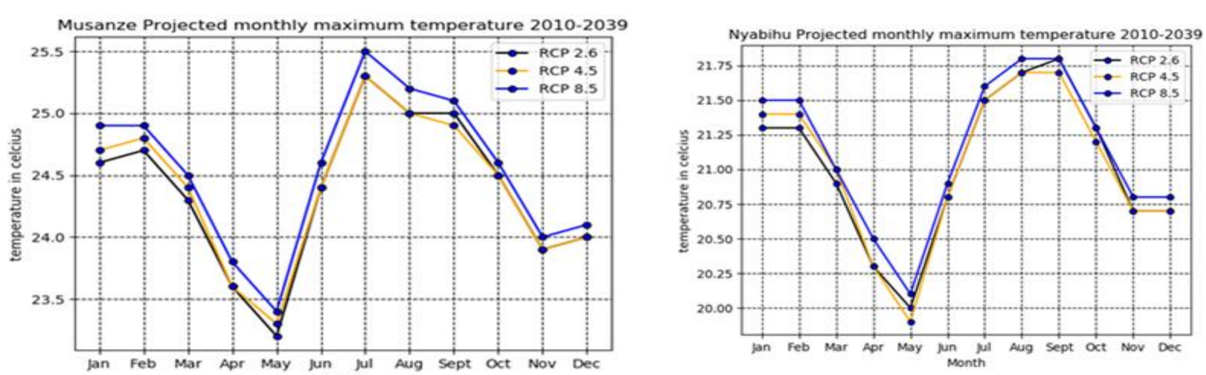


Figure 18.a: Musanze projected monthly maximum temperature (°c) from 2010 to 2039 using the three scenarios RCP2.6, RCP4.5 and RCP8.5.

Figure 18.b: Nyabihu projected monthly maximum temperature (°c) From 2010 to 2039 using the three scenarios RCP2.6, RCP4.5 and RCP8.5.

Figure 15 1: Musanze and Nyabihu Monthly maximum projected temperature from 2010-2039 using RCP 8.5, RCP 4.5 and RCP 2.6

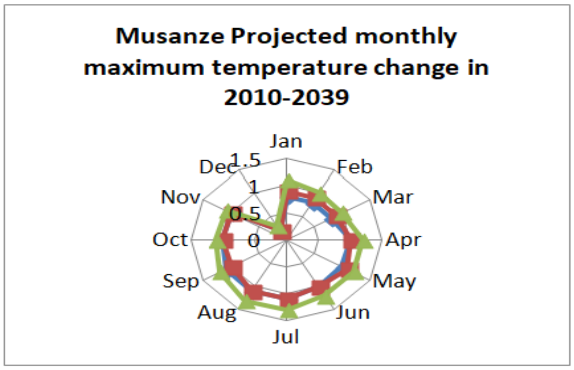


Figure 18.c: Musanze projected monthly maximum Temperature change (^{0}c)

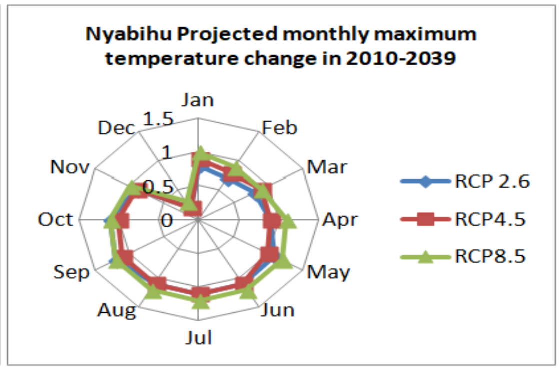


Figure 18.d: Nyabihu projected monthly maximum Temperature change (^{0}c)

Figure 15 2 Musanze and Nyabihu projected monthly maximum temperature change

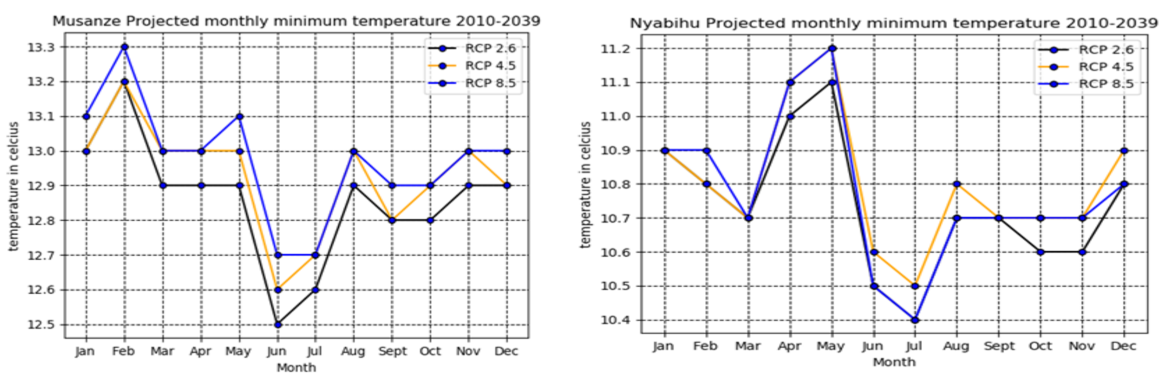


Figure 19.a: Nyabihu(left) and Musanze (right) projected monthly minimum temperature (^{0}c) from 2010 to 2039 using the three scenarios RCP2.6, RCP4.5 and RCP8.5.

Figure 15 3: Musanze and Nyabihu Monthly minimum projected temperature from 2010-2039 using RCP 8.5, RCP 4.5 and RCP 2.6

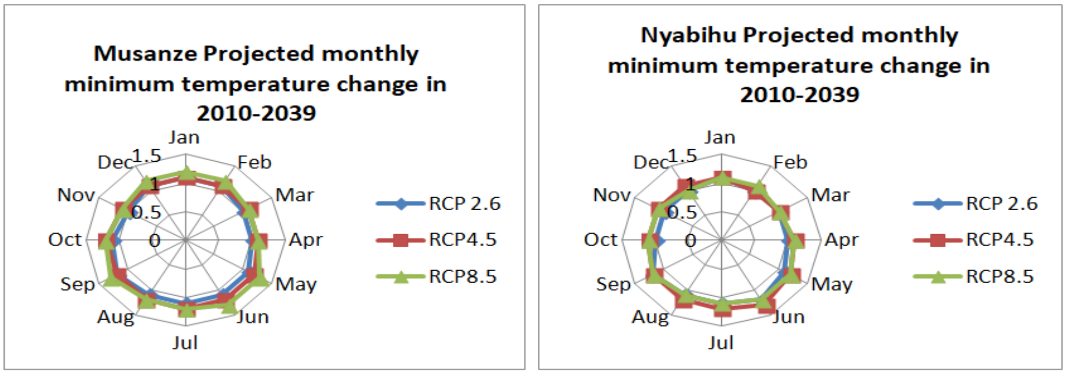


Figure 2.19 b: Nyabihu and Musanze projected monthly minimum temperature change (^0c) from 2010 to 2039

Figure 15 4 Musanze and Nyabihu projected monthly minimum temperature change

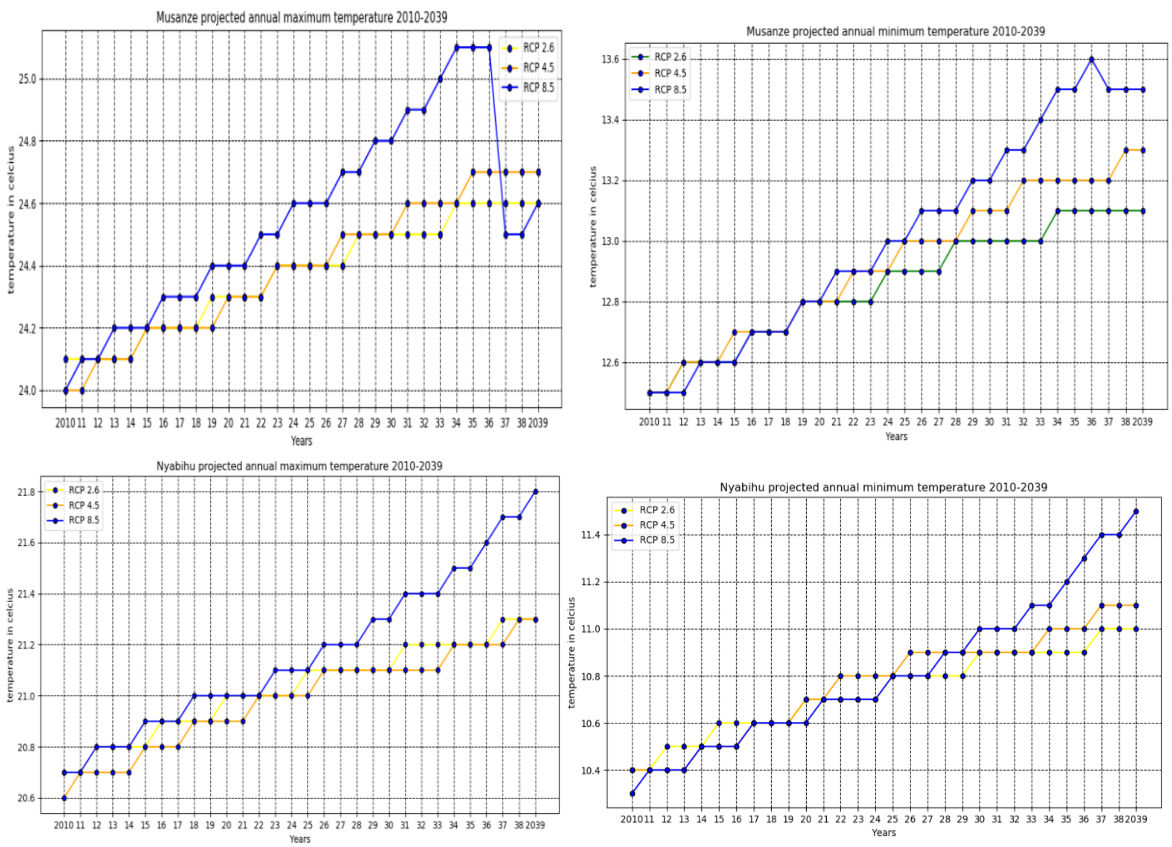
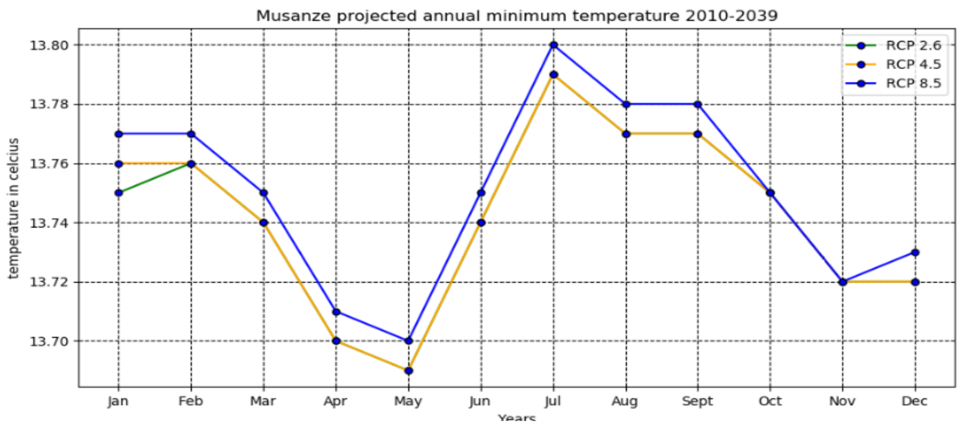
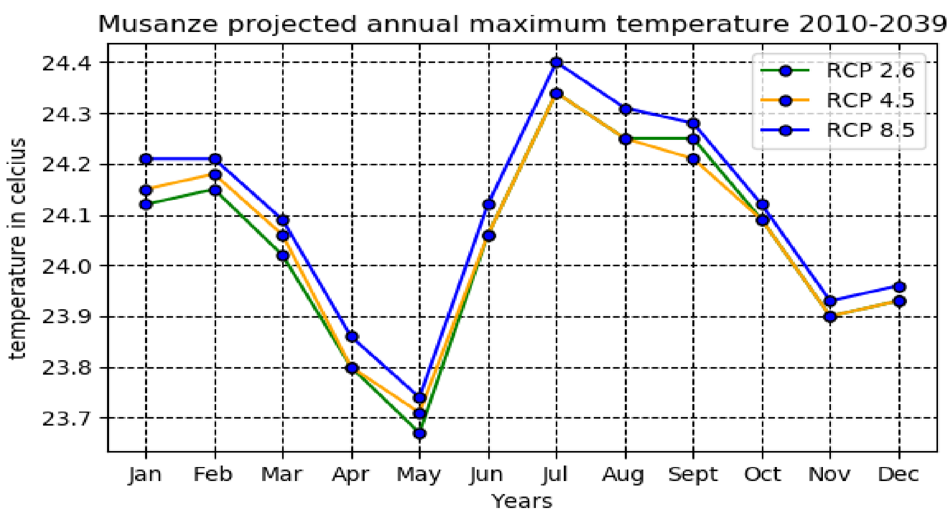
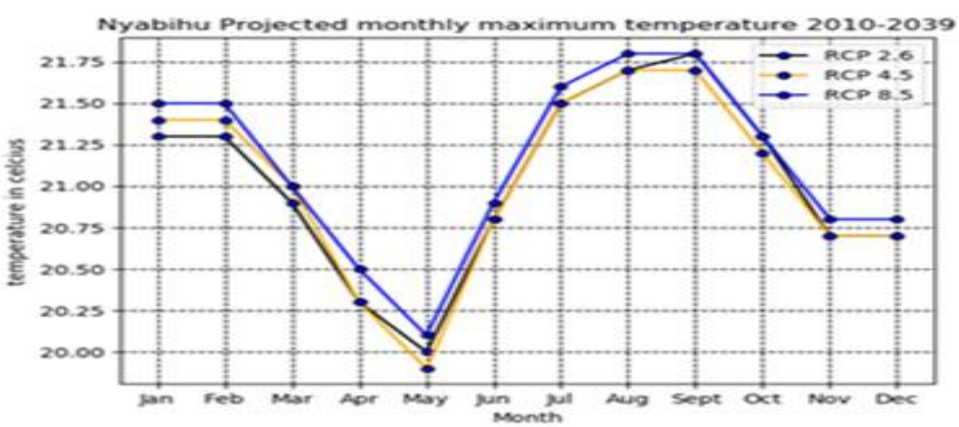
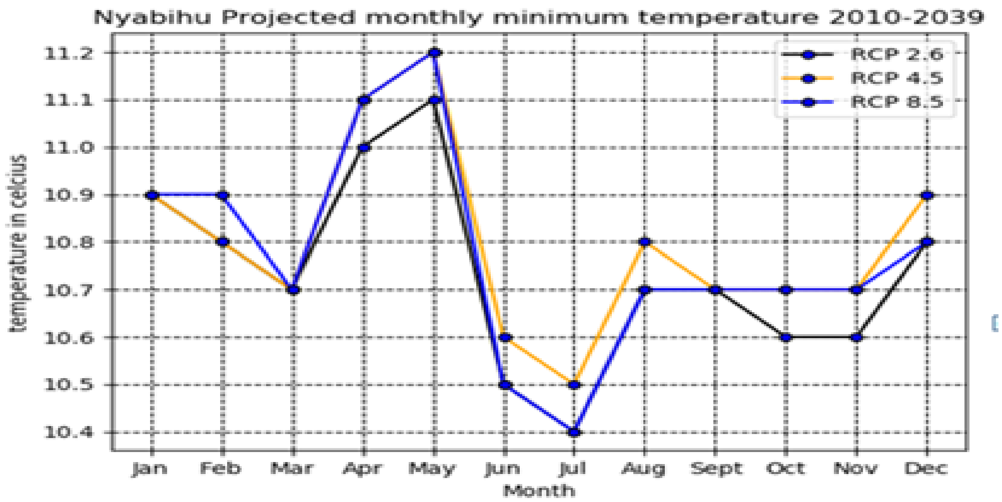


Figure 16 1. Projected Musanze and Nyabihu Annual maximum and Minimum Temperature during 2010 -2039 using three scenarios RCP 2.6, RCP4.5 and RCP 8.5.


Musanze projected annual minimum temperature 2010-2039
RCP 2.6
RCP 4.5
RCP 8.5
temperature in celcius
13.80
13.78
13.76
13.74
13.72
13.70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec


Musanze projected annual maximum temperature 2010-2039
RCP 2.6
RCP 4.5
RCP 8.5
temperature in celcius
24.4
24.3
24.2
24.1
24.0
23.9
23.8
23.7
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Years


Nyabihu Projected monthly maximum temperature 2010-2039
RCP 2.6
RCP 4.5
RCP 8.5
temperature in celcius
21.75
21.50
21.25
21.00
20.75
20.50
20.25
20.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month



Figures 16 2. Musanze and Nyabihu projected maximum and minimum monthly temperature during 2010-20139 after linear regression

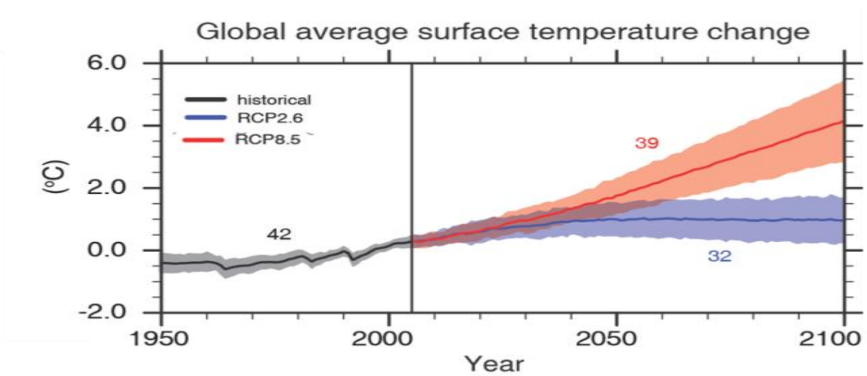


Figure 16 2 . Global Average surface temperature measures

Addendum 2: Tables

Table 3: Selected indices for analysis of extreme air temperature in this study

Indices	Name	Definition	Units
SCDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DRT	Diurnal temperature range	Annual mean difference between TX and TN	^{0}C
GSL	Growing season length	Annual (1 Jan–31 Dec in NH) count between first span of at least 6 days with TG< 58C and first span after 1 July of 6 days with TG <58C	Days
TNn	Min Tmax	Annual minimum value of daily minimum temp	^{0}C
TNx	Max Tmin	Annual maximum value of daily minimum temp	^{0}C
TXn	Min Tmax	Annual minimum value of daily maximum temp	^{0}C
TXx	Max Tmax	Annual maximum value of daily maximum temp	^{0}C
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX<90th percentile indicator	Days

Table 4: summary of extreme indices

	SCDI		DRT		GLS		TNn		TNx		TXn		TXx		WSDI	
Year	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE	NYABIHU	MUSANZE
2007	0	0	10.26	11.21	365	365	5.47	8.10	12.33	14.73	10.87	14.27	25.90	28.73	0	0
2008	0	0	9.70	11.01	364	364	6.43	8.23	12.97	15.07	12.83	15.77	24.30	27.47	0	0
2009	0	0	9.48	10.84	364	364	5.83	8.07	12.83	14.67	11.77	14.87	25.60	28.03	0	0
2010	0	0	9.80	10.92	364	364	5.97	8.27	13.00	15.40	12.80	15.30	25.27	29.13	0	0
2011	0	0	9.90	11.09	365	365	5.87	8.10	12.37	13.87	10.53	13.33	24.27	26.83	0	0
2012	0	0	9.89	11.05	364	364	6.10	8.10	11.80	13.97	10.60	15.00	26.63	28.97	0	7
2013	0	0	9.88	11.14	364	364	6.33	8.43	12.20	14.37	11.83	15.07	26.27	29.27	0	0
2014	0	0	9.67	11.03	364	364	6.43	8.17	12.77	15.20	12.23	15.13	25.67	28.93	0	0
2015	0	0	9.59	10.61	365	365	8.97	9.83	14.23	15.33	17.67	20.00	24.03	26.83	0	0
2016	0	0	9.48	10.81	364	364	8.83	9.83	14.97	16.40	15.87	18.97	24.83	27.43	0	0
2017	0	0														

Table 5: Summary of Annual Temperature characteristics

Year	Peak's month of Maximum Temperature	Peak's month of Minimum Temperature	Number of warm spell's days		Number of cold spell's days		Potato yield in MT	
			MUSANZE	*NYABIH*	*MUSANZE*	*NYABIHU*	*MUSANZE*	*NYABI*

	MUSANZE	***NYABIHU***	***MUSANZE***	***NYABIHU***		***U***				***HU***
2007	February	February	January	January	0	0	0	0	108,516	54,811
2008	December	December	May	May	0	0	0	0	142,931	151,721
2009	November	November	May	May	0	0	0	0	193,748	174,134
2010	January	January	February	February	0	0	0	0	276,306	289,410
2011	February	February	October	October	0	0	0	0	320,411	472,436
2012	February	February	May	May	7	0	0	0	414,869	402,346
2013	January	January	May	May	0	0	0	0	320,101	476,562
2014	November	November	October	October	0	0	0	0	320,101	476,562
2015	August	August	April	April	0	0	0	0	175,630	346,774
2016	August	August	May	April	0	0	0	0	175,630	346,774
2017	January	January	January	January	0	0	0	0	113,576	211,216

Table 6: Annual Tmin and Annual potato production trend

Year	Annual mean Tmin Amount		Annual potato production(MT)	
	MUSANZE	NYABIHU	MUSANZE	NYABIHU
2007	11.4	9.4	108.516	54.811
2008	11.3	9.2	142.931	151.721
2009	11.3	9.2	193.748	174.134
2010	11.7	9.8	276.306	289.410
2011	11.0	9.0	320.411	472.436
2012	11.1	9.1	414.869	402.346
2013	11.4	9.3	320.101	476.562
2014	11.6	9.3	320.101	476.562
2015	13.0	11.3	175.630	346.774
2016	13.3	11.8	175.630	346.774
2017	12.8	11.8	113.576	211.216

Table 7: Monthly Maximum and minimum Temperature Bias

MONTHS	**MAXIMUM TEMPERATURE(^{O}C)**		**MINIIMUM TEMPERATURE(^{O}C)**	
	BIAS		**BIAS**	
	MUSANZE	**NYABIHU**	**MUSANZE**	**NYABIHU**
JAN	0.81	-0.12	0.71	0.97
FEB	0.71	0.11	0.39	0.76
MAR	0.63	-0.13	0.60	1.65

APR	0.38	-0.20	-0.11	0.84
MAY	0.59	0.45	-0.51	0.73
JUN	1.46	1.08	-0.08	0.84
JUL	2.80	3.10	0.92	2.06
AUG	1.55	2.75	0.51	2.13
SEPT	1.11	2.21	0.08	1.33
OCT	1.29	1.97	0.36	0.47
NOV	0.45	-0.22	0.65	1.93
DEC	0.56	-0.30	0.31	1.19

Table 8: projected maximum temperature and maximum temperature change during 2010-2039

Month	**Observed maximum temperature(^{0}C)**		**Projected maximum temperature(^{0}C)**						**Projected maximum Temperature change (^{0}C)**					
	Nyabihu	**Musanze**	**Nyabihu**			**Musanze**			**Nyabihu**			**Musanze**		
			RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP4.5	RCP8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5
Jan	20.5	23.8	21.3	21.4	21.5	24.6	24.7	24.9	0.8	0.9	1	0.8	0.9	1.1
Feb	20.6	23.9	21.3	21.4	21.5	24.7	24.8	24.9	0.7	0.8	0.9	0.8	0.9	1
Mar	20.1	23.5	20.9	21.0	21.0	24.3	24.4	24.5	0.8	0.9	0.9	0.8	0.9	1
Apr	19.4	22.6	20.3	20.3	20.5	23.6	23.6	23.8	0.9	0.9	1.1	1	1	1.2
May	18.9	22.2	20.0	19.9	20.1	23.2	23.3	23.4	1.1	1	1.2	1	1.1	1.2
June	19.7	23.4	20.8	20.8	20.9	24.4	24.4	24.6	1.1	1.1	1.2	1	1	1.2
Jul	20.4	24.2	21.5	21.5	21.6	25.3	25.3	25.5	1.1	1.1	1.2	1.1	1.1	1.3
Aug	20.6	23.9	21.7	21.7	21.8	25.0	25.0	25.2	1.1	1.1	1.2	1.1	1.1	1.3
Sept	20.6	23.9	21.8	21.7	21.8	25.0	24.9	25.1	1.2	1.1	1.2	1.1	1	1.2
Oct	20.2	23.5	21.3	21.2	21.3	24.5	24.5	24.6	1.1	1	1.1	1	1	1.1
Nov	19.8	22.9	20.7	20.7	20.8	23.9	23.9	24.0	0.9	0.9	1	1	1	1.1
Dec	20.5	23.8	20.7	20.7	20.8	24.0	24.0	24.1	0.2	0.2	0.3	0.2	0.2	0.3

Table 9 : Projected minimum temperature and minimum temperature change during 2010-2039

Month	Observed minimum temperature(^{0}C)		Projected minimum temperature(^{0}C)						Projected minimum Temperature change (^{0}C)					
	Nyabihu	Musanze	Nyabihu			Musanze			Nyabihu			Musanze		
			RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5
Jan	9.8	11.9	10.9	10.9	10.9	13.0	13.0	13.1	1.1	1.1	1.1	1.1	1.1	1.2
Feb	9.8	12.1	10.8	10.8	10.9	13.2	13.2	13.3	1	1	1.1	1.1	1.1	1.2
Mar	9.7	11.9	10.7	10.7	10.7	12.9	13.0	13.0	1	1	1	1	1.1	1.1
Apr	10	11.9	11.0	11.1	11.1	12.9	13.0	13.0	1	1.1	1.1	1	1.1	1.1
May	10	11.8	11.1	11.2	11.2	12.9	13.0	13.1	1.1	1.2	1.2	1.1	1.2	1.3
June	9.3	11.4	10.5	10.6	10.5	12.5	12.6	12.7	1.2	1.3	1.2	1.1	1.2	1.3
Jul	9.3	11.5	10.4	10.5	10.4	12.6	12.7	12.7	1.1	1.2	1.1	1.1	1.2	1.2
Aug	9.6	11.8	10.7	10.8	10.7	12.9	13.0	13.0	1.1	1.2	1.1	1.1	1.2	1.2
Sept	9.5	11.6	10.7	10.7	10.7	12.8	12.8	12.9	1.2	1.2	1.2	1.2	1.2	1.3
Oct	9.6	11.7	10.6	10.7	10.7	12.8	12.9	12.9	1	1.1	1.1	1.1	1.2	1.2
Nov	9.6	11.9	10.6	10.7	10.7	12.9	13.0	13.0	1	1.1	1.1	1	1.1	1.1
Dec	9.8	11.8	10.8	10.9	10.8	12.9	12.9	13.0	1	1.1	1	1.1	1.1	1.2