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DEPARTMENT OF METEOROLOGY

PREDICTING MAIZE *(ZEA MAYS)* YIELDS IN EASTERN PROVINCE OF RWANDA USING AQUACROP MODEL.

BY

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DECLARATION

This Dissertation is my original work and has not been submitted for a degree in this or any other University.

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Dr. Christopher Oludhe, University of Nairobi

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DEDICATION

To my beloved family:

My wife, MUKASHEMA Judith (NYOTA) and our daughter, IGABE Kaella Ariana for their patience during my absence and words of encouragement.

To my beloved Parents:

My father, MAVUDIKO Mathias and NANGARABA Véronique for instilling in me hard working at early age, discipline and their words of encouragement.

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To all my brothers and sisters.

ABSTRACT

Rwanda is affected by prolonged droughts leading to reduction in crop production and livestock production with severe food insecurity. Rain fed agriculture in Rwanda is affected by drought and variation in seasonal rainfall amounts within the last decades and climate change impacts have been reported in many areas of the country. Eastern Province is considered one of the most productive rain-fed agricultural areas in Rwanda, where it contributes more than 32 % of the cereals produced in the country. Therefore, the general objective of this work was to predict maize yields under reined agriculture by using AquaCrop model in Eastern province of Rwanda.

Trend analysis was carried out on climatic parameters (1981-2016) such as the rainfall, maximum and minimum temperatures, evapotranspiration and maize yield (2002-2016). Results showed that rainfall trend was not significant over the study area, indicating non significant change in rainfall during the last decade. Minimum and maximum temperatures had significant trends (increasing) over the study area, implying that the temperature has been rising over the last decade. Maximum and minimum temperature showed a negative relationship with negative correlation coefficients of -0.38 and -0.39 with maize yield respectively. This implies that an increase in temperature beyond the optimum level (low temperature below 8°C and high temperature of above 30°C) results in a decline in maize yield and vice versa. On the other hand Correlation analysis showed a positive relationship between maize yield and rainfall (0.57 and 0.59) for both Districts (Bugesera and Nyagatare) and maize and evapotranspiration (0.29 and 0.27). This means that an increase in rainfall enhances significantly or not maize production.

Monthly results of coefficient of variation values indicated an increase in climate variability, which was shown by larger season to season fluctuations, with a higher coefficient of variation implying less predictability in the climate parameters.

It was observed that 25.4% and 50.7% of the variability in maize yield could be explained by these climatic parameters (maximum and minimum temperature, evapotranspiration and rainfall) and was significant at $p=0.024$ and 0.0103.

The impacts of changes in climate parameters; temperature and annual rainfall, was determined by using comparisons between the observed data (past and present) and projected data (CNRM

Cordex Model).Climate variability results analysis revealed significant increase in minimum temperature of 9.88% and 13.09% (1.14 °C and 1.49°C) for Bugesera and Nyagatare by 2046, while rainfall was projected to decrease by 20.65% and 20.97% (163.59 and 174.65 mm) for Bugesera and Nyagatare respectively over Eastern province area during the same period.

The outputs of the study using AquaCrop model showed that by 2050, the study area’s seasonal rainfall (September-January) will decline by 233.6 mm (10.9%), The average predicted future simulated maize yield for September-January season (2021-2050) were 1282.3kg/ha and 1316.8 kg/ha over Bugesera and Nyagatare areas respectively. Comparison with the observed maize yields for September-January season (2002 up to 2016) of 1675.5 kg/ha and 1760.9 kg/ha indicated there will be a decrease in future maize yields (23.4%) in Bugesera and (25.2%) in Nyagatare area. Seasonal temperature have significant impacts in maize yields, There were projected increases in minimum and maximum temperature by 1.20°C (4.55% and 4.54%) and 1.14°C (9.88% and 13.09%) respectively for Bugesera and Nyagatare Districts. This implies that maize yield production will be very sensitive to reduction in rainfall and increase of temperature during the season over the study area. The extreme impacts of climatic parameters occurred over the last years was depicted and its associated effects on maize yields was done using correlation and regression techniques. Man Kendall Trend analysis and coefficient of variation estimates statistics was computed in order to quantify the magnitude of climate variability and change in climatic parameters and its direction.

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LIST OF ACRONYMS

CCx	Maximum Canopy Cover
CGC	Canopy Growth Coefficient
CNRM	Centre National de Recherché Meteorologiques
CORDEX	Coordinate Regional Climate Downscaling Experiment
CV	Coefficient of Variation
EDPRS	Economic Development Poverty Reduction Strategy
ETO	Reference Eva-transpiration
FAO	Food and Agriculture Organization
FEWS NET	Famine Early Warning System Network
GDD	Growing Degree Day
GDP	Gross Domestic Populations
GoR	Government of Rwanda
HI	Harvest Index
INDCs	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
IWWI	International Water Management Institute
KC	Crop Coefficient
KY	Crop response factor
LAI	Leaf Area Index
MINAGRI	Ministry of Agriculture and Animals Resources
MINECOFIN	Ministry of Agriculture Economic Planning
MINIRENA	Ministry of Natural Resource of Rwanda
MIROC	Model for interdisciplinary research on Climate Change
MLO	Mauna Loa Observatory
NISR	National Institute of Statistic of Rwanda
NRMS	Normalized Root mean Square Error
PET	Potential Evapotranspiration
RDI	Regulated Deficit Irrigation

RMSE	Root Mean Square Error
SNHT	Standard Normal Homogeneity Test
Tmax	Maximum Temperature
Tmin	Minimum Temperature
USDA	United States Department of Agriculture
WMO	World Meteorological Organization
WOFOST	World Food Studies
WP	Water Productivity
WRSI	Water Requirement Satisfaction Index

CHAPTER ONE

1.0 INTRODUCTION

This chapter is subdivided into six sections namely, background information, problem statement, general objective and specific objectives, research hypothesis, justification of study and finally description of the study area.

1.1 Background information

Rwanda is defined as a sub-Saharan country where the region's water scarcity problems are the major challenge. However the results are more severe in dry areas of the country. The Eastern province is among part of regions that experience little amount of rainfall in Rwanda with high risk of food security.

Rwanda is among tropical countries; its high altitude implicates the climate temperate. On the top of mountains, frost and snow are possible. There are influenced two rain seasons (March to May and mid-September to mid-December) and two dry periods determined by occasional light rains. The average annual rainfall varies between 750mm to 2200mm annually. The lower amount of rainfall allocates in the northeastern region of the country (750mm); while in the northwestern and southwestern areas of the country it is about 2200mm. The average annual temperature is all most around 20°C over the country. Daily temperature perturbations are influenced by landscape. The lapse rate is about 0.56°C per 100m (MINAGRI, 2006).

To raise up crop production in the eastern province of the country, irrigation water is highly needed but is extremely inefficient (Scarcity). Furthermore this province is among recognized as driest and hottest of the country (MINAGRI, 2006). Eastern province has usually some challenge due to water availability that may be excluded through water storage and efficient use especially for domestic, Irrigation water and hydropower development. The first step is the developing and implementing water management through water harvesting techniques for maximum growth of different crops species.

1.2 Problem Statement

Agriculture in Rwanda is based on rainfed and because of this, farmers follows a cropping seasonal calendar. There are mainly two rain seasons starting from March to May and Mid-September and mid-December. As a tropical region, Rwanda is affected by prolonged droughts leading to decrease crop production as well as livestock production and when the amount of rainfall decreases there is usually severe food insecurity problems.

Poverty and hunger are the major challenges especially in the Eastern part of Rwanda, that subject under nutritional climatology conditions. However, the large proportion of arable land is under water scarce areas subject to recurrent dry spells. Such short and recurrent periods of prolonged drought during crop development stage is key of yield reduction.

Thus, this research work will provide a tool which use for predicting yield for maize production. The knowledge generated over the study area could be utilized for climate and monitoring as agriculture risk management tool in the projection on maize yield production over the study area. As parts of the country, Eastern region faces similar challenges. The total annual production and consumption of maize yields do not satisfy population needs. The majority of land users is depended on rainfall patterns. In this drought prone dry lands there are several problems related both due to rainfall characteristics (poorly temporal distribution and high rate of evaporation), soil and plant species problems originating from mainly dry spell damages and nutrients deficiency.

This research work therefore aims to validate the AquaCrop model for predicting maize yields under rainfed agriculture.

1.3 Objective of the Study

The mainly objective of this study is predicting maize yields in Eastern province of Rwanda using AquaCrop model under rainfed agriculture. The specific objectives are:

1 To determine the spatial and temporal variability and trends of climatic parameters and Maize yield over Eastern province of Rwanda.

2. Determine the relationship between climatic characteristics and Maize yield over Eastern province of Rwanda.

3. Predict maize yield based on future climate variability and change over Eastern province of Rwanda using AquaCrop and multiple regression Models.

1.4 Research hypothesis

There are three hypotheses to be tested in this study

1. There is no significant change in both temperature and rainfall

2. The expected future change in mean rainfall and temperature patterns, and variability of extreme events has no effect on the Maize yield

3 AquaCrop model is useful tools for predicting maize crop during growing season over Eastern province of Rwanda.

1.5 Justification of the Study

In Rwanda, agriculture is one of the main pillars of the national economy. In last year's rainfed agriculture has been affected significantly by climate change and variability, which may lead to reduction in agricultural productivity by reducing the suitable productive parts. Thus research work on validation of AquaCrop model by comparing the different climatic parameters estimates and their resulting for enabling model to better track agriculture drought and estimates yield prediction over the study area. The climatic parameters are usually decreasingly or increasingly a major constraint for agriculture production while their adaptation techniques is still low in Rwanda..

This research carried out as a contribution to the National Economic Development and Poverty Reduction Strategy (EDPRS) that aims on leading agricultural production though reducing soil erosion control and environmental conservation from further degradation (MINECOFIN, 2008). The national strategy is formulated toward helping framers to be aware on adaptation practices against negative and costly problems of land degradation and water management. Moreover , Eastern province is one of the most productive area of the country and any research to analyze the impact of climate variability and change for predicting maize yield production is mainly in right direction. This work can help the Government to come out with organizational structures to assist farmers supplement their efforts towards achieving it objective of fighting food insecurity and poverty reduction (hunger).

1.6 Description of the Study Area

Rwanda is a tropical country and located in the sub-Saharan African countries. It shares boarders with Tanzania in East and South-East, Burundi in South, Democratic Republic of Congo in West and Uganda in the North. Generally with a total area of about 26,338 km^2 of which 14,000 km^2 are arable and with a population of over 11.21 million as published in 2017. Figure 1 shows the Administrative map of Rwanda.

Map No. 3717 Rev. 10 UNITED NATIONS
June 2008

Department of Field Support
Cartographic Section

Figure 1: Administrative map of Rwanda (www.statistics.gov.rw)

1.6.1 Relief

Rwanda relief is dominated by mountainous and hilly with an altitude ranging about 900 m to 4507 m. This relief is characterized by Congo Nile Ridge overlying Lake Kivu with an elevation ranging about 2500 m to 3000 m. It is occupied by five volcanic on which the highest is named as Karisimbi with an altitude of 4507 m in Northwest, central plateau shows a relief of different hills with an elevation varying around 1500 to 2000 m.

Lowlands are characterized by a depression dominated by different hills with a less or more round trip top with an altitude about 1000 to 1500 m in Eastern part. Lowlands (plain of Bugarama) has an elevation of 900 m as the result from tectonic depression (African Rift valley) in the South-Western. Figure 2 shows the agro - ecological zones of Rwanda.

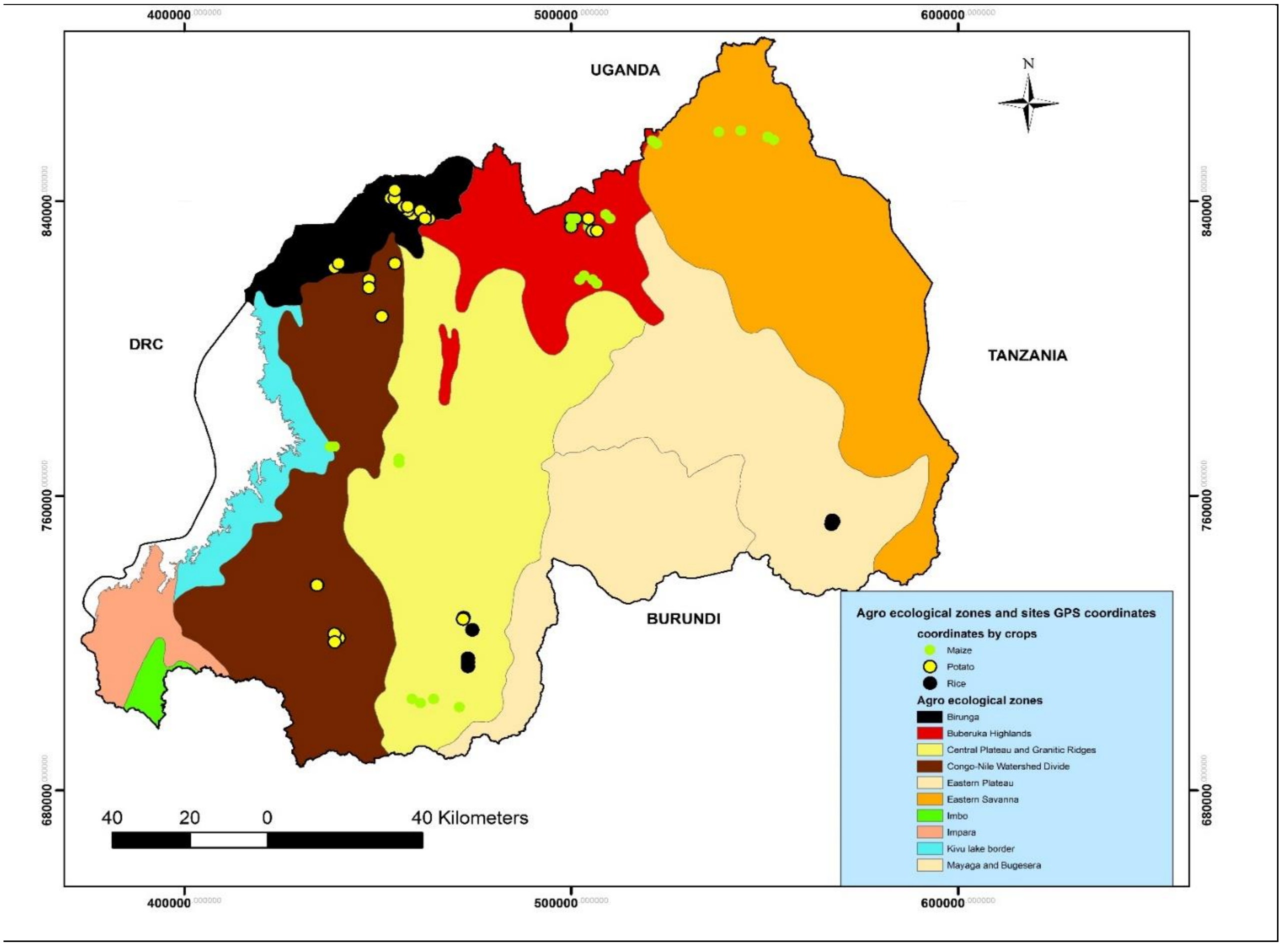

Figure 2: Agro - ecological zones of Rwanda defined by MINAGRI,

1.6.2 Climate

Rwanda has a tropical temperate due to its landscape. The average annual temperature are about 16^{o}C to 20^{o}C, without significant variability. Rainfall distribution has always irregularities. Winds speed are usually about 1 to 3 m/s. Higher regions of Congo-nil ridge, temperatures varies around 15^{o}C to 17^{o}C with abundant rainfall. The volcanic region is characterized by lowest temperature, it can leads below 0^{o}C within different local climate. Areas under intermediary altitude, Annual temperature range around 19^{o}C to 21^{o}C and an annual rainfall about 1000 mm/year. Rainfall irregularity provides prolonged drought periods over Eastern and South-Eastern (lowlands) where the temperature is beyond 30 ^{o}C in February and July-August. This region is dominated by lower abundant rainfall with around 700 to 970 mm/year (MINIRENA, 2010).

The intertropical convergence zones (ITCZ) is the main synoptic features scale system controlling rainfall (Lunga *et al.*, 2016). ITCZ is characterized by low pressures, maximum humidity and the convergence of winds, it passes twice per year and provides two different rainy seasons in (mid-September to December) and other in (March to May). Moreover, the diversity of the Rwanda topography and moderating effect of Lake Victoria by maintaining some rainfall along season from March to May.

The rainfall is normally well distributed along the year with some irregularities. South-East and Eastern part are more accredited by severe droughts while the Western and Northern areas are dominated by abundant rainfall that usually manifests erosion, landsides and flooding (MINAGRI, 20016). Figure 3 shows the temperature distribution in Rwanda (latitude 19.9403^{0}S and 29.8739^{0}E as longitude).

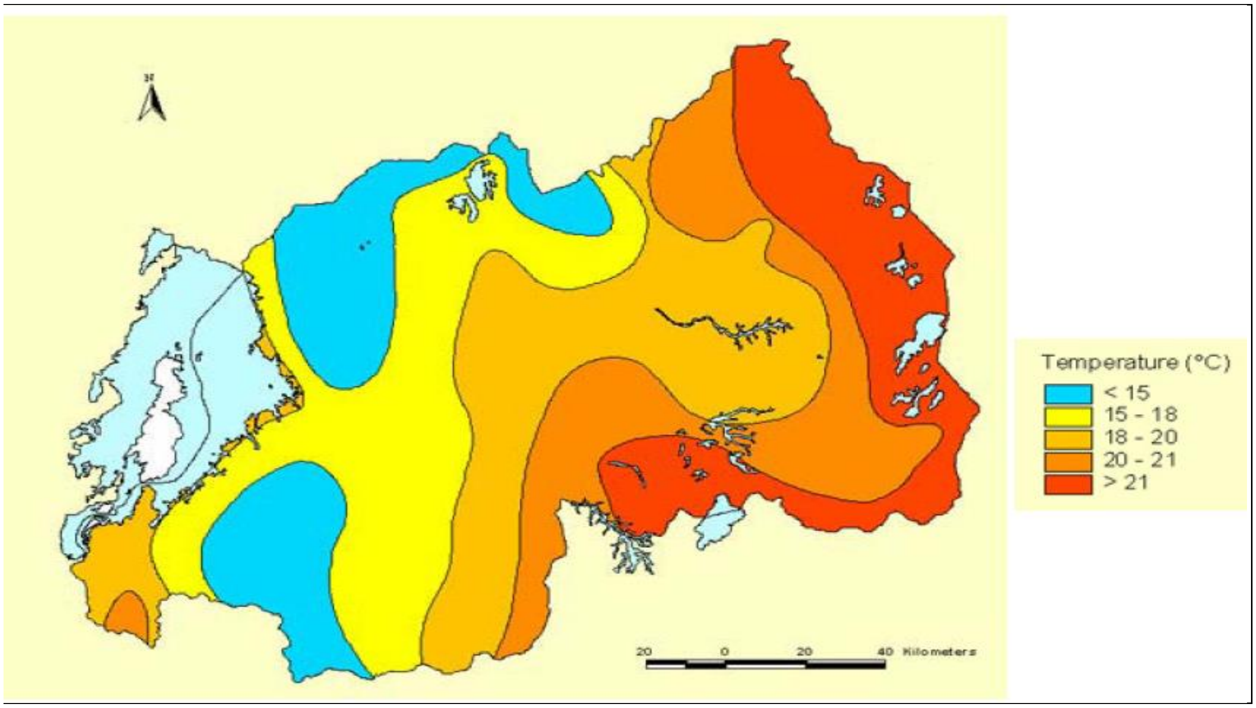

Figure 3: Temperature distribution in Rwanda (MINAGRI, 2006)

1.6.2 Soils

The soil of Eastern province of Rwanda is characterized by the tightness of the humifere layer of the soil brought about the grassy savanna and by the vertisoils properties that are rich in mineral nutrients but lacking organic substances. In additional these soils, considered suitable for agricultural and Livestock production. Figure 4 shows soil map of Rwanda accordingly to soil taxonomy classification by USDA.

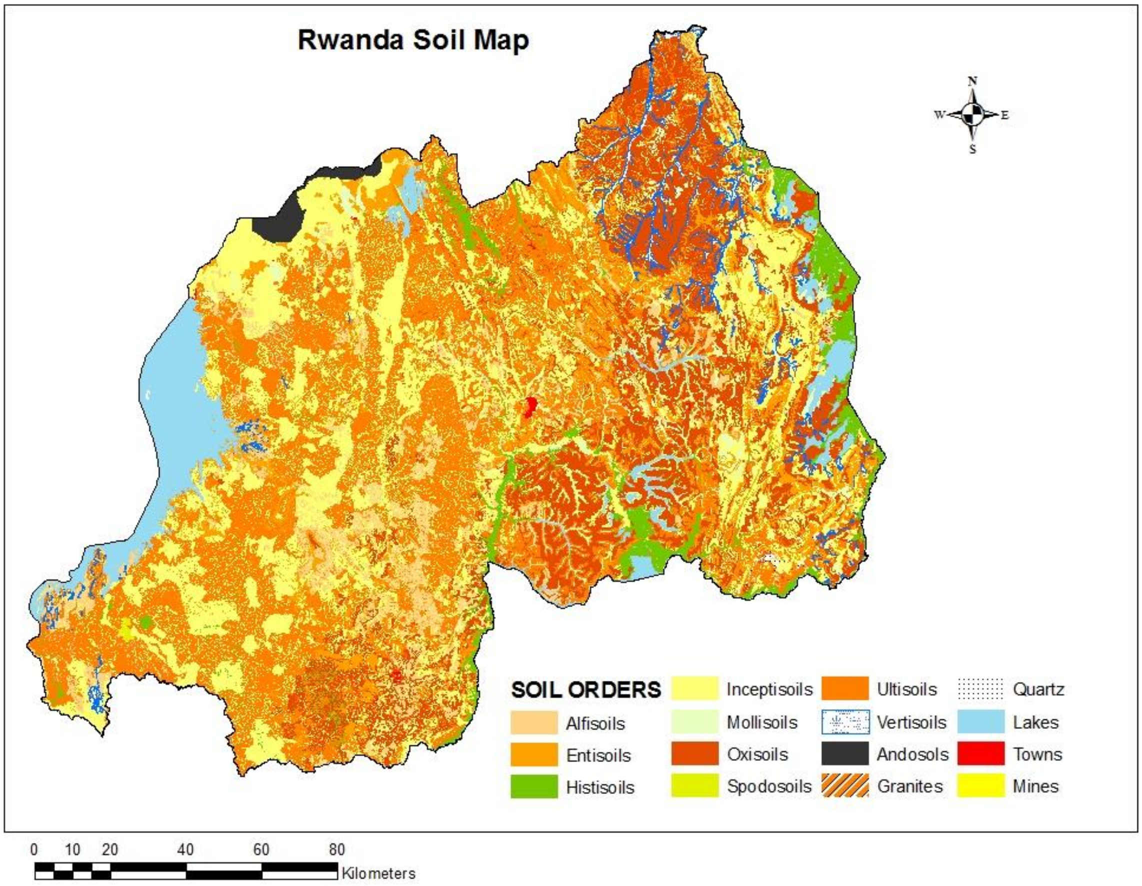

Figure 4: Rwanda soil map. Soils are classified using the USDA soil taxonomy (source: Data collected from MINAGRI, using the Rwanda soil database) doi:10.1371/journal.pone.0107449.g005.

CHAPTER TWO
LITERATURE REVIEW

2.0 INTRODUCTION

This chapter gives all the details of the information and sources from different published papers, journals and thesis as well focusing to growth and development of maize crop and some details on AquaCrop model.

2.1 Origin and Geographical distribution of Maize

The primary origin of maize is considered by most institutions to be the Central America and Mexico, where the many diverse types of maize are found. The discovery of fossil maze pollen with other archaeological proof in Mexico that explains Mexico to be the native maize. Maize crop is cultivated throughout the worldwide between 40^0S to 58^0N latitude. Maharashtra are mainly important states of maize production (FAO, 2011)

Maize is the mostly valuable crop in the world in terms of yield production compared to wheat and rice are also the always important as directly human and animal feedings. Maize seeds are consumed by humans directly or after processing and are involved as major highlighted to livestock feeding, alcohol as biofuel and vegetable oil are mostly extracted under maize grains. Total area occupied by cereals and the yield/ha have been changed over time, annual production was 819 million tons by 2009 (FAO, 2011). The yield production of wheat and rice for each year are around 16% lower than maize, with rice cultivated although same size of area as maize and wheat cultivated on 30% more than maize crop. Generally all the maize yielding are hybrids.

2.2 Growth and Development of maize

Maize leaves parts are developed and expanded accordingly to their position with the nodes on the stem. Cultivars change with the number of leaves largely depending on their life-cycle, the mostly number of high-yielding cultivars ranges between 18-22 leaves (Rhoads and Bennett, 1990). Because few leaves always covers the smaller leaf area per crop, short seasonal cropping usually require to be cultivated at an adequate density for reaching the maximum canopy cover (CCx) as a long-seasonal cultivars.

Areas with limited rainfall or no irrigation, or poor soil mineral substances, crop population can be decreased to match for availability resources. As a C_4 plant, the growth and development of leaves is higher for reaching to maximum Canopy Growth Coefficient (CGC) (Rhoads and Bennet, 1990)

2.3 Water, Soil and Climatic Requirements of maize crop

Maize crop is sensitive to both moisture stress and excessive moisture, hence irrigation should be regulated according to the requirement. Should be ensured Optimum moisture availability during the most critical phase (45 to 65 days after sowing); otherwise yield will be reduced by a considerable extent. Irrigation according to the following growth phase of the crop. Critical stages are, 6th leaf, late knee high, tasselling, 50% silking and dough stages. Tasseling and silking are most critical stages and water stress during these stages reduces the maize yields considerably. About 600-700 mm is needed for 100 days crop. Deep, fertile, rich in organic matter and well drained soils are the most preferred ones for the crop; however, maize can be grown on a variety of soil type (Ayers and Westcot, 1985)

The soil should be medium textured with good water holding capacity. The crop is very sensitive to water logging and since it is mainly grown during rainy season, care should be taken to assure that water does not stagnate on the soil surface for more than 4-5 hours. Loamy or silty loam soil or silty clay loam soil having fairly permeable sub soil are ideal soil types. Thus, the ideal soil is neither clayey nor sandy and has a pH between 6.5 and 7.5 along with an exchangeable ion capacity of around 20 milli-equivalent/100g, base saturation of 70-90%, bulk density of about 1.3 g/cc and water-holding capacity of about 16cm/m depth responses (Bradford and Hsiao, 1982).

The Maize requires temperatures ranging from 9°C to 30°C (9°C as minimum temperature and 30°C as maximum temperature) from planting to emergence. During emergence to silking, leaf number increases with temperature and photoperiod. Time to tassel increases as the diurnal variation increase from 0-17°C. Maximum rate of maize growth is at 30°C. The longer the grain filling period, the higher the grain yield provided no freezing temperature. The higher the solar radiation, the higher will be the photosynthesis rate in maize (de Wit, 1958; Steduto *et al*., 2007).

2.4 Harvesting and Yield of Maize

In the last few decades maize grain has raised in the world, much of this raising up is because of higher planting population, improved fertility, maximal irrigation and maximum canopy cover, late- maturity regarding to life cycles. Yield of about 17 tons/ha for late- maturity maize, grown with availability of mineral substances and water under favorable environmental conditions with sustainable weed and pest management, published in different research and farm tests. In farm yields about 11 to 14 tons per hectare are usually harvested under optimal irrigation and higher fertilization management (Caldwell and Hansen, 1993).

2.5 Maize Plant Properties and Uses

Maize crop is defined as staple human food, livestock feed and others industrial uses. I contains more starch (65%). Maize is divided into different two categories of millets. Wet millet provide industrial starch. Therefore manufactures numerous transformed maize starch for sizing, laundry and textile finishing. Dry millet is harmonizing process for maize meal and livestock feeding, distilling industries and fermentation. It can be alternate crop to wheat and rice. Almost 35% production for human consumption, 25% cattle and poultry feeding, 5% industrial food processing (Hillel and Vlek, 2005).

2.6 Relationship of Maize yield and climate parameters

Agriculture drought occurs when there is in adequate soil moisture and evapotranspirative demands was not enough to initiate and sustain crop growth. Therefore, soil water deficit and plant water available is not sufficient for optimal plant growth. The deficit rainfall influences the maize crop in its different development stage (Dutra *et al.,* 2012), and leads to malfunction and deficiency topsoil moisture at sowing time and resulting in significantly reduction of Yields (wilhite *et al.*, 1985). The sector of economic agriculture is mostly affected by prolonged drought especially if the deficit soil moisture is associated by high temperature and strong winds. The lowlands are expected to record a decreasing trend in major food crops yields as result of observed decreasing trends in mean rainfall and frequency. The projected increase in crop yields during long rains season for cereals crops (maize, rice and rice) are in the correlation to increase in climatic parameters such as (rainfall, temperature and evapotranspiration).

2.7 Modeling Crop Production

AquaCrop model was formulated by the Land and Water Division of FAO and published for use in 2009 (Steduto *et al,*. 2009; Raes *et al,*. 2009a). One of the important key features of AquaCrop model to simulate attainable crop biomass and harvestable yield in response to the water availability of the major herbaceous crops. It facilitates for developing efficient strategies through conserving water resources for sustainable agriculture.

The model flow chart relationship between the plan-soil –atmosphere systems makes it totally complicate for one to explain how much water is required for optimum growth of crops. However, simulation models can greatly help us to understand the interrelationship of factors within the system. Models harmonize the processes in the real system and predict variables at every stage in the simulation. In recent year, simulation models are widely used to innovate solutions for water management problems. AquaCrop model however needs to be calibrated and validated for local crops with regard to local soil characteristics and climate. CropSyst depends on radiation and water driven modules, while the WOFOST is used to simulate plant growth implying a driven carbon its fraction to intercept soil radiation (Todorovic *et al.,* 2009). However, it was advised that under limited inputs and yield prediction accordingly to water users conditions, researchers are preferred to utilize the AquaCrop model as simplest model over other complex models. Figure 5 shows the flow chart of the AquaCrop model, showing the function relationship between the different model components.

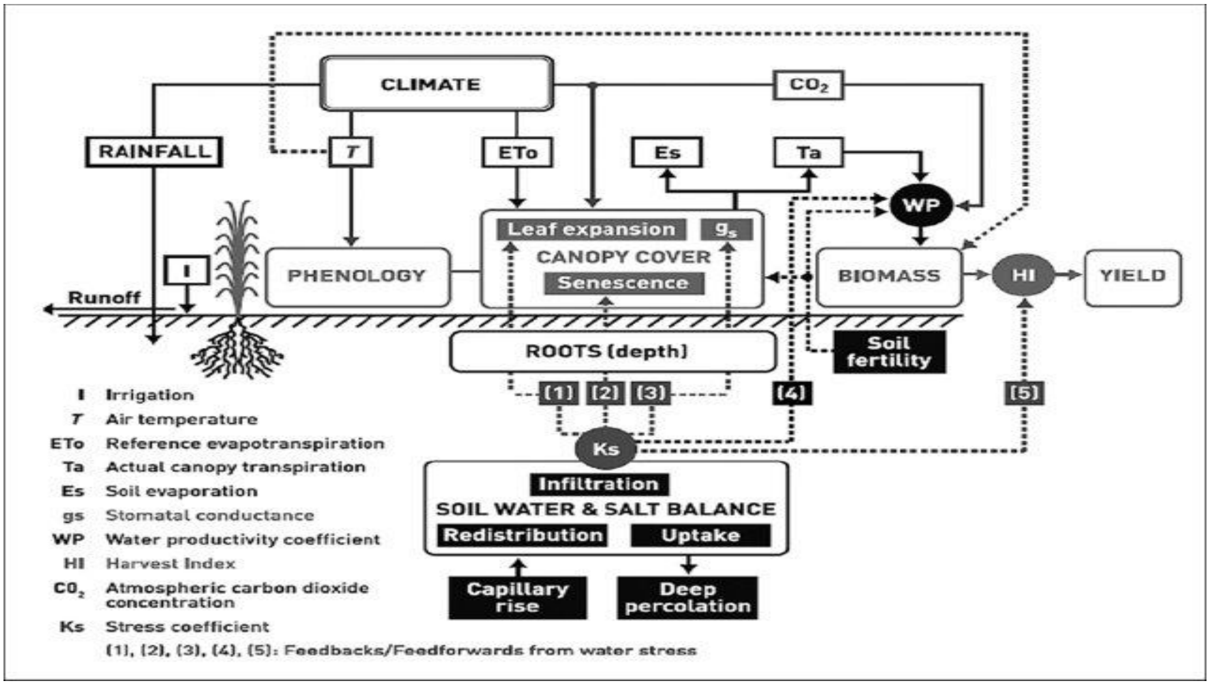

Figure 5: AquaCrop model flow chart and the relationship between the model components (Raes *et al.*, 2009a)

2.7.1 Soil Water Balance

The principle of water balance is a removal or a transport within the soil-plant-atmosphere of the inputs and outputs of water. The water balance diagram, whether it is an agricultural field, watershed or continent, can be characterized by computing the input, output and storage changes of water on the earth's surface (Ines et al., 2001). The major input of water is derived from precipitation and irrigation and outputs is evapotranspiration ((Steduto *et al,*. 2007; 2009).

2.7.2 Evapotranspiration

Evapotranspiration (ET) is defined as an important component of water cycle and is divided into two sub-processes: evaporation from vegetation and soil surfaces and transpiration that allows of the exchange of moisture and the plant and atmosphere through plant leaves (stomata). The evapotranspiration can be difficult to quantify accurately, especially at large spatial scales, several hydrological modeling practices have been innovated to estimate actual evapotranspiration by using satellite remote sensing (Bastiaans *et al.*, 2003; Allen *et al.*, 2007; Senay *et al.*, 2007).

CHAPTER THREE

DATA AND METHODOLOGY

3.0 INTRODUCTION

This chapter gives the details of the type, duration and sources of the data as well as the methodologies that is used to achieve the specific objectives of this study.

3.1 Data

3.1.1 Climate Data

The climate datasets that were utilized in this study are daily maximum and minimum temperatures (1983-2016), rainfall (1983-2016) and evapotranspiration (1983-2016) from agro-meteorological stations in Eastern province of Rwanda. These datasets were obtained from Rwanda Meteorological Agency, Carbon dioxide concentration data was retrieved from the FAO manual, Mauna Loa Observatory (MLO).

3.1.2 Crop data

The required crop datasets included crop type (maize), time of planting emergency for 90% initial canopy cover, planting density phonological states (emergence,flowering,maturity,haversting) and length of growth cycle from (2002-2016). These data were obtained from Rwanda Agriculture Board (RAB), Ministry of Agriculture and Animals Resources (MINAGRI) and National Institute of Statistic of Rwanda (NISR).

3.1.3 Soil data

The soil data included soil type, soil texture, root depth and water balance. These datasets are obtained from Rwanda Agriculture Board (RAB) in Rwanda and other from Food Agriculture Organization (FAO) manual.

3.1.4 Management data

In the Eastern province of Rwanda the method of planning as practiced by framers is not documented. Therefore, default values of management input data in AquaCrop is in relation to rainfed, fertilizer application and land use were used.

3.1.5 Model data

In this study simulated monthly rainfall and temperature data from CORDEX RCMs will be used. The datasets are quality controlled and may be used according to the terms of use (http://wcrp-cordex.ipsl.jussieu.fr/). The spatial grid resolutions of all simulated data is about 50km (0.44°) over CORDEX Africa domain. The data set to be used is 1980-2000 and GCMSs over Africa will be tested, RCP 4.5 and 8.5 will be used. The detailed description of CORDEX RCMs, their dynamics and physical parameterization will be used according (Nikurin ,2012 and (Luhunga *et al., 2016)* in his test of CORDEX –Africa, to simulate rainfall in Tanzania.

3.2 Methodology

3.2.1 Estimation of missing data and quality control

There are several methods to estimate missing weather data. The chosen method depends on the nature of missing data (spatial or temporal). The study employed correlation and arithmetic mean method because of the few missing data among data sets through the below formula showed in Equation1:

$$xi = xo\ \frac{\overline{x\imath}}{\overline{xo}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(1)}$$

Where X_i is the estimated data

X_o is the data of the station with highest correlation with station whose data is missing, while

$\overline{xo}$ represent the mean value for the station with complete data

$\overline{x\imath}$ is the mean value for the station with missing data

The contingency rainfall, temperature and maize yield datasets were tested by using the Standard Normal homogeneity Test (SNHT).

The SNHT (Standard Normal homogeneity Test) was developed by Alexanderson (1986) to detect a change in series of all climatic datasets. The test is applied to series of ratios that compare observations of measuring station with the average several stations.

3.2.2 Determining the Trend and Variability of Climate Parameters and Maize

The statistical techniques used for trend analysis can be either parametric or non-parametric. For parametric method, the coefficient of variation is used to check the variability of climatic parameters while the Mann Kendall Test is used to determining the trend of climate parameters for non-parametric method. The coefficient of variation and Mann Kendall techniques are discussed in the next sub-section.

3.2.3 Mann Kendall Test

The Mann Kendall (MK) Test help to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time (Kendall, 1978). A monotonic upward (downward) trend implies that the variables constantly increases (decreases) with either a linear or nonlinear trend (Hirsch, *et al.,* 1982) pointed out that the MK Test is best utilized as an exploratory analysis and is mostly used to differentiate stations where changes are significant or of large magnitude and to quality these findings.

$$\boldsymbol{S} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n-1}} \sum_{\boldsymbol{j=i+1}}^{\mathbf{n}} \mathbf{sgn}(\mathbf{Xj} - \mathbf{Xi}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{2})$$

Where X_i and X_j are sequential values data and n is the length of datasets. If S is positive, observations recorded later tend to be larger than observations done earlier. If S is negative, then the observations provided later tend to be smaller than observations done earlier

3.2.4 Coefficient of variation

Coefficient of variation (CV) was used for determining variability in temperature and rainfall was applied to meteorological datasets. The coefficient of variation (CV) is a statistical measure of how the individual data points vary about the mean value (Trendberth, 1984). Coefficient of variation was calculated by dividing the standard deviation by the mean. Values less than 1 explain that the data form are relatively close group about the mean. Values larger than 1 explain that the data show a greater degree of scatter about the mean.

Coefficient of variation (CV) = (Standard deviation/Mean) x100………………………….. (3)

3.2.5 Determining the Relationship between the Weather parameters and Maize Yield

To determine the relation between the climate data and maize yield production, there are several statistics tools or techniques, which can be used but this study adopted correlation and regression techniques. Focus was made on annual data (1981-2017) to understand how the events impacts on maize yields.

3.2.6 Correlation Analysis

This method provides interrelationship within two variables. The Pearson correlation coefficient r is a measure of the linear relationship between two attributes or columns of data. The value of (r) range from -1 to +1. The value of r near 0 indicates little correlation between variables, a value near -1 to +1 indicates a high level of correlation. For this study, the value of r were computed using the Pearson correlation coefficient equation.

$$\boldsymbol{r} = \frac{\sum_{i=1}^{N}(Xi-\bar{X})(Yi-\bar{Y})}{\left[\sum_{i=1}^{N}(Xi-\bar{X})^{2}\sum_{i=1}^{N}((Yi-\bar{Y})^{2}\right]}\,\tfrac{1}{2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ (4)$$

Where r is correlation coefficient, X is independent variable and represent the Temperature, Rainfall, and evapotranspiration. Y is dependent variable and represents the maize yield $\bar{X}$ and $\bar{Y}$

are the mean of independent and dependent variables respectively. i=1, 2, 3…..N where N is number of variables.

To test the significance of the correlation coefficient obtained, Student t Test as shown in Equation 5 was used.

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Where: t is the absolute student t statistic, r is the correlation coefficient obtained from equation 4, n is sample size, n-2 is degree of freedom

3.2.7 Multiple Regression Analysis

Multiple regression is a simple linear regression in which more than one independent variable (X) is used to predict a single dependent variable(Y). The response of Y_n formulated though Equation 6 below:

$$Y_n = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where Y is the dependent variable b_o is an intercept, b is coefficient of independent variables X and n refers to the nth observation.

3.2.8 AquaCrop model for maize yields prediction

To model Maize yield predicting, the AquaCrop model was used. The AquaCrop model utilizes daily climatic (rainfall, temperature, reference evapotranspiration and carbon dioxide concentration. S=as inputs data. The combination of these climatic variables were used to make climate files for the base e year and the year under climate variability. In AquaCrop, the inputs were saved in climate, type of crop, soil type, management (irrigation) and initial soil water condition files (Raes *et al.,* 2009a). Those model parameters that do not change with time such as normalized water productivity (WP*), canopy development coefficient (CDC),harvest index (HI), and actual transpiration (Ta) was named conservative (nearly constant).Detailed description of the model was given by Steduto *et al.,*2009). This model was run to simulate crop growth and data and data generated was compared with measured datasets.

3.2.9 Modelling Crop Production

Parameters and input data as in other crop models, AquaCrop consist of soil-plant-atmosphere continuum. The climate component requires daily weather data on maximum and minimum air temperature, rainfall, reference evapotranspiration (ET_O) and carbon dioxide concentration (CO_2). These data were collected from agro-meteorological-stations based in Eastern province of Rwanda. The daily ETo was computed though FAO ETo calculator version 3.2, as software based on FAO Penman-Monteith Equation (Version three, January 2009; Raes *et al.,* 2009b). This method is the widely recommended standard equation for computing ETo (Allen *et al.,* 1998). Daily inputs for FAO ETo Calculator are maximum and minimum temperatures based on actual measured weather data during plant growth. The simulation results of AquaCrop estimates the biomass and expected crop yield for a specified environmental and climate.

3.2.10 The performance of CORDEX- RCMs in simulating climate over Rwanda

The ability of CORDEX RCMs to simulate Rwanda rainfall and temperature data will be assessed, using Regional Climate Model Evaluation System (RCMES). This system is a suite of software resources to standardize and streamline the process by interacting with observational data and climate Regional Climate Models (RCM) output (Luhunga et al., 2016).

The temperature and rainfall models output from CORDEX RCMs Africa will be compared to blended data (temperature and rainfall) from ENACTs dataset, hosted by Rwanda meteorology Agency. The CORDEX baseline to be tested I relation to observation data is 1980-2010. Some error analysis techniques such as BIAS, Root Mean Square Error RMSE) and Pearson correlation coefficient (r) will be computed and used

$$\textbf{Bias} = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(7)}$$

$$\textbf{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(8)}$$

Where F and O in eq. (7) and (8) are the simulated and observed value respectively, while I refer to simulated and observed pairs and N is the number of those pairs. Normalized bias and RSME will be calculated to compare simulated values and observed data. Normalized bias in equation (7) gives eq. (9) which normalized bias (N Bias), and normalized eq. (10) gives equation (8), which normalized root mean square error (NRMSE).

$$\textbf{N Bias} = \frac{\boldsymbol{Bias}}{\boldsymbol{Mean_{Observation}}} \times \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(9)}$$

This will test whether simulations values from RCM models underestimates or overestimate climate variables. N Bias is negative where simulations underestimate climate variables and positives where they overestimate.

$$\textbf{N RMSE} = \frac{\boldsymbol{RMSE}}{\boldsymbol{Mean}\ \boldsymbol{_{Observation}}} \times \mathbf{100} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(10)}$$

Normalized RMSE will test the absolute error of climate model in simulating rainfall and temperature, the small value imply good model and vice versa.

$$\boldsymbol{r}_{(\boldsymbol{F},\boldsymbol{O})} = \frac{\sum_{i=1}^{N}(\boldsymbol{F_i}-\bar{\boldsymbol{F}})(\boldsymbol{O_i}-\bar{\boldsymbol{O}})}{\sqrt{\sum_{i=1}^{N}(\boldsymbol{O_i}-\bar{\boldsymbol{O}})^2}\sqrt{\sum_{i=1}^{N}(\boldsymbol{F_i}-\bar{\boldsymbol{F}})^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(11)}$$

Equation (11) stands for Pearson correlation coefficient (r), which measure the relationship between simulated value and observation values. It is ranging from +1to 11, where positive value indicate good positive correlations between observed and model data, while negative values indicate perfect negative correlation between the two datasets

3.2.11 Conceptual framework for AquaCrop model

Figure 6 shows the flow chart of conceptual framework and the different model inputs in AquaCrop model.

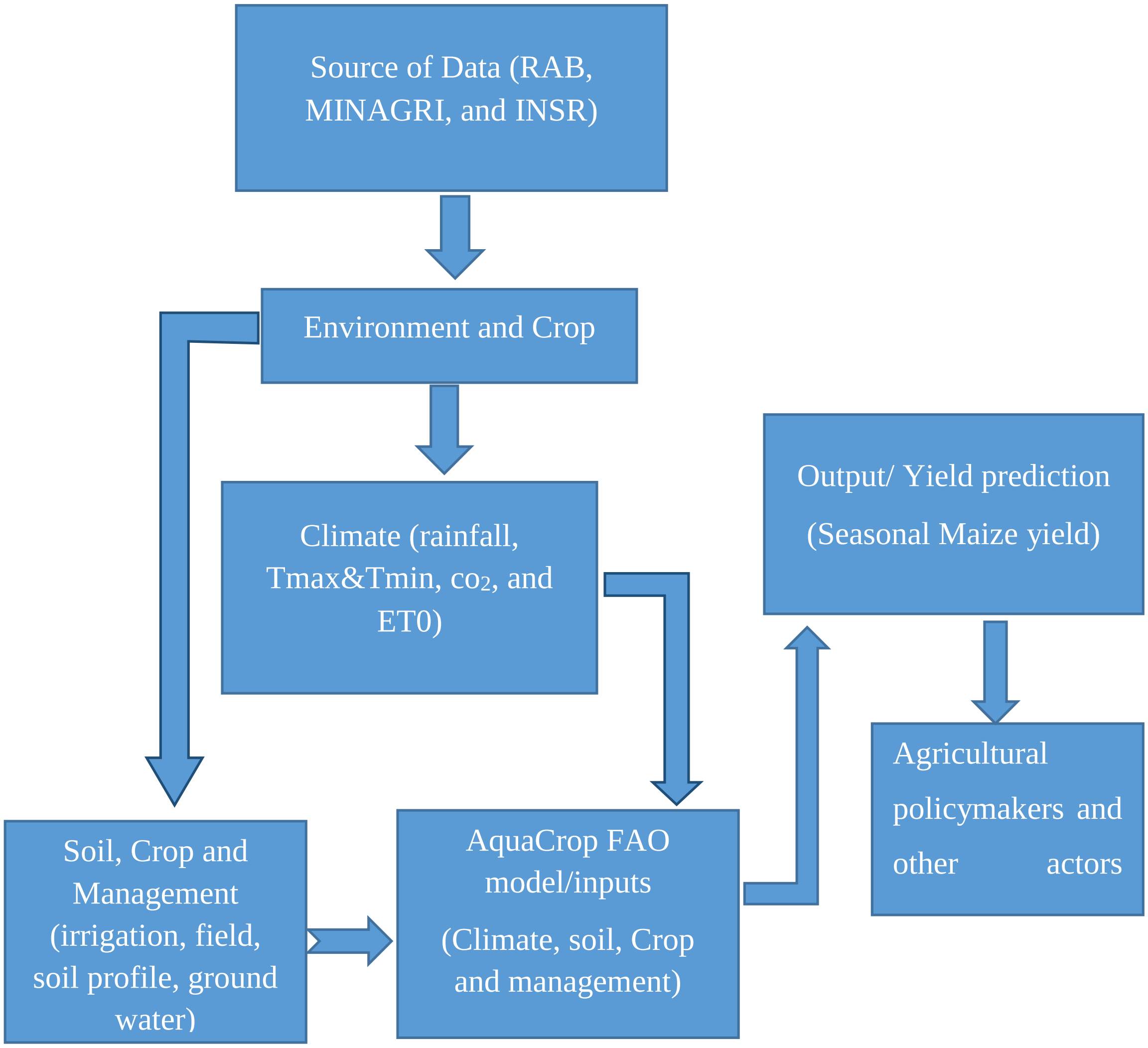

Figure 6: Conceptual framework for AquaCrop model.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter summarizes the outcome from various analysis methods utilized to fulfil the main and specific objectives of this work.

4.1 Data Quality control

4.1.1 Estimation of Missing Data

The climatic data sets (rainfall, maximum temperature and minimum temperature) of Nyagatare and Bugesera meteorological stations over Eastern province of Rwanda were available from (1981-2017), evaporation was calculated through ETO calculator version 3.2 produced in September 2012 by FAO. While the maize yield data was available for 15 years starting from 2002-2016 within two districts (Nyagatare and Bugesera) over Eastern province without missing data (all climate datasets are gridded).

4.1.2 Test for Data Homogeneity

Bellow Figures 7 to 10 show the homogeneity test results, in which standard normal (SNHT) of these four climatic parameters (rainfall, maximum temperature, minimum temperature, and evapotranspiration) for Nyagatare and Bugesera stations over Eastern Province were plotted against time. The plotted time series for rainfall indicated homogeneity for selected years from 1990 to 2016 for Nyagatare and 1993 to 210 for Bugesera (Figure 7). Minimum temperature were same homogeneous from 1983 to 2015 for two Districts (Figure 9). Maximum temperature was found to be homogeneous from years 1983 to 2015 for Nyagatare and 1983 to 2005 for Bugesera districts (Figure 8) and SNHT for evatranspiration shows homogeneity from 1991 to 2015 for Nyagatare and from 1992 to 2014 for Bugesera. The above climatic parameters were used in this study, were homogeneous and the maize yield datasets used in this study was available from years 2002 up to 2016.

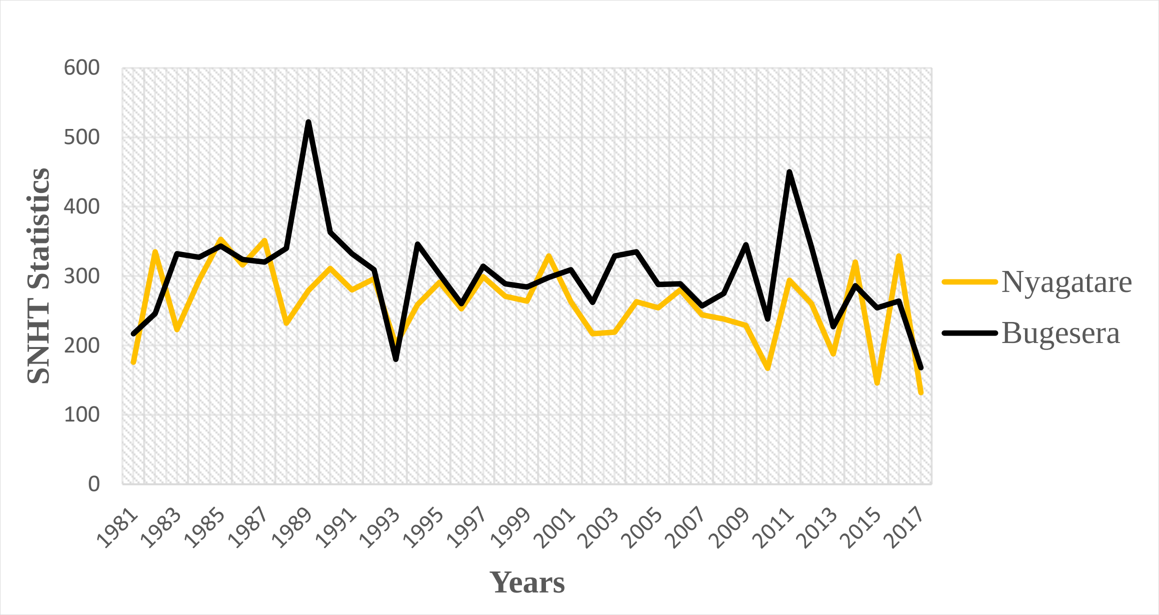

Figure 7: Standard normal homogeneity test of rainfall for Nyagatare and Bugesera Districts over Eastern province from 1981 to 2017

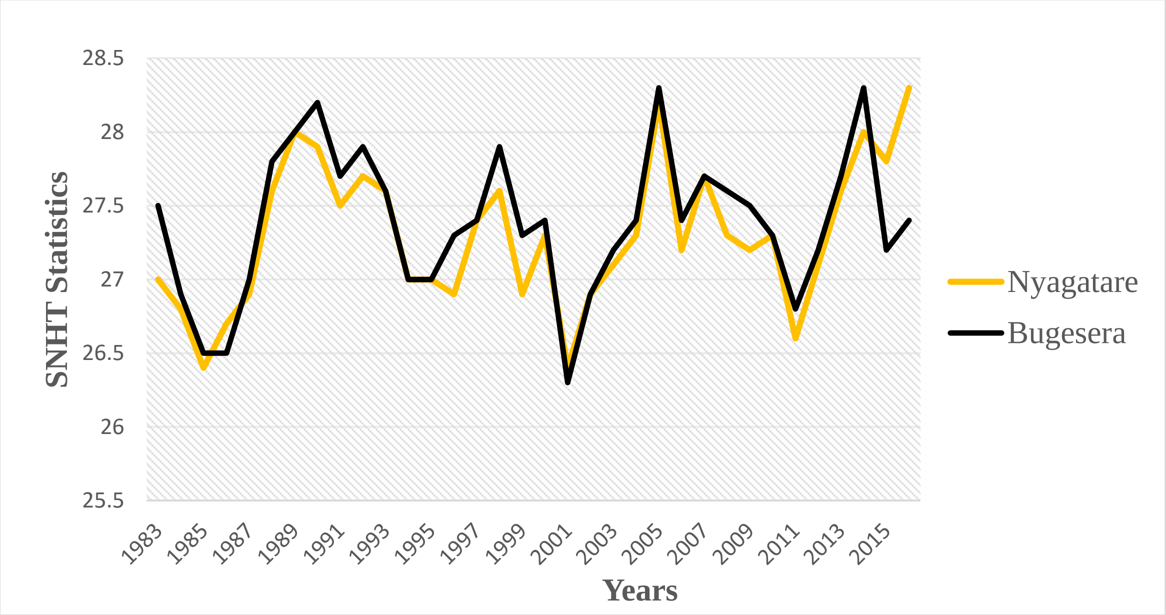

Figure 8: Standard normal homogeneity test of average maximum temperature for Nyagatare and Bugesera Districts over Eastern province from 1983 to 2016.

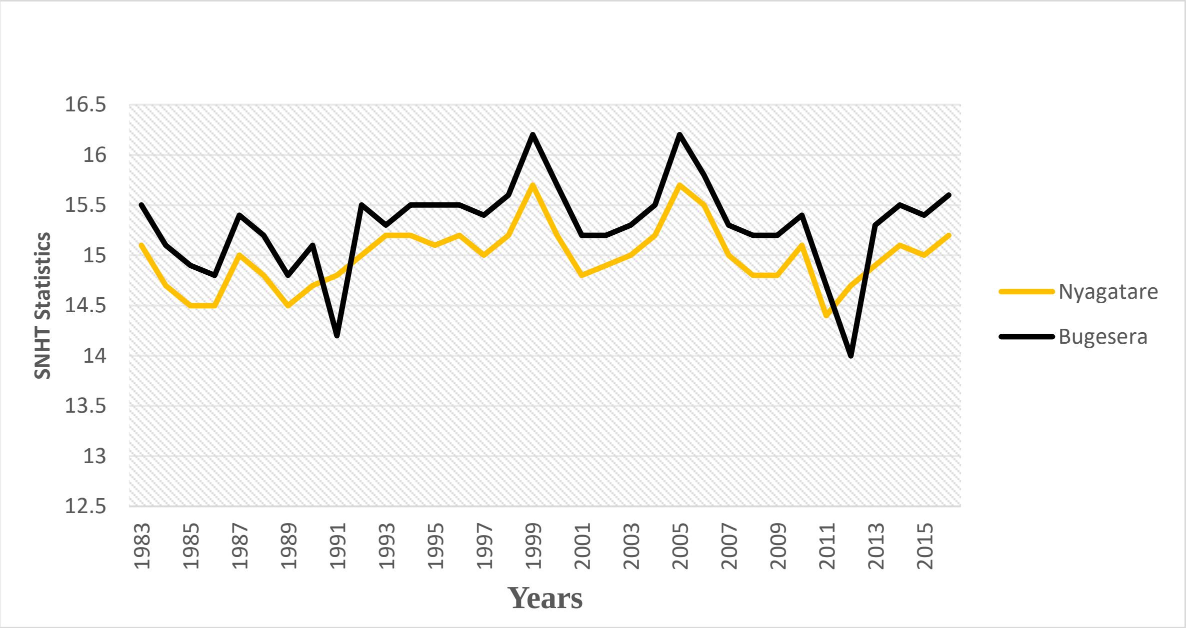

Figure 9: Standard normal homogeneity test of average minimum temperature for Nyagatare and Bugesera in Eastern province from 1983 to 2016.

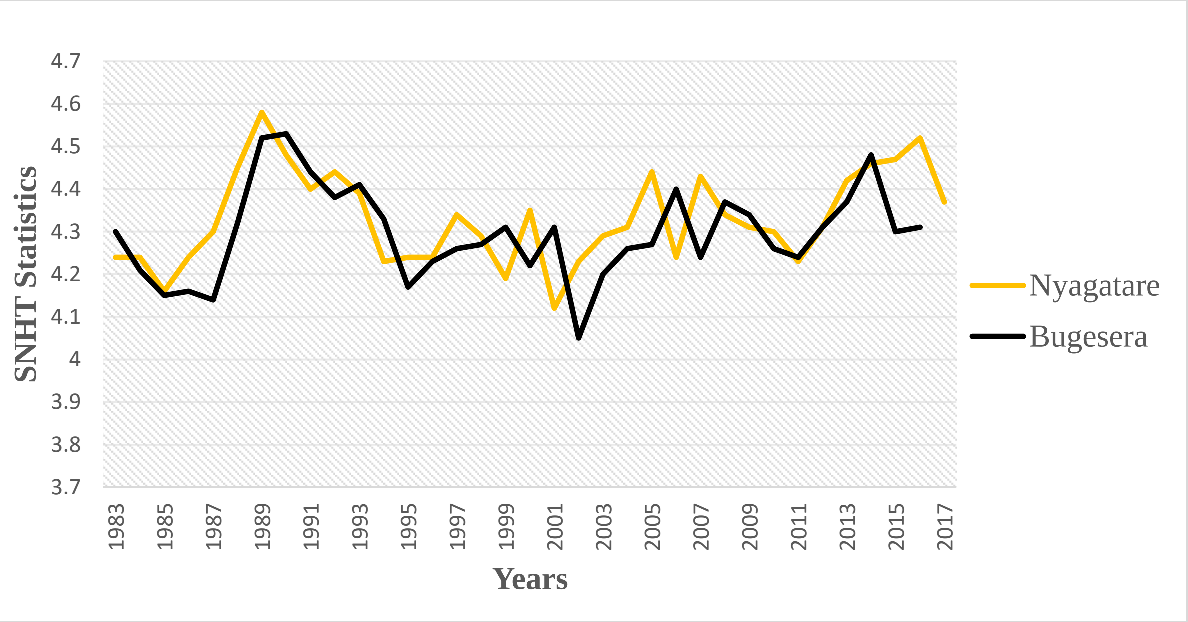

Figure 10: Standard normal homogeneity test of evapotranspiration for Nyagatare and Bugesera Districts in Eastern province from 1983 to 2016.

4.2 Variability of Climate Parameters and Maize Yield

4.2.1 Trend Analysis

The trend analysis was carried out for climatic parameters such as the rainfall, maximum and minimum temperatures, evapotranspiration and maize yield. Table 1 shows that, Maize yield (Figures 11 and 12) and rainfall (Figures 13 and 14) have an insignificant trend (decrease) for Bugesera and Nyagatare areas, because the calculated p-value was lower than significance level alpha=0.05, for rainfall almost equal or close to one. The other remaining climatic parameters such as maximum temperature (Figures 15 and 16), minimum temperature (Figures 17 and 18), mean temperature (Figures 19 and 20), evapotranspiration (Figures 21 and 22) showed a significant trends (increase) over the study areas, because the computed p-value were l than significance level alpha respectively.

Table 1: Mann-Kendall trend test

Districts	Climate Parameters	Computed P-values	Alpha (P≤ 0.05)
Bugesera	Maize yield	0.570	Insignificant
	Rainfall	0.941	Insignificant
	Maximum temperature	0.00934	Significant
	Mean temperature	0.00270	Significant
	Minimum temperature	0.00249	Significant
	Evapotranspiration	0.00414	Significant
Nyagatare	Maize yield	0.511	Insignificant
	Rainfall	0.824	Insignificant
	Maximum temperature	0. 0084	Significant
	Mean temperature	0.0071	Significant
	Minimum temperature	0. 00187	Significant
	Evapotranspiration	0. 00175	Significant

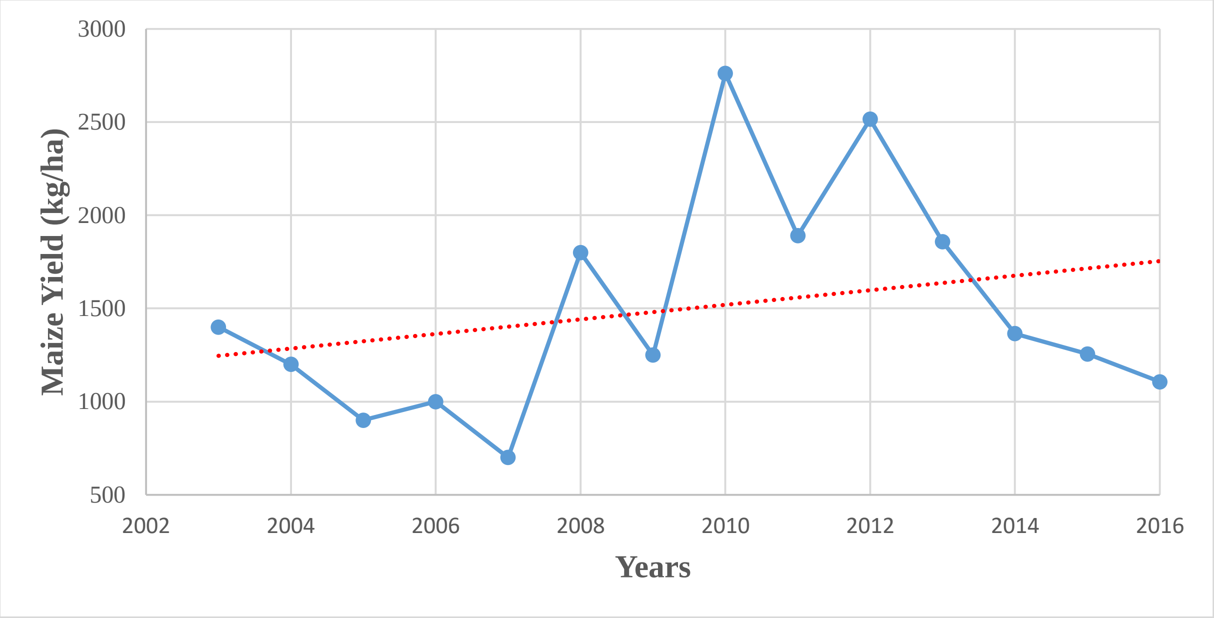

Figure 11: Mann Kendall Trend Analysis of Maize Yield for Bugesera over Eastern province from 2002 to 2016.

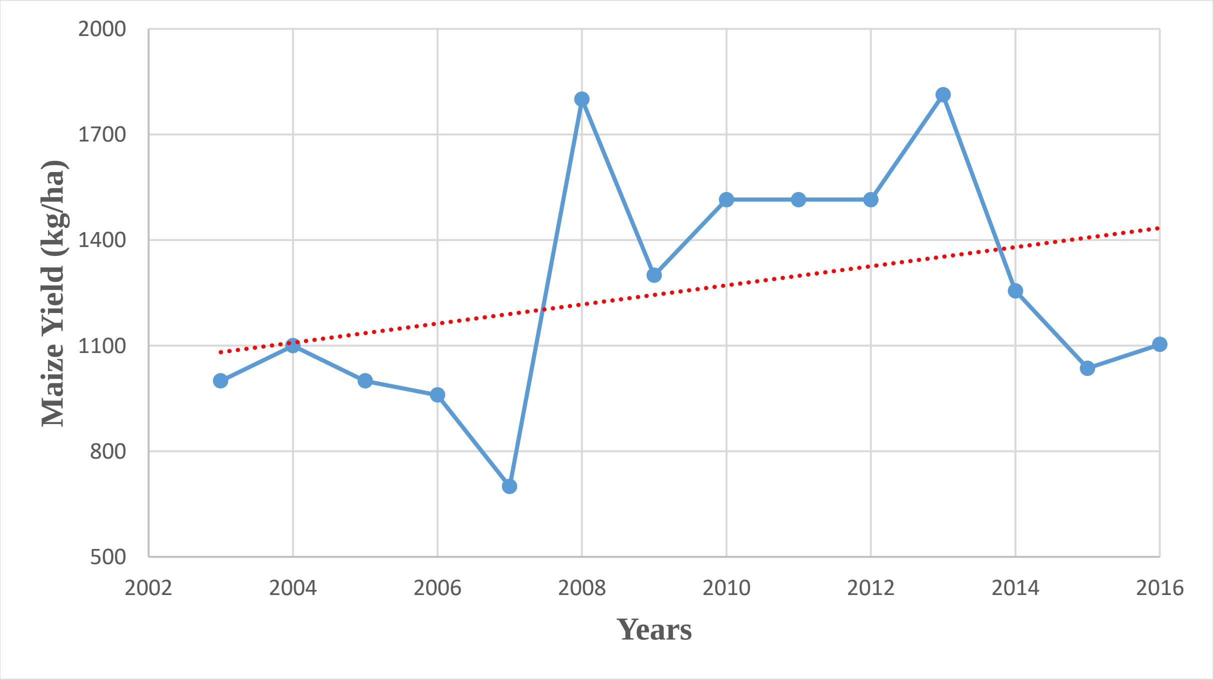

Figure 12: Mann Kendal Trend Analysis of Maize Yield for Nyagatare District over Eastern province from 2002 to 2016.

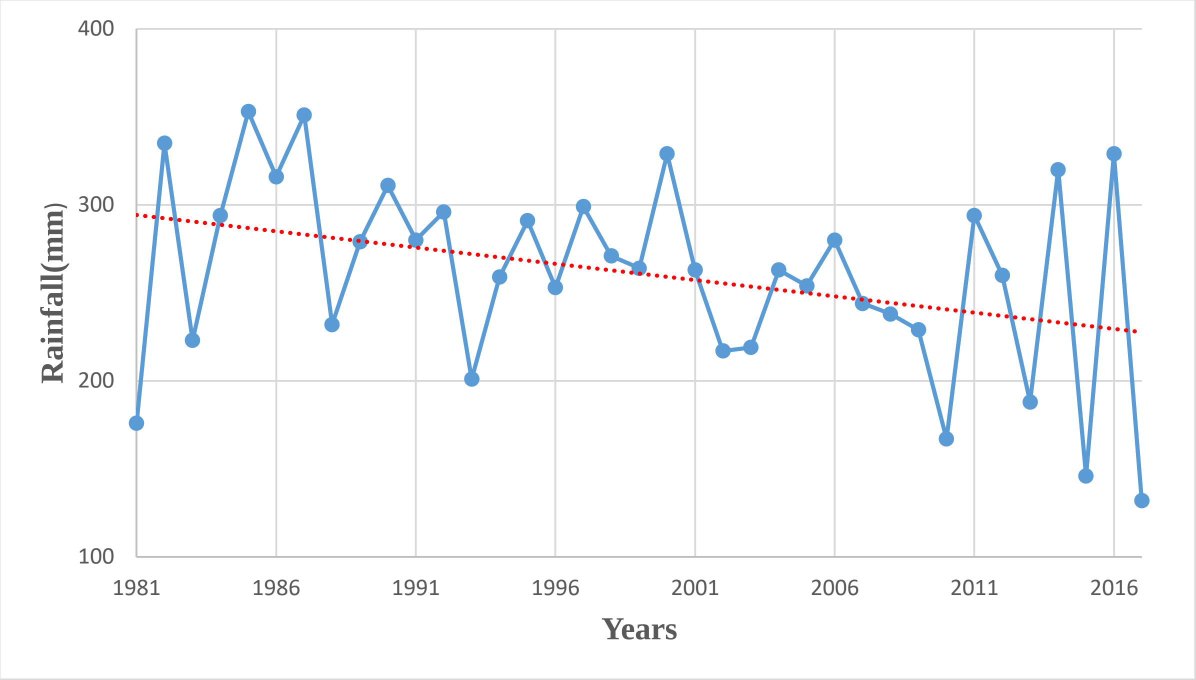

Figure 13: Mann Kendall Trend Analysis of Annual Rainfall for Nyagatare District over Eastern province from 1981 to 2017.

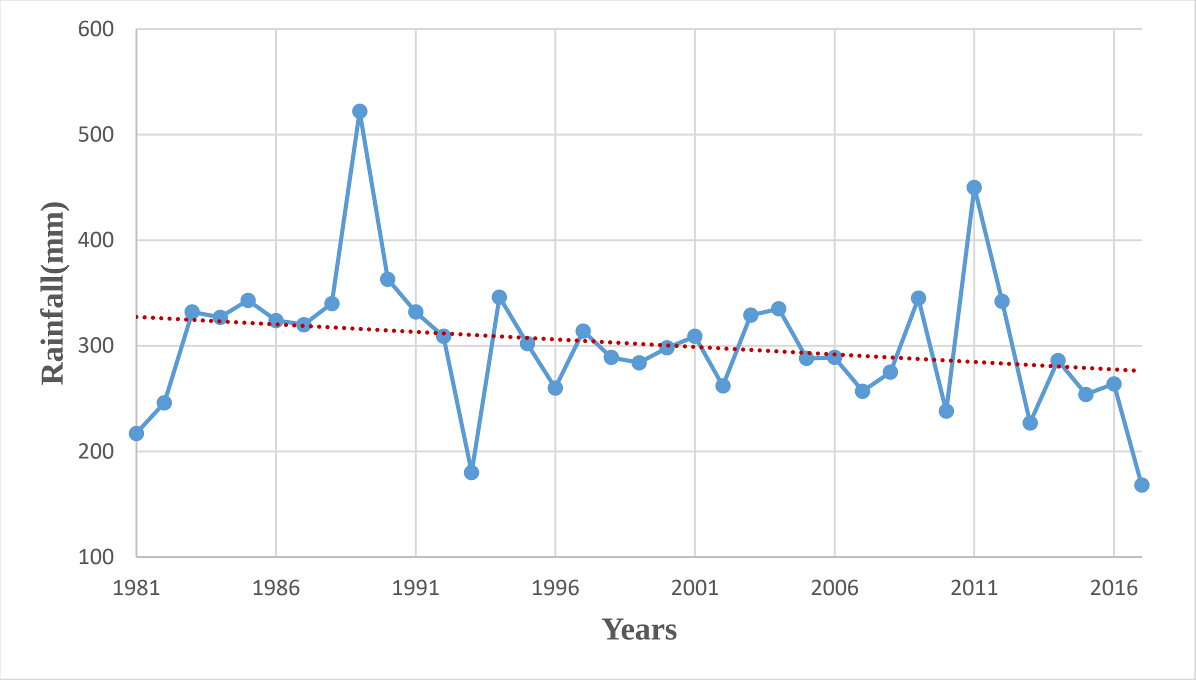

Figure 14: Mann Kendall Trend Analysis of Rainfall for Bugesera District over Eastern province from 1981 to 2017.

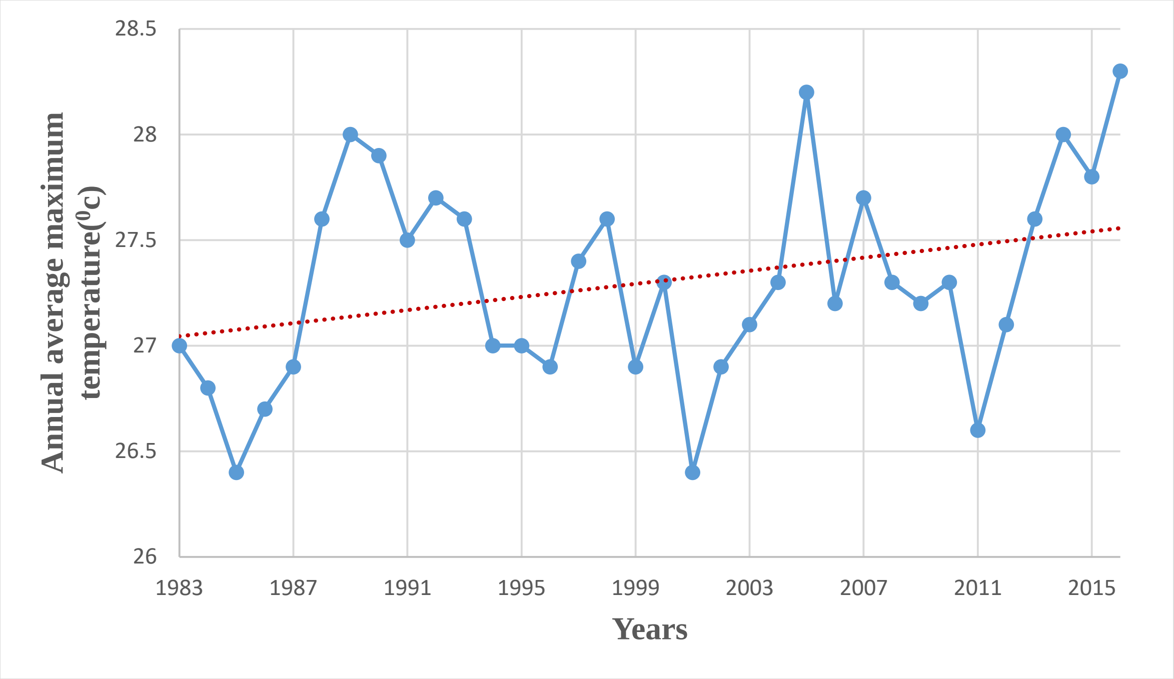

Figure 15: Mann Kendall of Annual Average Maximum Temperature for Nyagatare District over Eastern province from 1983 to 2016.

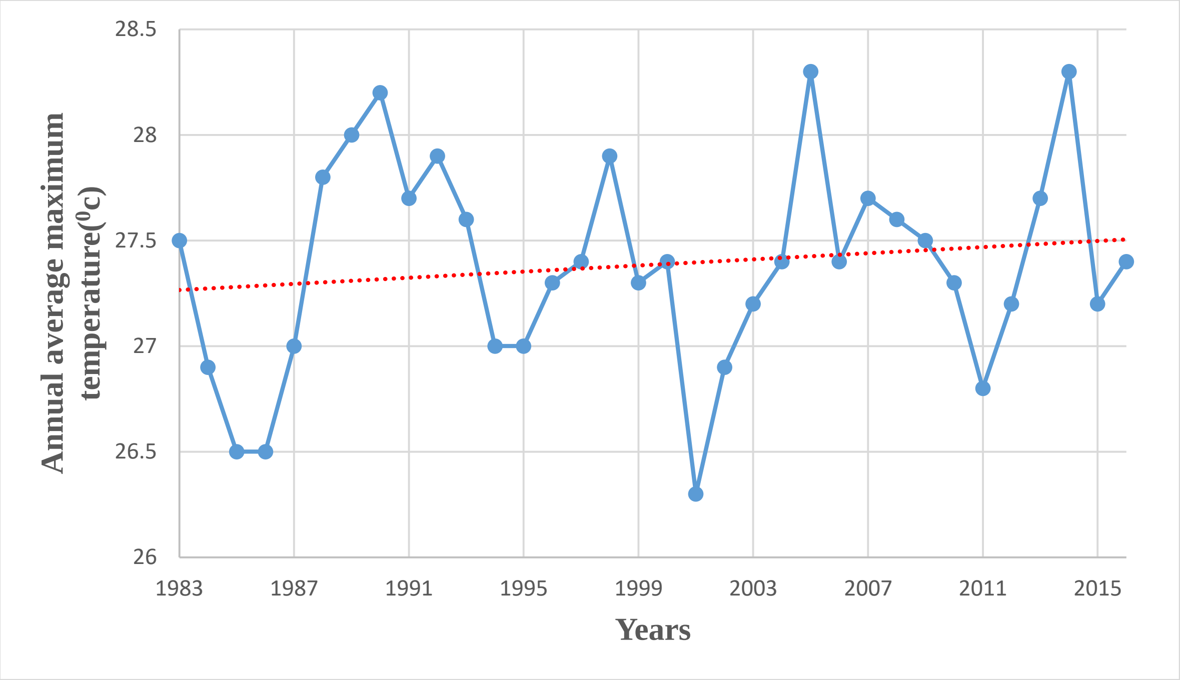

Figure 16: Mann Kendall Trend Analysis of Annual Average Maximum Temperature for Bugesera District over Eastern province from 1983 to 2016.

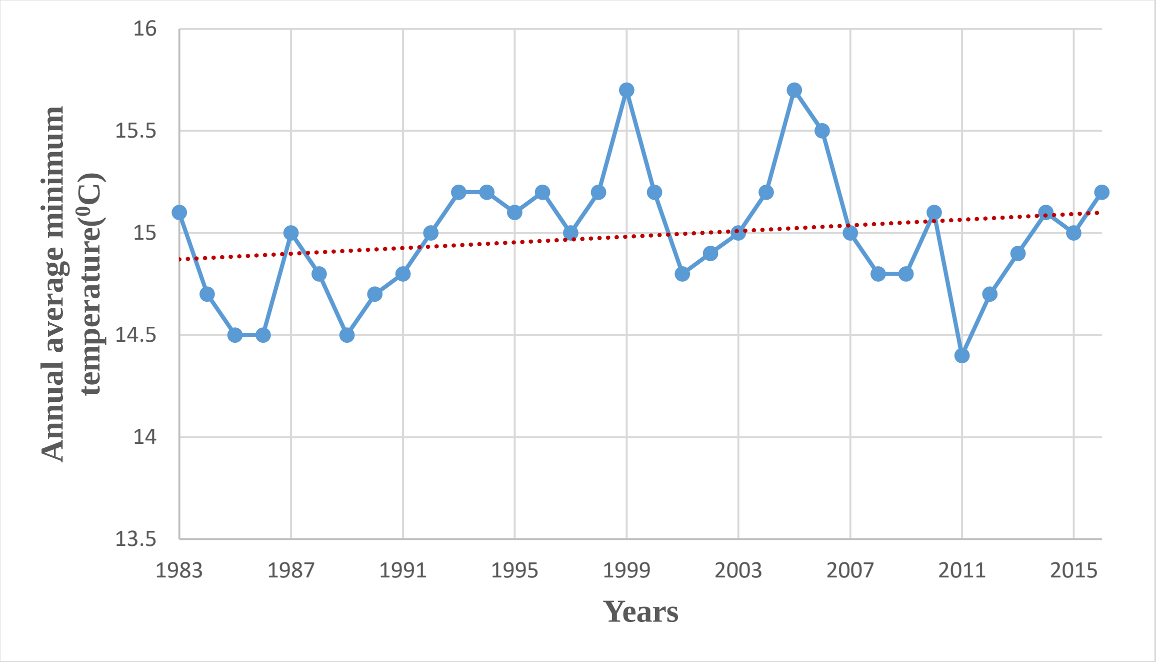

Figure 17: Mann Kendall Trend Analysis of Annual Average Minimum Temperature for Nyagatare District over Eastern province from 1983 to 2016.

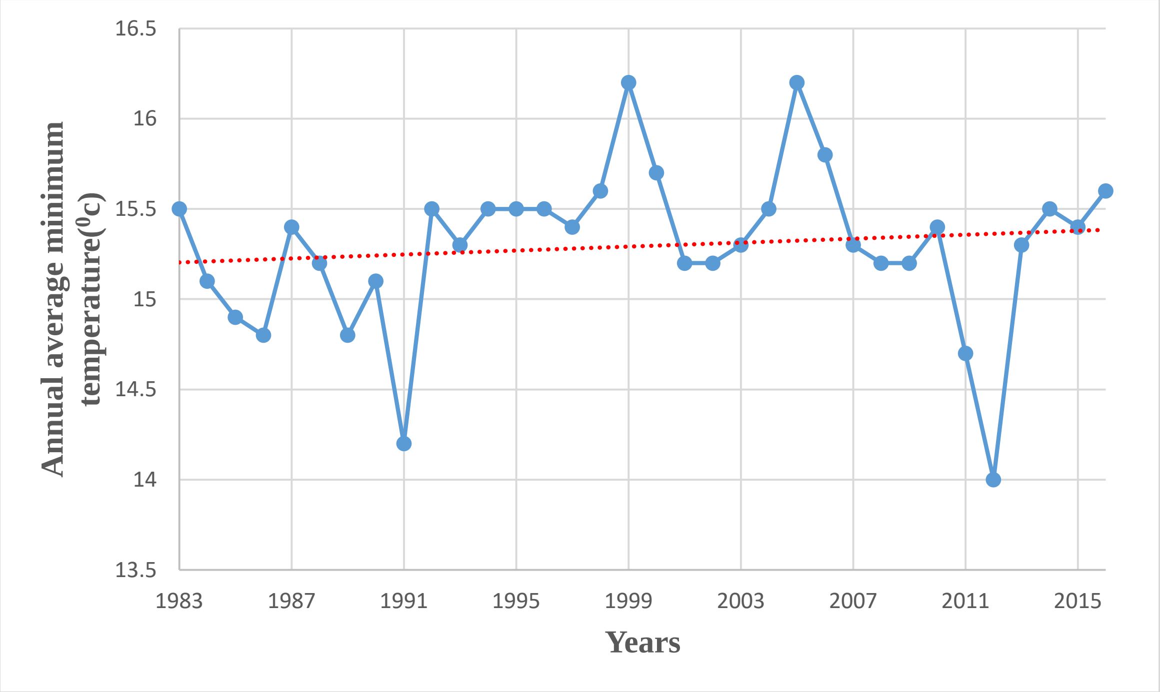

Figure 18: Mann Kendal Trend Analysis of Annual maximum Temperature for Bugesera District over Eastern province from 1983 to 2016.

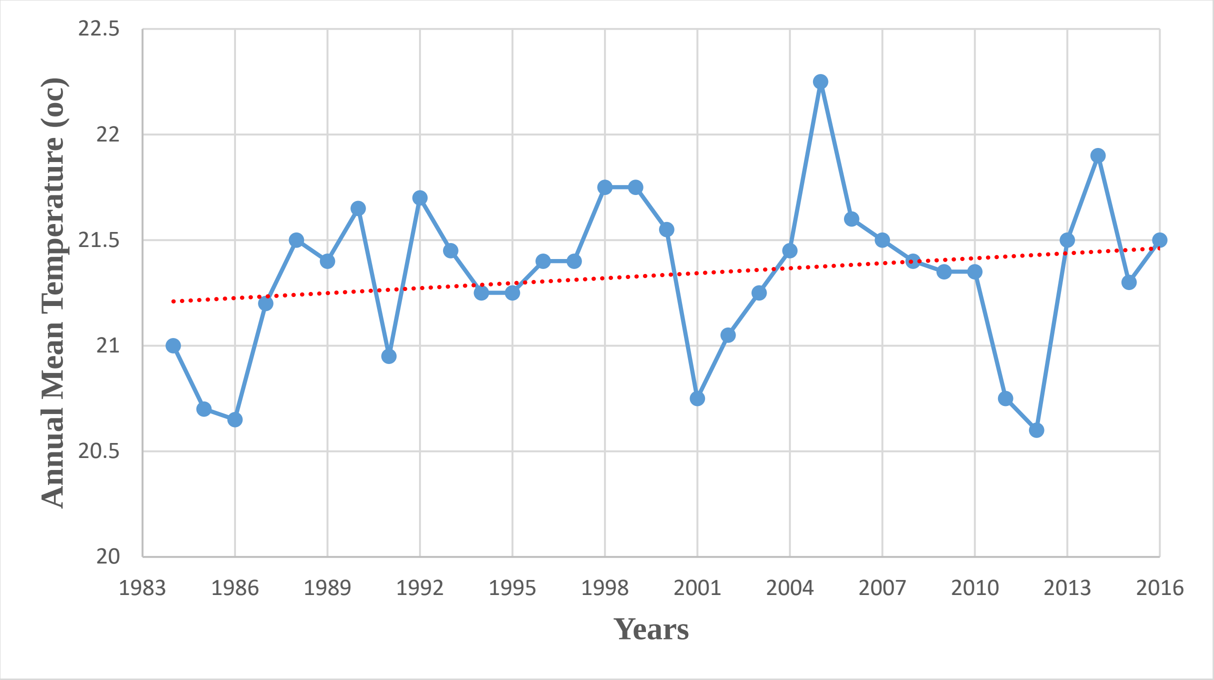

Figure 19: Mann Kendal Trend Analysis of Mean Temperature for Bugesera District over Eastern province from 1983 to 2016.

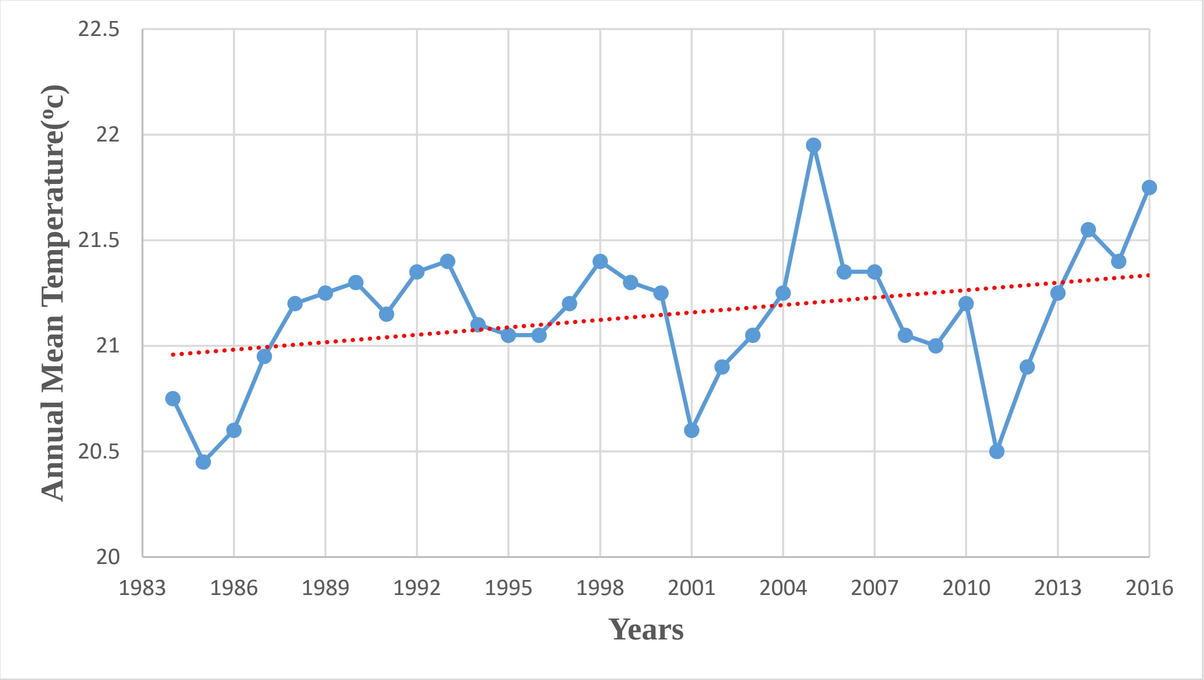

Figure 20: Mann Kendal Trend Analysis of Mean Temperature for Nyagatare District over Eastern province from 1983 to 2016.

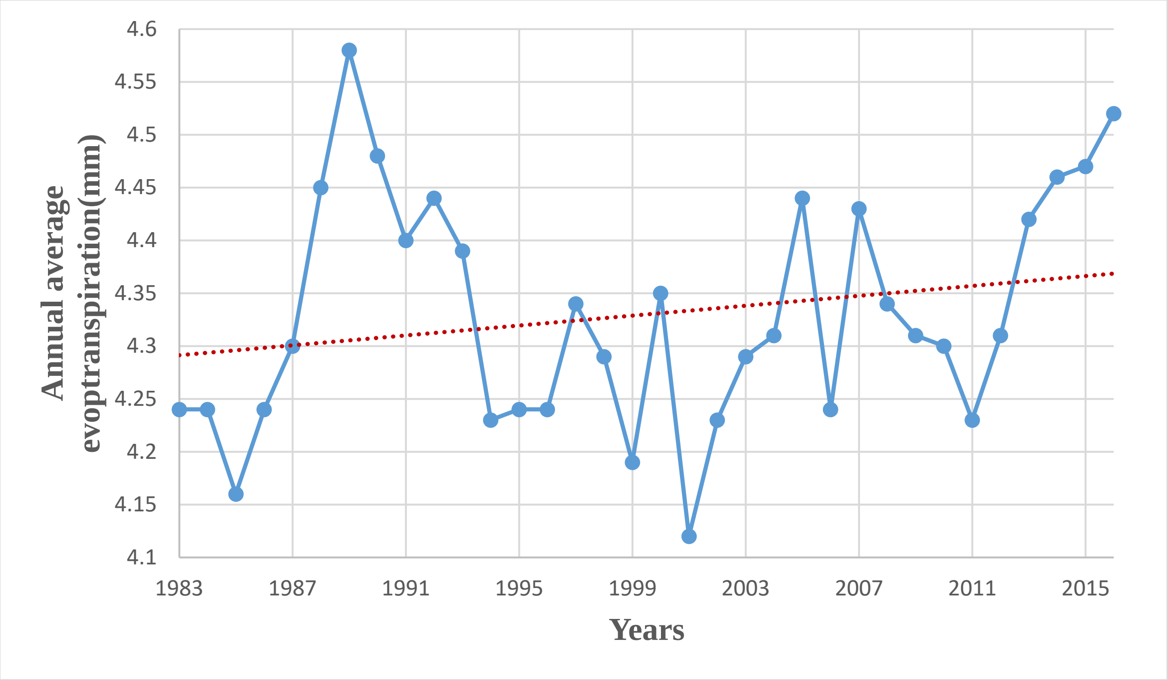

Figure 21: Mann Kendall Trend Analysis of Annual Average Evapotranspiration for Nyagatare district over Eastern province from 1983 to 2016.

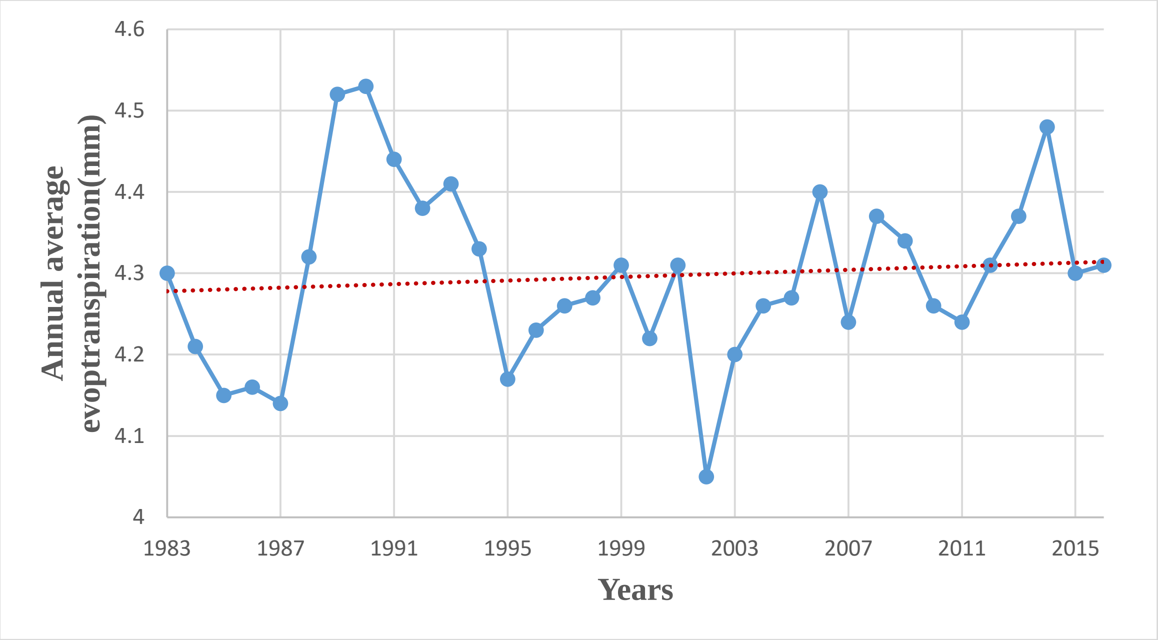

Figure 22: Mann Kendall Trend Analysis of Annual Average Evapotranspiration for Bugesera District over Eastern province from 1983 to 2016.

4.2. 2 Coefficient of Variation

Analysis of coefficient of variation for climatic parameters

CV was used to explain climate factor variability in Nyagatare and Bugesera Districts over Eastern province. Higher value of CV indicated a higher degree of scatter about the mean or climate factors from year to year.

Monthly coefficient of variation values are shown in table below. Increase in climate variability was shown by larger year to year fluctuations, with a higher coefficient of variation implying less predictability in the climate.

Table 2: Coefficient of variation of Minimum and Maximum Temperature, rainfall and Evapotranspiration for Bugesera and Nyagatare.

Districts	**CV % of**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Bugesera	**Rain**	0.9	1.5	1.1	0.8	0.5	1.0	3.1	2.9	1.4	1.6	0.8	0.7
	Tmax	7.5	9.2	8.1	7.7	6.1	5.3	4.9	5.8	6.2	10.1	9.7	9.0
	Tmin	6.7	7.4	6.4	6.7	5.9	6.2	6.8	8.4	7.6	10.1	8.9	7.1
	Eva	0.1	0.3	0.1	0.5	0.1	0.6	0.2	0.1	0.3	0.4	0.1	0.3
Nyagatare	**Rain**	0.7	1.6	0.8	0.9	0.6	1.0	1.9	4.3	1.1	1.0	O.7	0.6
	Tmax	8.0	9.8	9.8	8.3	7.5	6.2	6.0	6.9	10.2	11.3	9.3	11.7
	Tmin	5.8	8.9	6.8	7.6	5.8	6.7	10.3	8.6	9.1	8.1	8.0	7.6
	Eva	0.2	0.4	0.1	0.3	0.5	0.2	0.1	0.6	0.4	0.1	0.6	0.3

Rain is Rainfall, **Tmax** is Maximum Temperature, **Tmin** is Minimum Temperature, and **Eva** is evapotranspiration.

4.2.3 Seasonal Variation of Rainfall, Temperature and Evapotranspiration over Nyagatare and Bugesera Districts.

Seasonal variations of average maximum and minimum temperatures, rainfall and evapotranspiration and, are plotted, analyzed and compared to show the variability of climatic parameters during the seasons of MAM and SOND. The Figures 23 to 26 show the significant variations of each parameter during these seasons for the area of study over the long term. These are in agreement with the patterns of coefficient of variations for the same seasons and climate parameters in Nyagatare and Bugesera Districts. The maize planting season corresponds with September to December season when the region receives higher amount of rainfall (precipitation).

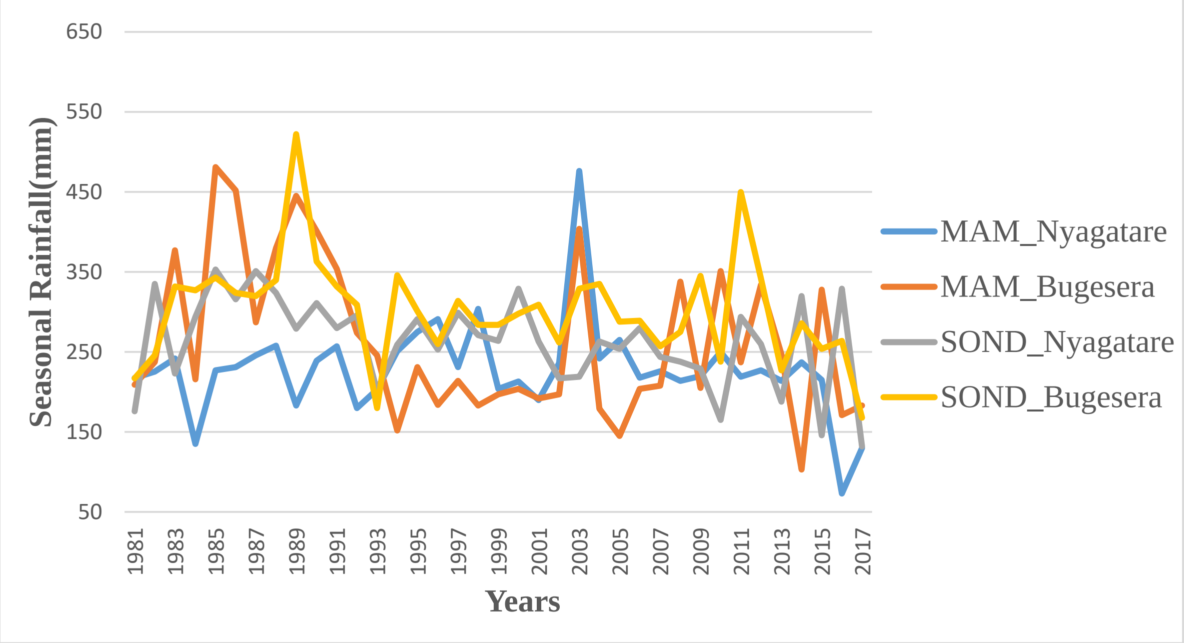

Figure 23: Seasonal Rainfall during the Seasons of MAM and SOND for Nyagatare and Bugesera Districts.

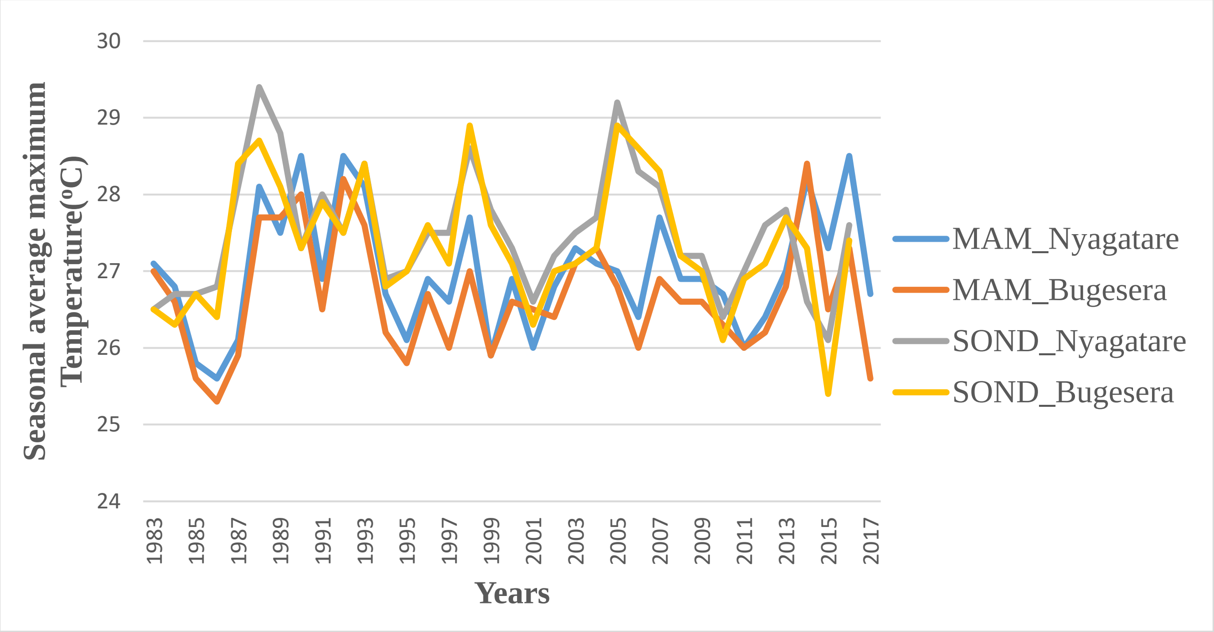

Figure 24: Seasonal Average of Maximum Temperature during the Seasons of MAM, and OND for Nyagatare and Bugesera Districts.

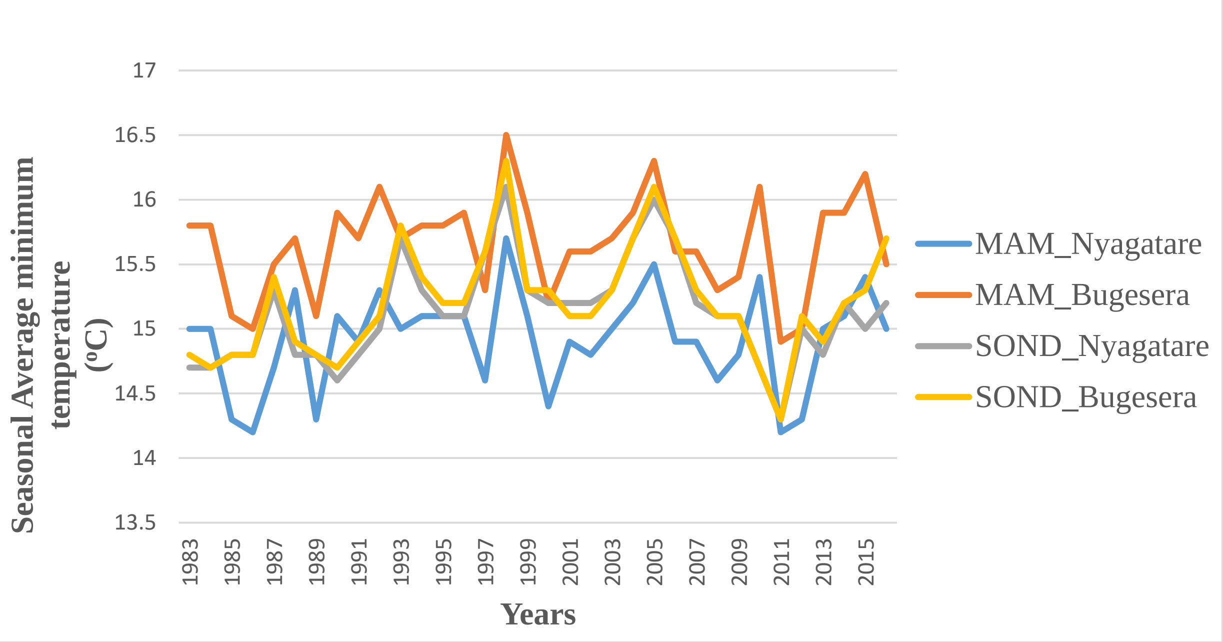

Figure 25: Seasonal Average of Minimum Temperature during the Seasons of MAM, and OND for Nyagatare and Bugesera Districts.

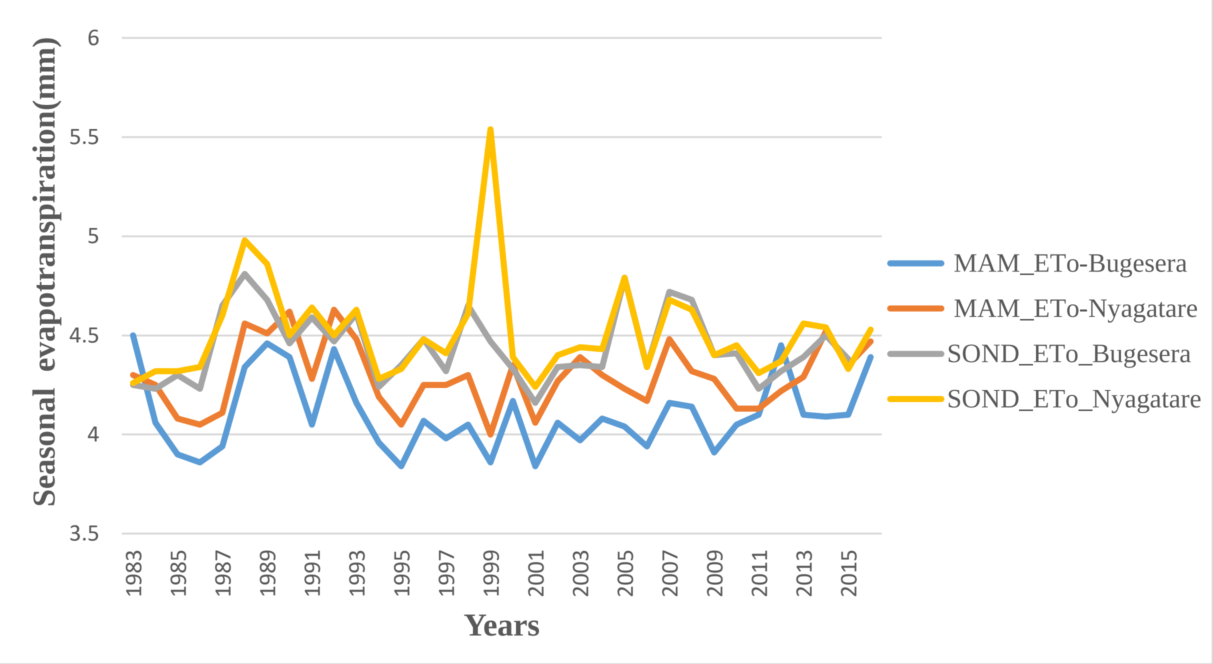

Figure 26: Seasonal Average of Minimum Temperature during the Seasons of MAM, and OND for Nyagatare and Bugesera Districts.

4.3 Relationship between the Maize Yield and Climate Parameters over the Area of Study

4.3.1 Correlation Analysis

In order to evaluate the individual relationship between maize yield and the climatic parameters used in this dissertation, correlation analysis was calculated. Table 3 shows the correlation coefficient for climate parameters and maize yield for Bugesera and Nyagatare Districts over Eastern province. Significance of correlation was tested using student t and the values tabulated in Table (3) bellow.

Table 3: Correlation results between maize yield and climatic parameters.

Districts	Parameters	Correlation coefficient	T Computed	T tabulated	Relationship description
Bugesera	Maize yield and rainfall	0.57	2.420	2.179	Significant
	Maize yield and Maximum temperature	-0.38	2.205	2.179	Significant
	Maize yield and minimum temperature	-0.35	2.191	2.179	Significant
	Maize yield and evapotranspiration	0.29	2.187	2.179	Significant
Nyagatare	Maize yield and rainfall	-0.59	2.289	2.179	Significant
	Maize yield and Maximum temperature	-0.39	2.260	2.179	Significant
	Maize yield and minimum temperature	-0.36	2.195	2.179	Significant
	Maize yield and evapotranspiration	0.27	2.181	2.179	Significant

Correlation analysis showed a positive relationship between maize yield and rainfall (0.57) over Bugesera and also between maize yield and evapotranspiration (0.29 and 0.27) over Bugesera and Nyagatare. This means that an increase in rainfall enhances maize yield production, while its decrease results in lower maize yield. A negative relationship between maize yield and rainfall (-0.59) was obtained over Nyagatare. This implies that an increase or a decrease in rainfall beyond the maximum level results in a decline in maize yield production. On the other hand, the correlation analysis of climatic parameters over both Bugesera and Nyagatare (maximum and minimum temperature and, evapotranspiration) showed a negative relationship with correlation coefficient of -0.38,-0.35and -0.39,-0.36 with maize yield respectively. This means that an increase in temperature beyond the maximum level (high temperature beyond 30 ^{0}C and low temperature below 8 ^{0}C) results in a decline in maize production and vice versa.

In order to examine the influence attributed to each of the climatic factors used in this study, a significance test was carried out. The results of the significance test for correlation coefficient are shown in Table 3.

A strong significance variation between the four values of t for rainfall, temperature an evapotranspiration was observed and showed the significant influence. This is evident through the computed t values being greater than the tabulated values. It is, therefore, concluded that rainfall, maximum and minimum temperature and evapotranspiration are crucial in maize production over the study area according to those outputs was carried out.

4.3.2 Multiple regression Analysis

Multiple Regressions test was performed to determine how the climate parameters affect maize yield and Table 4 shows the equation of multiple line regression, p-values and the coefficient of determination (R^2). Figures 27 and 28 is explained the relationship between actual maize yield and predicted maize yield for Nyagatare and Bugesera districts over Eastern Province.

Table 4: Multiple Regression Models for Maize and Climate Parameters for Nyagatare and Bugesera.

Districts	Climate parameters	Multiple regression model	Coefficient of determination $\mathbf{R^2}$ %	$P \leq 0.05$
Bugesera	Maize yield and rainfall,Tmax,Tmin and Evapotranspiration	$Y=5273.411-1.023\mathbf{X_1}+32.731\mathbf{X_2}-379.185\mathbf{X_3}+277.41\mathbf{X_4}$	0.254	0.024
Nyagatare	Maize yield and rainfall,Tmax,Tmin and Evapotranspiration	$Y=6687.568-2.457\mathbf{X_1}+2969.826\mathbf{X_2}-2104.16\mathbf{X_3}-12566.95\mathbf{X_4}$	0.507	0.013

Y is Maize predicted, X_1 is Rainfall (mm), X_2 is Maximum Temperature (^oC), X_3 Minimum Temperature (^oC) and X_4 is Evapotranspiration (mm).

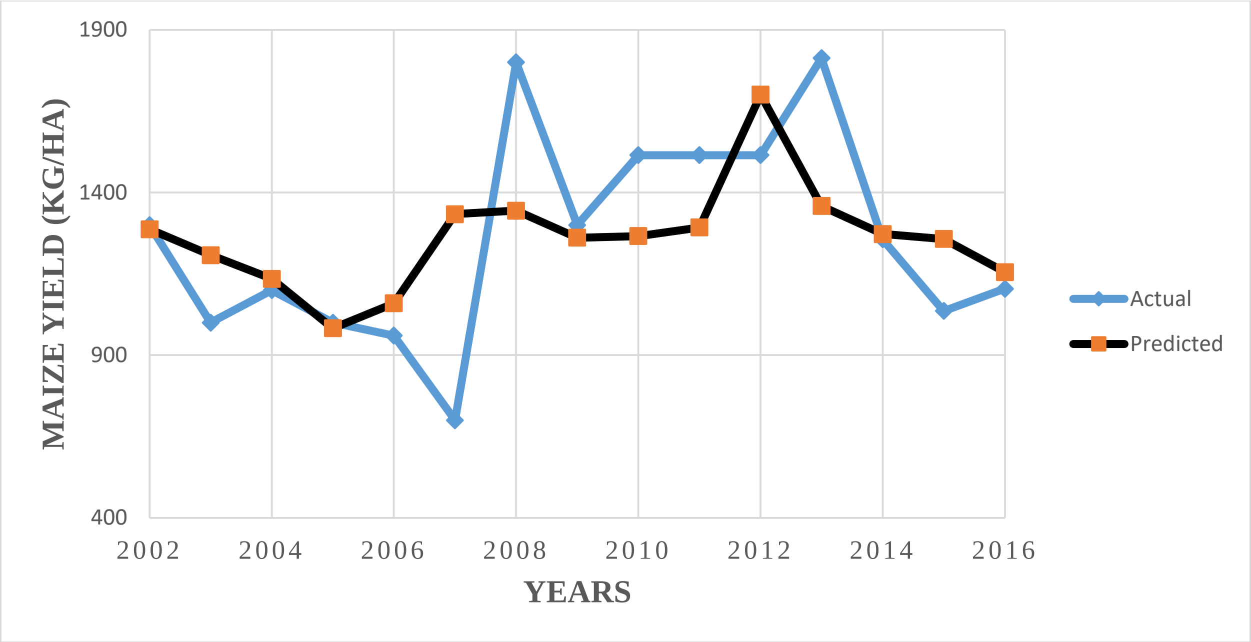

Figure 27: Shows the Predicted and Actual Maize Yields due to combination of Rainfall, Maximum Temperature, Minimum Temperature and Evapotranspiration for Bugesera from 2002 to 2016.

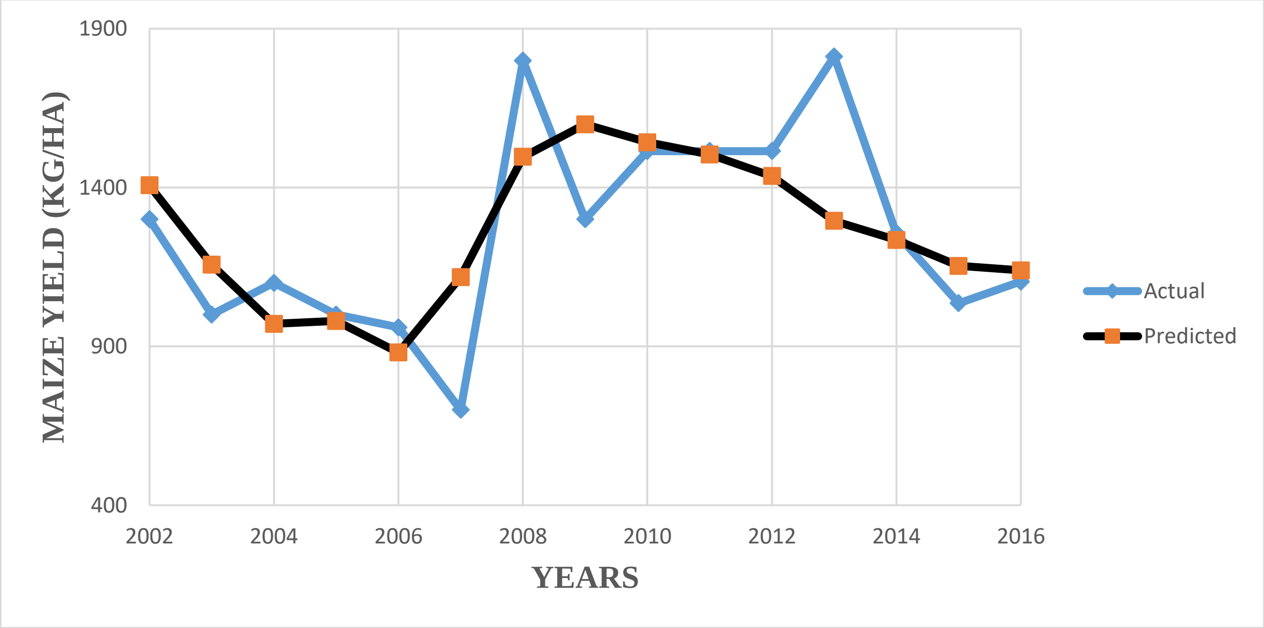

Figure 28: Shows the Predicted and Actual Maize Yields due to combination of Rainfall, Maximum Temperature, Minimum Temperature and Evapotranspiration for Nyagatare from 2002 to 2016.

The coefficient of determination (R^2) was calculated to identify the relationship between maize yield and climatic parameters (Table 4). The result of analysis of multiple regression showed a high (25.4% and 50.7%) relationship between maize yield and climatic parameters for Bugesera and Nyagatare areas. This means that the model explains 25.4% and 50.7% % of the variance of all variability of the response data around its mean over the study areas.

It was observed that 24.5% and 50.7% of the variability in maize yield could be explained by these climatic factors (rainfall, maximum temperature, minimum temperature and evapotranspiration) and significant relationship result to combination of all those climatic factors and maize crop (p-values were 0.024 and 0.013).Otherwise, there could be other factors which may also play important roles in the process of maize production, such as solar radiation, humidity, wind speed, soil temperature, rainfall distribution and modern agricultural practices (fertelization,irrigation,weed and pesticide control).

4.4 Assessing Effect of Climate variability and change on Maize Yield

To assess the effect of climatic variability and change on the maize yield, AquaCrop model was applied. Climate variability refers to the inter-annual variation of climatic parameters over area study. The AquaCrop model utilizes temperature, reference evapotranspiration, carbon dioxide concentration and rainfall as input datasets. The combination of all these variables were used to formulate climate files for the base year (2021-2050) and the years under climate variability. By selecting the name of the crop and soil characteristic or type, the model automatically generated the soil data.

4.4.1 Evaluation of CORDEX Model

Two methods were utilized to test the accuracy of the CORDEX models in simulating the observed temperature and rainfall. The methods included correlation analysis and mean root square error (RMSE) with the results of each metric shown in the Table 5 and 6.The CNRM model was more accurate in simulating the observed variables relative to MIROC model. It also had high positive correlation of 0.56 for maximum temperature for Bugesera and 0.55 for Nyagatare with the observed as compared to other models. The CNRM model also had low RMSE of maximum and minimum temperature for Bugesera and Nyagatare (2.59, 2.85 and 2.51, 2.85). The study therefore utilized projection datasets from CNRM model to evaluate the effect on future climatic variability and change for maize yield over Eastern province of Rwanda.

Table 5: Correlation coefficients between the observed climate Data and cordex Generated modelling Data.

Districts	**Climate Parameters**	**CNRM**	**MIROC**
Bugesera	**Rainfall**	**0.24**	0.22
	Maximum Temperature	**0.56**	0.44
	Minimum Temperature	**0.19**	0.10
Nyagatare	**Rainfall**	**0.30**	0.30
	Maximum Temperature	**0.55**	0.43
	Minimum Temperature	**0.09**	0.03

Table 6: RMSE between the Observed climate Data and cordex Generated modelling Data.

Districts	**Climate Parameters**	**CNRM**	**MIROC**
Bugesera	**Rainfall**	**2.96**	3.20
	Maximum Temperature	**2.59**	2.78
	Minimum Temperature	**2.85**	3.16
Nyagatare	**Rainfall**	**3.35**	3.79
	Maximum Temperature	**2.51**	2.96
	Minimum Temperature	**2.85**	4.12

4.4.2 AquaCrop model validation

In calibration of the AquaCrop model, climate parameters data sets from 2002 to 2016 as base period were used. Table 7 below shows the observed maize yields data used to compare the AquaCrop model simulated maize yields over Eastern province in the two districts of Nyagatare and Bugesera. The observed maize yields were closer to simulated maize yields over the study areas, where the highest value of observed maize yield was observed in 2011 and 2013 and the lowest value one in 2005 and 2007 over Bugesera and Nyagatare areas. While the highest value of simulated maize yield was observed in 2015 and 2014 and the lowest value one in 2006 and 2015 over Bugesera and Nyagatare areas.

Table 7: Maize Yield Data used for evaluation of AquaCrop model.

Years	Observed Maize yield (kg/ha) in Bugesera	Simulated Maize yield (kg/ha) in Bugesera	Differences between observed and simulated ((%))in Bugesera	Observed Maize yield (kg/ha) in Nyagatare	Simulated Maize yield (kg/ha) in Nyagatare	Differences between observed and simulated (%) in Nyagatare
2002	980	1572	60.4	1300	990	23.8
2003	1400	1587	13.4	1000	937	6.3
2004	1200	1597	33.1	1100	1018	7.5
2005	900	1621	80.1	1000	990	1.0
2006	1000	1540	54.0	960	1322	-37.7
2007	700	1626	132.3	700	925	-32.1
2008	1800	1630	-9.4	1800	1037	42.4
2009	1250	1614	29.1	1300	1176	9.5
2010	2760	1591	-42.4	1535	1111	27.6
2011	1890	1624	-14.1	1415	1018	28.1
2012	2515	1637	-34.9	1365	1150	15.8
2013	1857	1641	-11.6	1813	977	46.1
2014	1365	1672	22.5	1256	1255	0.1
2015	1256	1693	34.8	1036	772	25.5
2016	1106	1653	49.5	1104	1092	1.1

Figures (29 and 30) shows the scatter plot between observed and the simulated maize yields. There was showed a positive linear relationship between the observed maize yield and AquaCrop simulated maize yield for September to January season (A). The R^2 values for Bugesera and Nyagatare of 0.426 and 0.373 indicated 42.6% and 37.3% of the variability in the AquaCrop simulated maize yield and observed maize yield values. Therefore, AquaCrop model is up to 42.6% and 37.3% fit for prediction of maze yield.

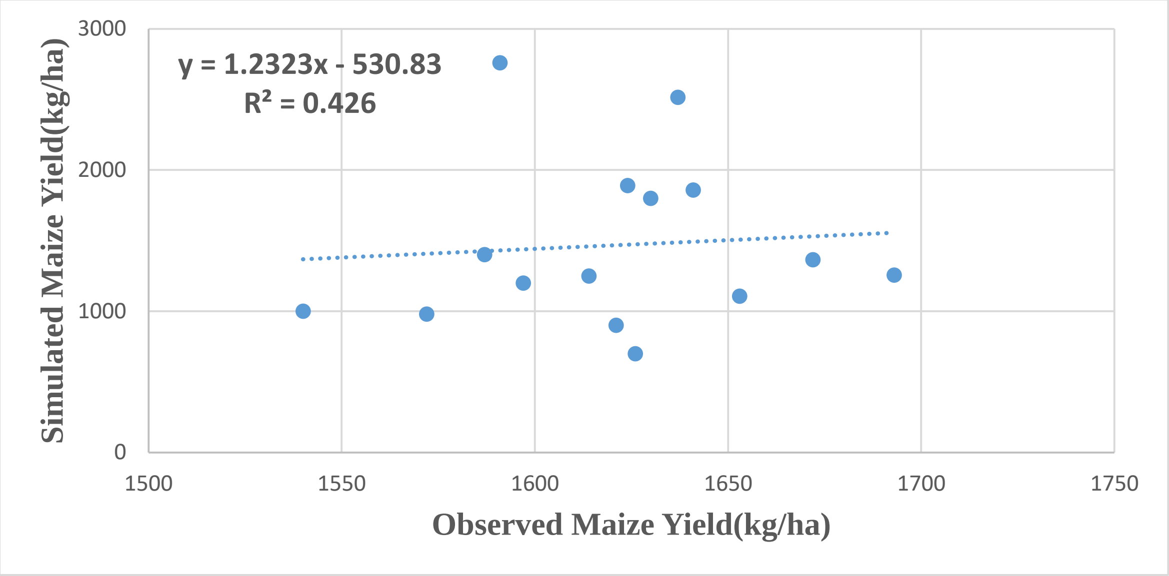

Figure 29: Relationship between Observed Maize Yield and AquaCrop Simulated Maize Yield for Bugesera District over Eastern Province.

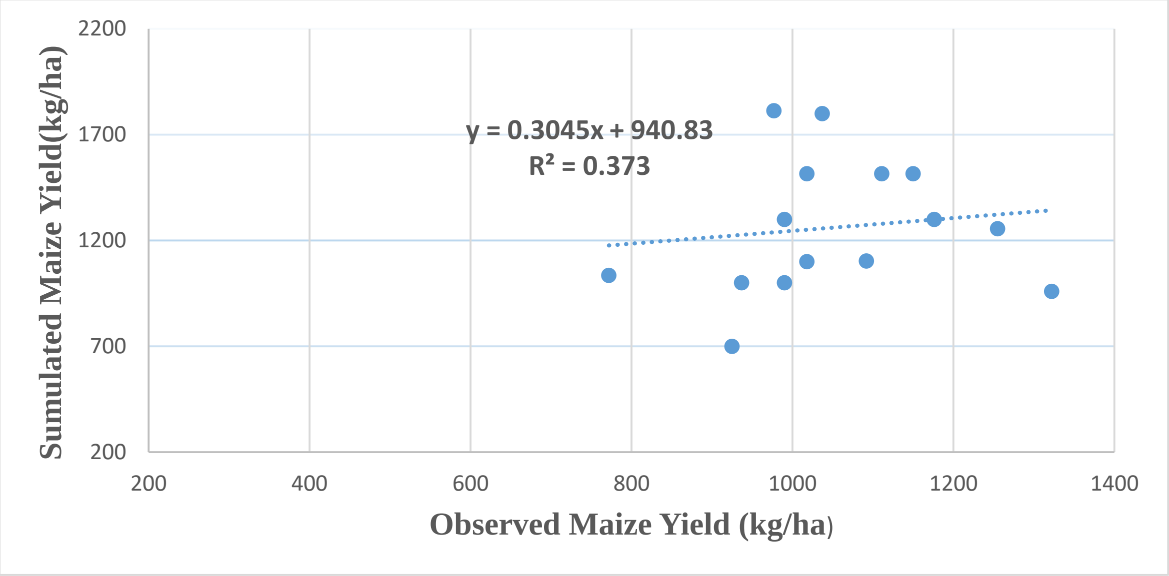

Figure 30: Relationship between Observed Maize Yield and AquaCrop Simulated Maize Yield for Nyagatare District over Eastern Province.

For more clarification of relationship between observed maize yield and AquaCrop simulated maize yield, correlation analysis was been done. The results showed high positive linear relationship between observed and simulated values, these both correlation were statistically significant at 95% level of significance (P<0.05)

Table 8: Correlation coefficients between observed values and AquaCrop simulated maize yields for Nyagatare and bugesera Districts.

Districts	Variables	Correlation coefficient	P Value
Bugesera	Observed Maize yield and Simulated Maize yield	0.081	0.017
Nyagatare	Observed Maize yield and Simulated Maize yield	0.132	0.016

The Average Error (AE) calculated for maize yield were 154.6 and 209.6 kg/ha for Bugesera and Nyagatare over Eastern province. The positive average absolute indicate that the model over predicted the maize yield. To adjust this value of over prediction, the value of the AE was to be subtracted from each simulated value of future maize yield, to correct for the simulated future values of maize yield, and this served to validate the AquaCrop model for use in Bugesera and Nyagatare area. The AquaCrop simulated maize yield under climate change for the year 2021-2050, for season September to over Bugesera and Nyagatare. Average Error obtained during evaluation and calibration of AquaCrop model (154.6 and 209.6 kg/ha for maize yield) was subtracted and the true values of the expected maize grain yield were obtained (Table 8).

4.4.3 Variation of Climate Parameters due to the Effect of Future Climate Change

For further evidences and demonstration of patterns and behaviours variation of climatic parameters due to effect of future climate change, Table 9 shows the comparison between the average of observed climatic parameters (maximum temperature, minimum temperature and rainfall,) from 2002 to 2016 and future climatic parameters for period from 2021 to 2050 The rainfall will be reduced during the next twenty nine years over Bugesera and Nyagatare area by 14.84% (63.59 mm) and 11.34% (74.65 mm). While, it indicated high significant change will occur in maximum temperature over Bugesera and Nyagatare area during this period 4.55% (1.20 ^{0}C) and 4.54% (1.20 ^{0}C) the increase will happen in minimum Temperature under future climate change. Figures 31 up to 36 indicate the annual variation of observed climatic parameters and future climate dataset over study area.

Table 9: Comparison between the Averages of Annual Observed Data and Annual Future Data for Nyagatare and bugesera Districts.

Districts	**Climate Parameters**	**Average of Observed Data**	**Average of Future Data**	**The Change**	**The percentage Change**
Bugesera	**Rainfall(mm)**	792.04	628.45,	163.59	20.65%
	Maximum Temperature (^{0}C)	26.37	27.60	1.20	4.55%
	Minimum Temperature	11.53	12.67	1.14	9.88%
Nyagatare	**Rainfall (mm)**	832.54	657.89,	174.65	20.97%
	Maximum Temperature (^{0}C)	26.40	27.60	1.20	4.54%
	Minimum Temperature (^{0}C)	11.38	12.87	1.49	13.09%

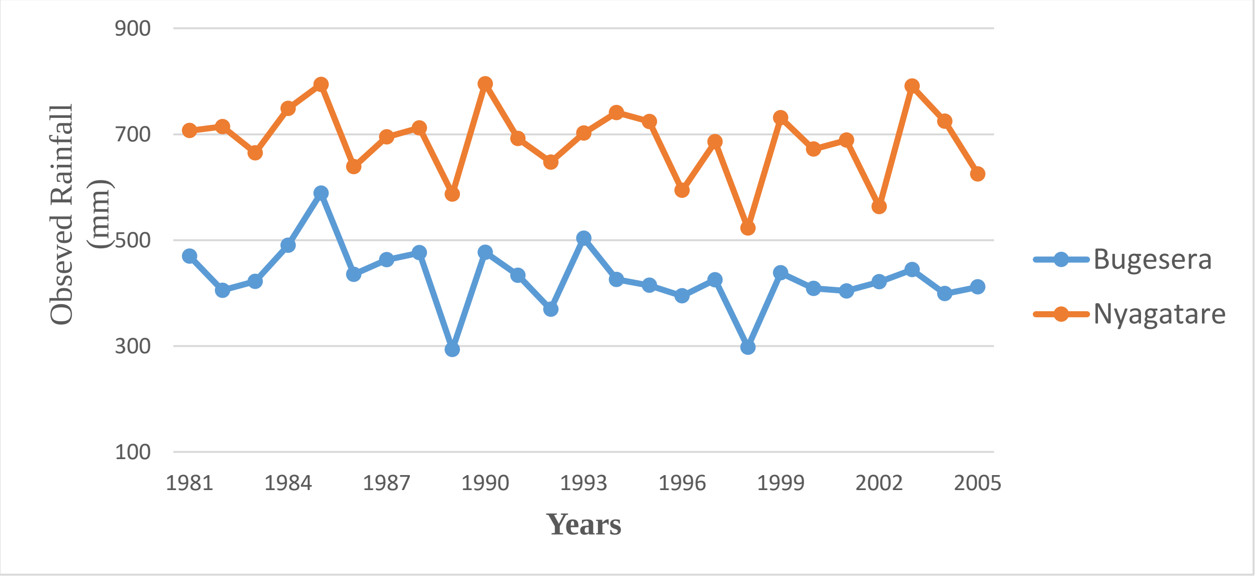

Figure 31: Annual Variation of Observed Rainfall for Nyagatare and Bugesera Districts.

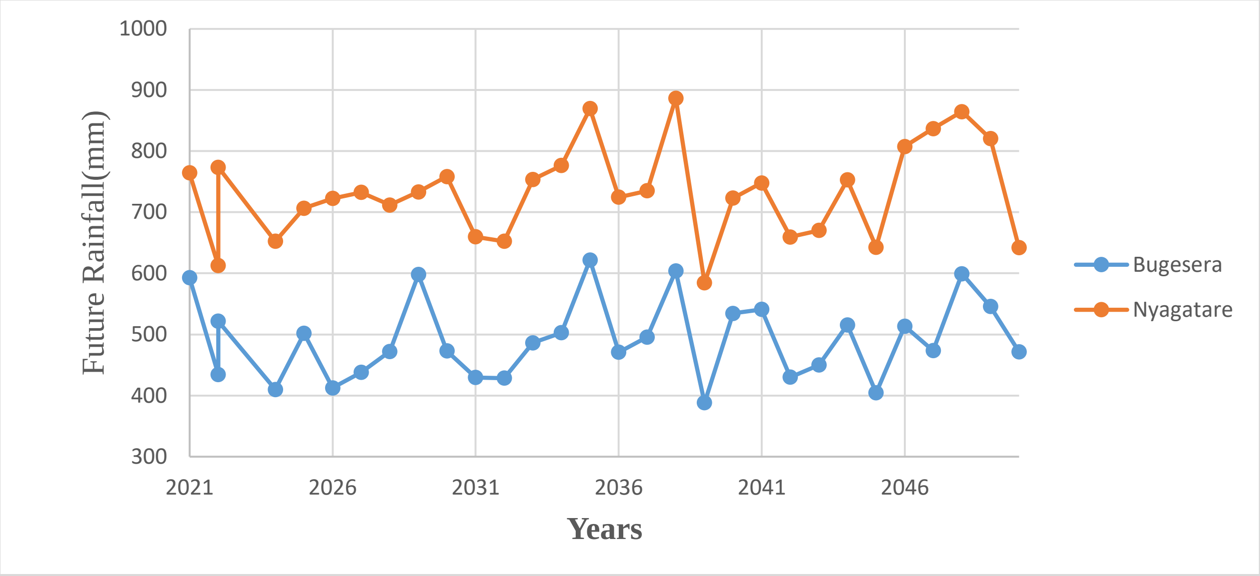

Figure 32: Annual Variation of Projected Rainfall for Nyagatare and Bugesera Districts.

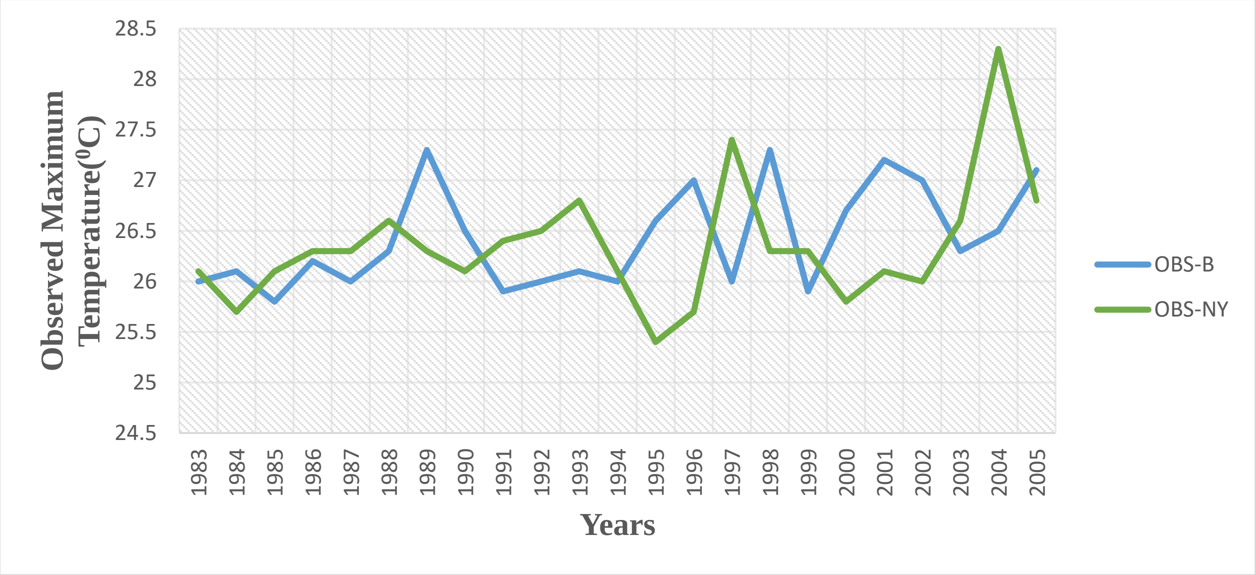

Figure 33: Annual Variation of Observed Maximum Temperature for Nyagatare and Bugesera Districts.

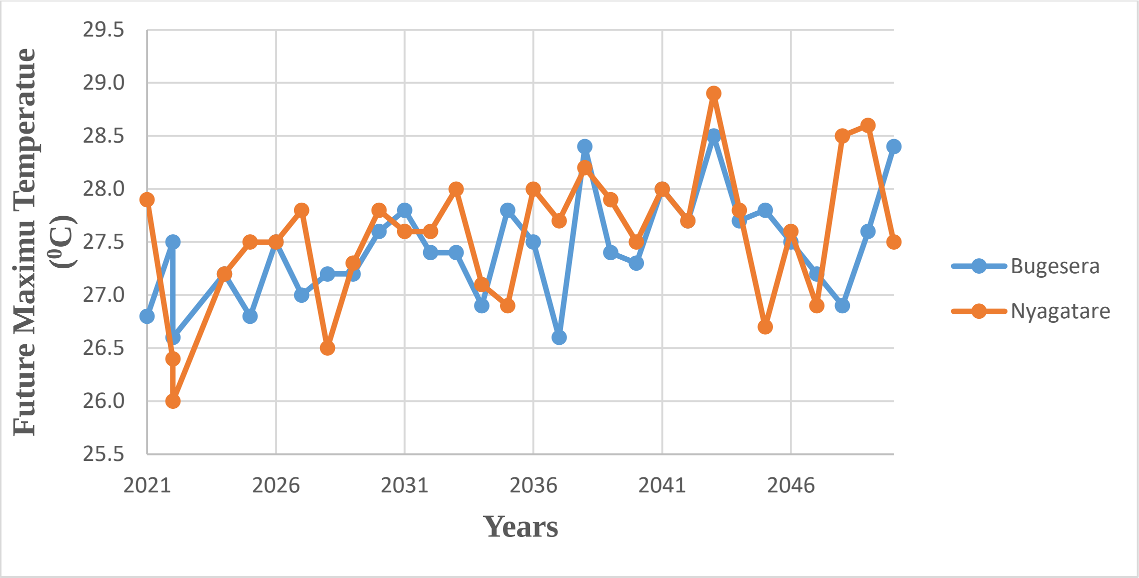

Figure 34: Annual Variation of Projected Maximum Temperature for Nyagatare and Bugesera Districts.

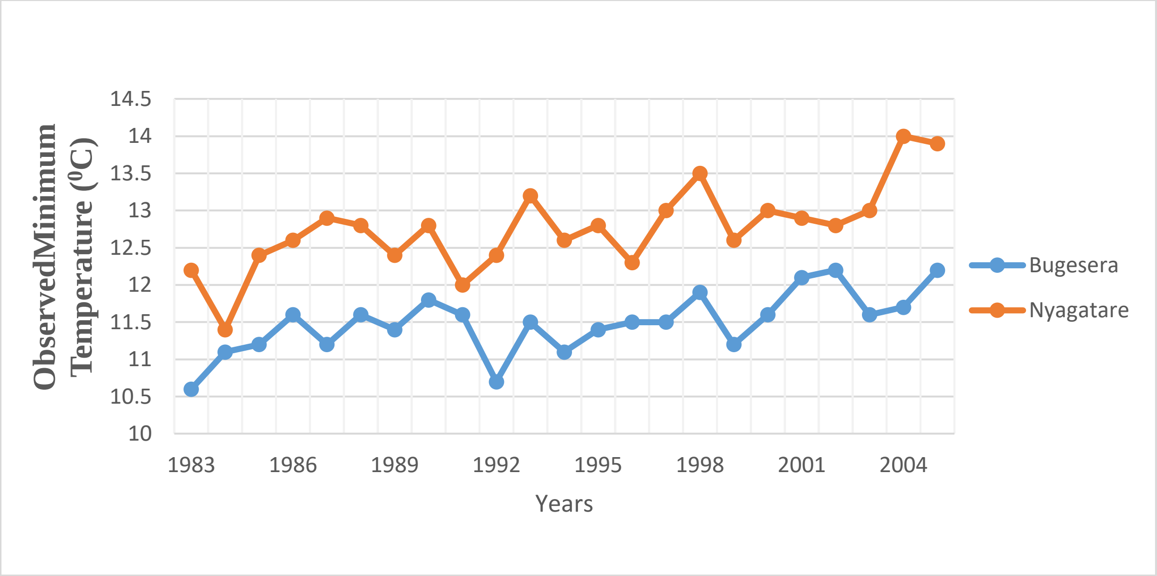

Figure 35: Annual Variation of Observed Minimum Temperature for Nyagatare and Bugesera Districts.

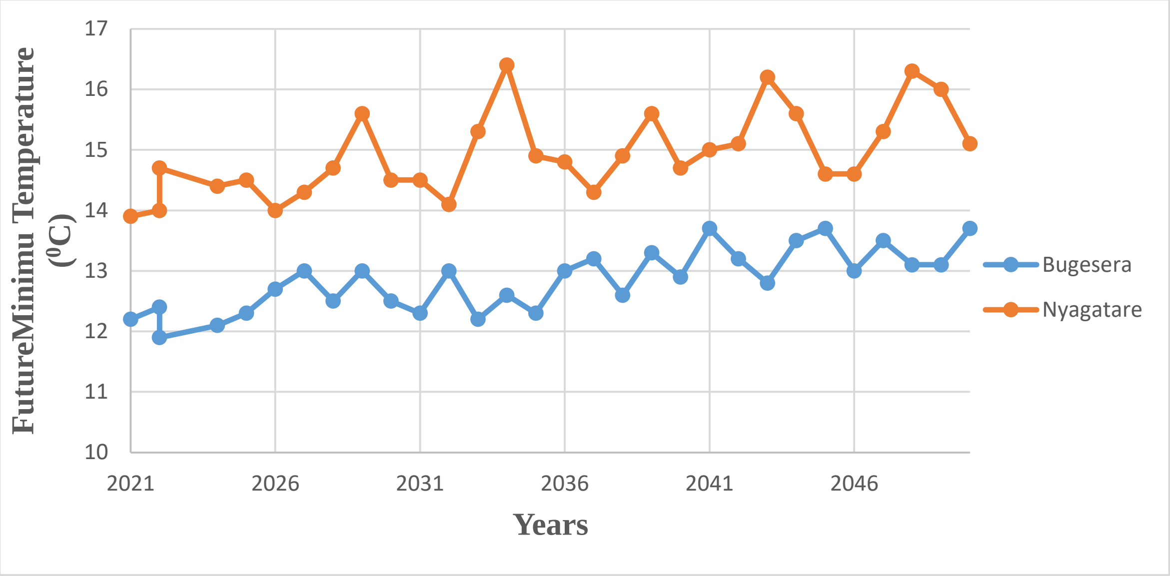

Figure 36: Annual Variation of Projected Minimum Temperature for Nyagatare and bugesera Districts.

The effect of change on the seasonal climatic parameters showed the seasonal rainfall will decrease by the 198.56 mm (30.85%) and 213.4 mm (29.77%) for Bugesera and Nyagatare by 2050.while it indicated that seasonal maximum and minimum temperatures will increase by 0.97 ºC (3.7%) and 0.1.35 ºC (11.7%) for Bugesera and 0.25ºC (4.7%) and 0.1.23ºC (17.6%) Nyagatare respectively by 2050, Table 10. This greater change in seasonal climatic parameters over study area agreed with the greater reduction of maize crop production will occurs in future and hence, Both rainfall and temperature are considered the crucial climate parameter in the process of maize cultivation during next decades for Nyagatare and Bugesera Districts over Eastern Province.

Table 10: Comparison between the Averages of Seasonal Observed Climate Data (1983-2005) and Average of Seasonal Future Climate Data (2021-2050) for Nyagatare and Bugesera Districts.

Districts	Climate Parameters	Average of Observed Data	Average of Future Data	The Change	The percentage Change
Bugesera	**Rainfall(mm)**	643.60	445.04	198.56	30.85%
	Maximum Temperature (^{0}C)	26.43	27.4	0.97	3.7%
	Minimum Temperature	11.49	12,84	1.35	11.7%
Nyagatare	**Rainfall (mm)**	715.58	502.54	213.04	29.77
	Maximum Temperature (^{0}C)	26.35	27.60	1.25	4.7%
	Minimum Temperature (^{0}C)	12.7	14.93	1.23	17.6%

4.4.4 Predicted Future Maize Yield under climate change

Table 11: Maize Yield Data used for evaluation of AquaCrop model.

Years	Simulated Maize yield (kg/ha) in Bugesera	Simulated Maize yield (kg/ha) in Nyagatare	Years	Simulated Maize yield (kg/ha) in Bugesera	Simulated Maize yield (kg/ha) in Nyagatare
2021	1348.2	1556.4	**2036**	1293.0	1737.0
2022	1348.2	1595.2	**2037**	1423.8	1681.0
2023	1470.9	1558.9	**2038**	1587.8	1781.5
2024	1278.1	1589.5	**2039**	1227.4	1804.1
2025	1453.6	1624.5	**2040**	1517.8	1793.5
2026	1420.7	1643.7	**2041**	1524.2	1806.8
2027	1368.1	1640.9	**2042**	1367.4	1806.7
2028	1313.5	1640.7	**2043**	1581.4	1793.2
2029	1572.3	1626.4	**2044**	1175.8	1788.1
2030	1364.1	1681.9	**2045**	1201.8	1895.4
2031	1368.0	1673.9	**2046**	1649.6	1795.4
2032	1410.1	1680.3	**2047**	1573.2	1784.9
2033	1155.6	1739.7	**2048**	1641.9	1843.3
2034	1428.5	1751.3	**2049**	1628.5	1790.2
2035	1569.9	1682.8			

The average predicted future simulated maize yield for September-January season (2021-2050) were 1282.3kg/ha and 1316.8 kg/ha over Bugesera and Nyagatare areas respectively. Comparison with the observed sorghum yields for September-January season (2002 up to 2016) of 1675.5 kg/ha and 1760.9 kg/ha indicated there will be a decrease in future maize yields (23.4%) in Bugesera and (25.2%) in Nyagatare area.

Further, the regression of simulated maize yield against the future seasonal rainfall for maize crop of September-January season for all simulated years indicated to positive relationship between the future seasonal rainfall and future simulated maize yield (figure 37 and 38). Therefore, decrease in seasonal rainfall, is expected to decrease maize yield. The R^2 value was much smaller for season September-January, since the past generally had more rainfall compared to the future.

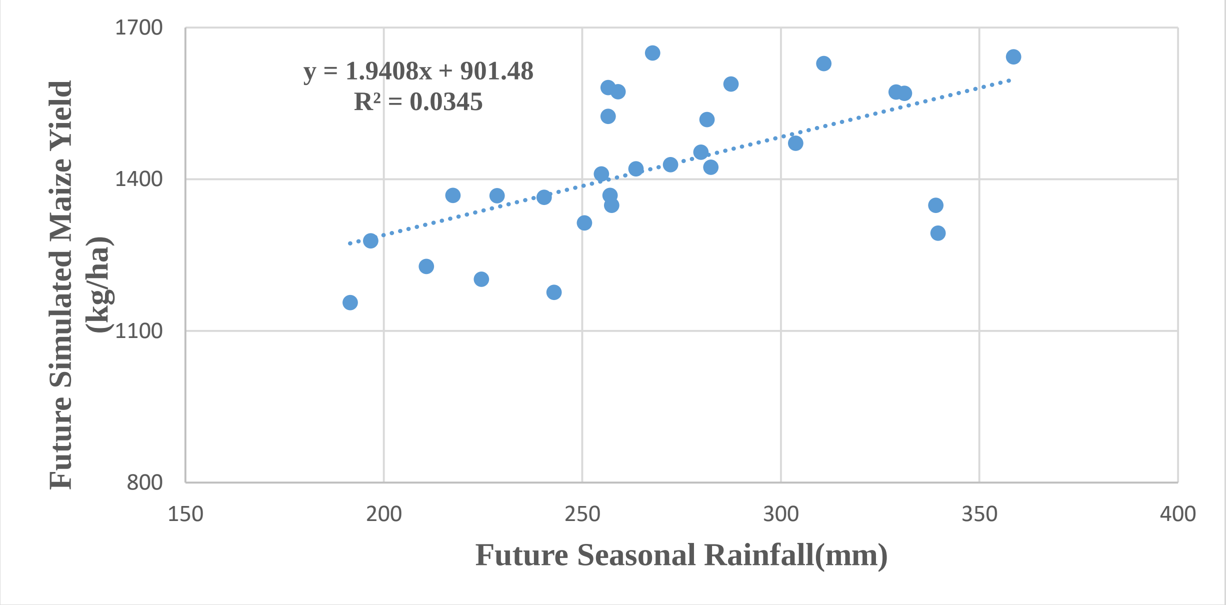

Figure 37: Relationship between Future Simulated Maize Yield and Future Seasonal Rainfall for Bugesera over Eastern Province.

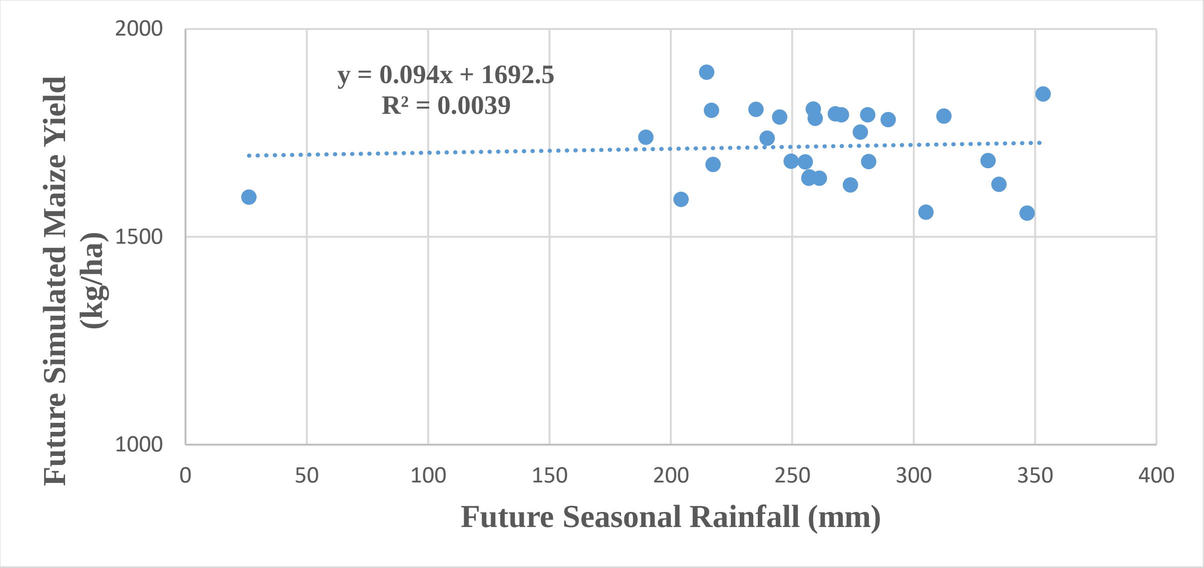

Figure 38: Relationship between Future Simulated Maize Yield and Future Seasonal Rainfall for Nyagatare over Eastern Province.

4.4.5 Variation of future simulated maize yield for Nyagatare and Bugesera Districts over Eastern Province.

The Figure 39 bellow showed the annual variation for the seasonal of future simulated maize yield for Bugesera and Nyagatare over Eastern province during the simulation period from (2021 up to 2050). Which that indicated to the high variation of future maize yield though simulation period. With greater decease in amount of maize crop production for both Districts after the year 2033 to 2044 and 2037 up to 2047, hence that, reveal clear picture for decrease of maize crop production under effect of climate change, will happen in future.

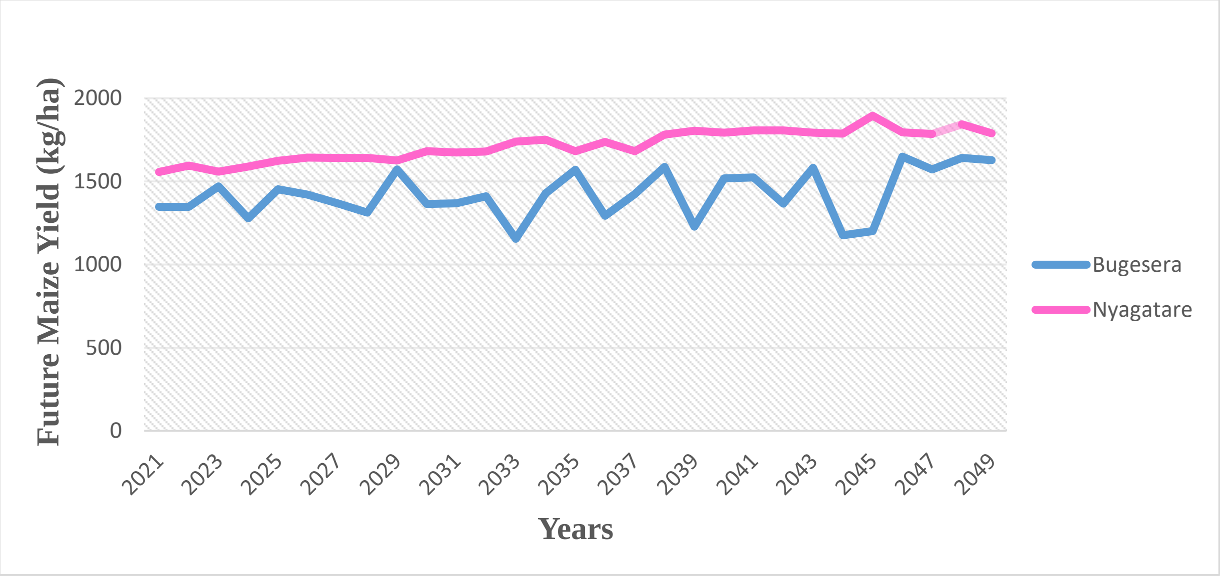

Figure 39: Annual Variation of Future Simulated Maize Yield for all Simulation Years for Nyagatare and Bugesera over Eastern Province.

4.4.6 Multiple Regression Analysis

The below Figures (40 and 41) show the multiple regression analysis output of the simulated maize yield and predicted maize yield for period from 2021 up to 2050 using future Climatic parameters(maximum and minimum temperature, rainfall and evapotranspiration) over Bugesera and Nyagatare area.

The analysis revealed similarity in the patterns and behaviours of maize yield for the simulated yield and predicted maize yield over Bugesera and Nyagatare area. The variability in the future maize yield predicted from the climatic parameters (maximum and minimum temperature, rainfall and evapotranspiration) explains nearly 56.4% and 73.2% variability in the simulated maize yield as indicated by R^2 value of 0.564 and 0.732 (Table12) over Bugesera and Nyagatare area. This is in agreement with the results between the observed maize yield and predicted maize yield for the same climatic parameters using dataset for period 2002 to 2016.

Table 12: Multiple Regression Models for maize and Future Climatic parameters for Nyagatare and Bugesera over Eastern Province.

Districts	Climate parameters	Multiple regression model	Coefficient of determination R^2 %	P≤ 0.05
Bugesera	Maize yield and rainfall,Tmax,Tmin and Evapotranspiration	$Y=1856.049+12.68\mathbf{X_1}+38.930\mathbf{X_2}+45.846\mathbf{X_3}-528.706\mathbf{X_4}$	0.564	0.01
Nyagatare	Maize yield and rainfall,Tmax,Tmin and Evapotranspiration	$Y=-2477.449+0.255\mathbf{X_1}-4.485\mathbf{X_2}+170.936\mathbf{X_3}+475.920\mathbf{X_4}$	0.732	0.03

Y is Maize predicted (kg/ha), X_1 is Rainfall (mm), X_2 is Maximum temperature (°C), X_3 Minimum temperature (°C) and X_4 is Evapotranspiration (mm).

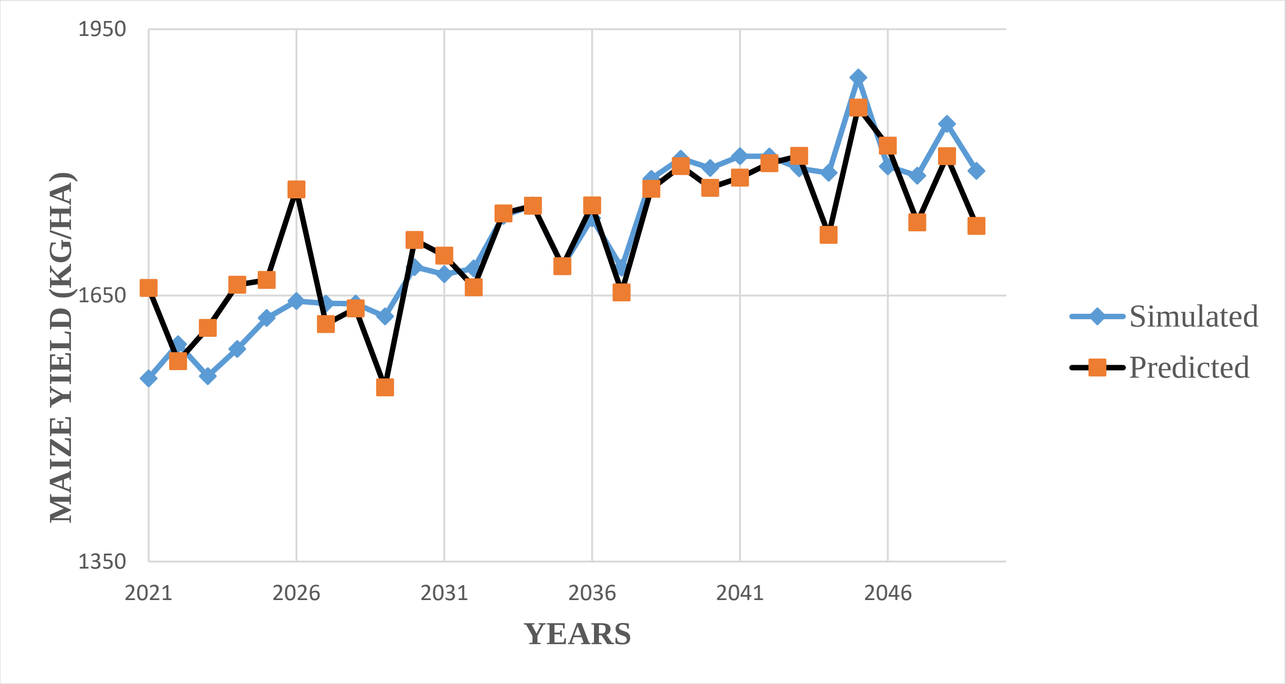

Figure 40: The Simulated (by AquaCrop Model) and predicted (by Multiple Regression model) Maize due to combination of Maximum and Minimum Temperature, Evapotranspiration and Rainfall over Nyagatare District.

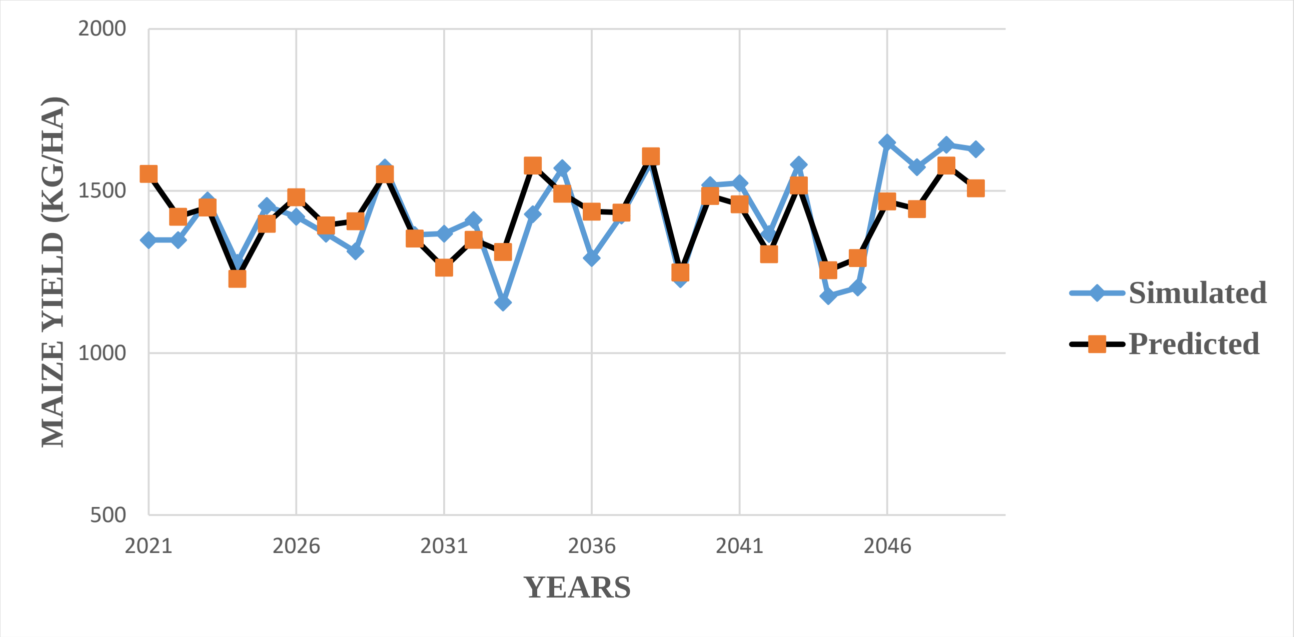

Figure 41: The Simulated (by AquaCrop Model) and predicted (by Multiple Regression model) Maize due to combination of Maximum and Minimum Temperature, Evapotranspiration and Rainfall over Bugesera District.

CHAPTER FIVE

5.0 CONCLUSSION AND RECOMMENDATIONS

5.1 Conclusion

Homogeneity test for climate data in the area of study was used, it indicated high homogenous for the period 1981 up to 20016 over study area. While the trend analysis results of climatic parameters indicated to significant trend (increase) for minimum and maximum temperature and evapotranspiration. However rainfall and maize yield, it had insignificant trends (decrease) over the study area. Also analysis results of coefficient of variance were explained, there are temporal variability for climatic parameters within the study area.

The output of Aqua Crop model for future maize crop production over the study area, it was demonstrated the climate change will have greater negative impact in maize crop production over study area by the year 2050.

5.2 Recommendations

Based on this review, the following recommendation are forwarded:

- If the predicted ,maize yield decrease according to the study results for future, the farmers, Field consultants ,government, water planners, policy analysts and scientist in the agricultural sector, they should adopt the strategies and decisions which will enable them to overcome the impacts of shortage in maize crop production will may happen in future. This may involve the identification of alternative livelihood sources and adoption of climate resilient crop varieties (seeds).

- Agriculture has significant contribution for climate variability and change disruption but the attention given for this situation is low. So, there should be more research and awareness creation on this important.

- Considering the current impacts of climate variability and change over the study area, it is recommended that farmers need external and support to effectively cope with changing climate and to adapt to current and projected climate variability and change for their impact on maize yield production. Therefore Climate parameters play a central role in agriculture production which is mainly key of the Rwanda economy and community livelihood.

- The uncertain in the future variability of rainfall and temperature calls for further studies and research in the study area so as to explain and interpret the negative impacts of climate change that may happen. Therefore, the future studies and research in the same area should attempt to involve other different climate parameters, like relative humidity, solar radiation, soil temperature, wind speed and rainfall distribution, in addition, other abiotic or biotic factors like seeds variety, fertilizer application, and irrigation method needs to be understand for better estimation of rainfall and crop yields, to provide further verification and confidence.

REFERENCES

Alexanderson, H. 1986 ‘A homogeneity test applied to precipitation data’ Climatological Journal, 6,661-675

Allen, R., L. Pereira., D. Raes and M. Smith, 1998. Crop evapotranspiration guidelines for computing crop water requirements. FAO, Rome. FAO irrigation and drainage paper, 56

Ashraf, M. and E.H.: can leaf water relation parameters be used as selection criteria for salt tolerance in safflower (Carthamus tinctorius l.) Pak. J. Bot. 40, 221-228 (2008)

AVRDC., 1990. Vegetable Production Training Manual. Asian Vegetable Research and Training Center. Shanhua, Tainan, 447 pp

AVRDC, 2005. Improving Vegetable Productivity in a Variable and Changing Climate. <http://www.ejournal.icrisat.org/../sp1.pdf.

Ayers, R.S. & westcot, D.w. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29 (Rev. 1). Rome, FAO. ISBN 92-5-102263-1.

Blum, A., 2005. Drought resistance, water use efficiency and yield potential, are they compatible, dissonant, or mutually exclusive. Aust. J. Agric. Res. 56: 1159-1168

Bradford, K.J. and T.C. Hsiao, 1982. Physiological responses to moderate water stress. p. 264–324. In O.R. Lange et al. (ed.) Encyclopedia plant physiology. New Series, Vol. 12B. Physiological Plant Ecology II. Springer-Verlag, Berlin

Caldwell, R.M. and J.W. Hansen, 1993. Simulation of multiple cropping systems with CropSys. p. 397-412. In: Penning de Vries, F.W.T., P. Teng and K. Metselaar, (ed.) Systems Approaches for Agricultural Development, Vol. 2. Kluwer, Dordrecht, The Netherlands

Chen, Z., Song, N., Wang, J.: Study On Water-saving Irrigation Management and Decision Support System. Transactions of the CSAE 25(suppl. 2), 1–6 (2009)

de Wit, C.T., 1958. Transpiration and crop yields. Agric. Res. Rep. 64(6). Pudoc, Wageningen: The Netherlands

Debaeke, P. and A. Aboudrane, 2004. Adaptation of crop management to water-limited environments. Euro. J. Agron. 21, 433-44

Deng, X.P., L. Shan., H. Zhang and N.C. Turner, 2006. Improving agricultural water use efficiency in arid and semi-arid areas of China. Agric. Water Manage. 80, 23-40

Doorenbos, J. and Kassam, 1986. Yield response to Water: FAO Irrigation and Drainage paper #33 FAO Rom

Duncan, w.G. 1975. Maize. In: Evans, L.T. (ed), Crop physiology: some case histories. UK, Cambridge University Press.

Dutra, E., Mwangi, E., Wetterhall, F., Giuseppe, F. Di and Pappenberger, F.(2014). Forecasting droughts in East Africa. : 611–620.

FAO. (1998). *Crop Water Requirement: Irrigation &Drainage Paper No. 56.* Rome: FAO Publication.

FAO, 2011. FAOSTAT online database, available at link http://faostat.fao.org/. Accessed on December 2017.

FAO/IAEA., 2008. Adaptation to Climate Change with improved Agricultural Water Management. Joint FAO/IAEA programme. Available at: http://wwwnaweb.Iaea.org/nafa/news/water management.html

Fechter, J., B.E. Allison., M.V.K. Sivakumar., R.R. van der Ploeg and J. Bley, 1991. An evaluation of the SWATRER and CERES-Millet models for southwest Niger. p. 505-513 In: M.V.K. Sivakumar., J.S. Wallace., C. Renard and C. Girous, (ed.). Soil Water Balance in the Sudano-Sahelian Zone. IAHS Publication no. 199. IAHS Press, Institute of Hydrology, Wallingford: UK

Fereres, E and R.G. Evans, 2006. Irrigation of fruit trees and vines: an introduction. Irrigation. Irrig. Sci. 24, 55-57

Fereres, E. and M.A. Soriano, 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany, 58(2): 147-159

GoR, (2011) Green Growth and Climate Resilience, National Strategy for Climate Change and low carbon Development. (October).Government of Rwanda.

Hillel, D. and P. Vlek, 2005. The sustainability of irrigation. Adv. Agron. 87, 55-84

Hirsch, R .M., Slack, R., and Smith, R.A (1982). Techniques of Trend Analysis for Monthly Water Quality Data. Water Resources Res, 18(1):170-121.

Hsiao, T.C. 1982. The soil-plant-atmosphere continuum in relation to drought and crop production. P. 39-52. In Drought resistance in crops, with emphasis on rice. IRRI, os an os, the Philippines

Hsiao, T.C., E. Fereres., E. Acevedo and D.W. Henderson, 1976. Water stress and dynamics of growth and yield of crop plants. P. 281-305. In Lange, O.L. L. Kappen, and E.D. Schulze (ed). Ecological Studies. Analysis and Synthesis. Water and Plant Life. Vol.19. Springer-Verlag, Berlin

Ines, A. V. M., P. Droogers., I.W. Makin and A.D. Gupta, 2001. Crop growth and soil water balance modeling to explore water management options. Working paper 22. International Water Management Institut

Kendall, M.G (1975). Rank Correlation Methods, 4th edition, Charles Griffin, London

Kirda, C. and R. Kanber, 1999. Water, no longer a plantifuk resource, should be used sparingly in irrigated agriculture. In: Kirda, C., P. Moutonnet., C. Hera and D.R. Nielsen, (eds.). Crop yield response to deficit irrigation, Dordrecht: The Netherlands, Kluwer Academic Publishers

L.Haimberger .Homogenization of radiosonde temperature time series using statistics. Journal of climate, 20(7):1377-1403, 2007

Lee, K.H., H. Theodore., E. Steve., H. Terry and S. Pasquale, 2009. Validating the FAO AquaCrop model for irrigated and water deficient field maize. Courtesy of Agronomy Journal April, 3, 2009

Li, Y., 2006. Water Saving Irrigation In China. Irrigation and Drainage Limited, Aylesford: UK

Luhunga, P., Botai, J. and Kahimba, F. (2016) Evaluation of the performance of CORDEX regional climate models in simulating present climate conditions of Tanzania (June).

Oweis, T., M. Pale and T. Rayan, 1998. Stabilizing rain fed wheat yields with supplemental irrigation and nitrogen in Mediterranean-type Climate. Agron.J. 90, 672-681

Passioura, J., 2006. Increasing crop productivity when water is scarce-from breeding to field management. Agric. Water Manage. 80, 176-196 135-17

Phene, C.J., 1989. Water management of tomatoes in the tropics. In: Green, S.K. (ed.). Tomato and pepper production in the tropics. AVRDC, Shanhua, Taiwan pp 308-322

Raes, D., P. Steduto., T.C. Hsiao and E. Fereres, 2009a. AquaCrop-The FAO crop model to simulate yield response to water. II. Main algorithms and software description. Agron J., 101: 438-447

Senay, G.B. & Verdin, J., 2003. Characteristization of yield reduction in Ethiopia using a GIS-based crop water balance model. Canadian Journal of Remote Sensing 29 (6): 687-692.

Smith, M., 2000. The application of climatic data for planning and management for sustainable rainfed and irrigated crop production. Agric. For. Meteor. 103, 99-108

Steduto Heng .P T.A. Howell L.K., T.C. Hsiao., and S.R. Evett., , 2009. Testing of FAO AquaCrop model for rainfed and irrigated maize. Agron. J. 101: 488–498

Steduto P.; D. Raes., M. Gracia., R. Miranda., J.A. Cusicanqui., C. Taboada., I. Mendoza., R. Huanca., A. Mamani., O. Condori., J. Mamani., B. Morales., V. Osco and Geerts, S.,, 2009. Simulating yield response of Quinoa to water availability with AquaCrop. Agron. J. 101, 499–508

Steduto, P. & T.C. Hsiao. 1998. Maize canopies under two soil water regimes. II. Seasonal trends of evapotranspiration, carbon dioxide assimilation and canopy conductance, and as related to leaf area index. Agricultural and Forestry Meteorology 89:185-200.

Steduto, P., Hsiao, T.C. and Fereres, E. 2007. On the conservative behaviour of biomass water productivity. Irrigation Science 25:189-207

Steduto, P., T.C. Hsiao., D. Raes and E. Fereres, 2009. AquaCrop-The FAO crop model to simulate yield response to water. I. Concepts and underlying principles. Agron. J., 101: 426-437

Todorovic, M., R. Albrizo., L, Zivotic., M.T. Abi Saab., C. Stöckle and P. Steduto, 2009. Assessment of AquaCrop, CropSyst and WOFOST Models in the Simulation of Sunflower Growth under Different Water Regimes. Available on: /https://www.agronomy.org/publications/aj/pdfs/101/3/509.

Trenberth,K(1984). Some effect of finite sample size and persistence on meteorological statistics.Part I:Autocorretaion.Mon.Wea. Rev, 112:2359-2368.

Wang, H., C. Liu and L. Zhang, 2002. Water- saving agriculture in China: An overview. Adv. Agron. 75.

Wilhite, D.A. and Glantz. M.H. 1985. Understand the drouhgt Phenomenon. The role of Definitions. *Water International* 10(3):111120.

WMO, (World Meteorological Organzation). (2016) . The Global Climate in 2011-2015., (1179).

Wolfe, D.W. 1984. Water and nitrogen effects on leaf senescence in maize (Zea mays). PhD.diss.Univ. of California, Davis (Diss.Abstr. 85-07341).