ANALYSING CLIMATE CHANGE PROJECTION ON WATER AVAILABILITY FOR RAINFED AGRICULTURE IN AWUN BASIN, KWARA STATE, NIGERIA

BY

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MTECH/SNAS/2013/4218

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA
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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA,
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTECH) IN CLIMATE CHANGE AND ADAPTED LAND USE

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DECLARATION

I hereby declare that this thesis, titled 'Analysing Climate Change Projection on Water Availability for Rainfed Agriculture in Awun Basin, Kwara State, Nigeria', is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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M.TECH/SNAS/2013/4218 FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA.	SIGNATURE & DATE

CERTIFICATION

The thesis titled: ‘Analysing the Impact of Climate Change Projection on Water Availability for Rainfed Agriculture in Awun Basin, Kwara State, Nigeria’ by GBANDOU, Talardia (MTECH/SNAS/2013/4218) meets the regulations governing the award of the degree of Master of Technology of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

Prof. O. D. Jimoh ……………………………
Supervisor Signature & Date

Dr. A. A. Okhimamhe ……………………………
Director, WASCAL CC & ALU Signature & Date

Prof. M.G.M. Kolo …………………………..
Dean, Postgraduate School Signature & Date

DEDICATION

I dedicate this research work to the Supreme God and to my family especially, my loving mother and father who passed away.

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ABSTRACT

This study investigates the impact of climate change projections on water availability for rainfed agriculture in Awun basin, Kwara State, Nigeria using high resolution (25 km spatial resolution) RegCM4 simulations. The study was guided by four (4) specific objectives which are (i) assessment of crop types, cropping patterns and farmers' perception of water availability, (ii) downscaling/bias correction of climate scenarios, (iii) evaluation of rainfall characteristics (onset, seasonality index, and hydrologic ratio), and (iv) assessment of the crops water requirements. RegCM4 runs for the control period and for two scenarios (RCP4.5 and RCP8.5) driven by two GCMs (MPI and GFDL) were collected at WASCAL competence centre, Burkina Faso. The simulations provided are rainfall, minimum and maximum temperature and relative humidity for the control period (1985-2004) and the scenario period (2080-2099). The observations (1985-2014) for the same parameters from the synoptic station of Ilorin were collected at NIMET, Abuja. A focus was made on major food crops (maize, sorghum, cassava, and yam) in the area. Onset of growing season was determined using Benoit method tested with HS and BMN ET models. BMN model was also used to compute ET0. The study showed that mean rainfall depth for the realistic scenario RCP4.5 will decrease by 9.6% and 13.1 % for MPI and GFDL driven runs while under the pessimistic scenario RCP8.5 the expected decreases in the mean rainfall depth are 15.2 % and 17.7 % for MPI and GFDL driven runs respectively. Minimum and maximum temperatures will increase from 1.5 ^{0}C to 2 ^{0}C for the realistic scenarios RCP4.5 and from 3.1^{0}C to 4.0^{0}C for the more pessimistic scenario RCP8.5 respectively. However the mean relative humidity will decrease by 10% by 2100s. The start of the growing season, independently of the ET model used, is projected to be late in the future. In fact the onset date is 5th May for baseline (1995-2014) while under RCP4.5 the dates are 23rd May and 2nd June for MPI and GFDL driven runs respectively and under the RCP8.5 the dates are 14th June and 9th June for MPI and GFDL respectively. A seasonality index (SI) included between 0.80 and 0.99, and a hydrologic ratio (HR) < 0.74 for all scenarios were found, meaning respectively that (i) the rainy season will get shorter and (ii) the area will get drier in the future. Results showed that the crop water need for the growing season of maize and sorghum will be satisfied while that of cassava will not. It showed that cassava could not be planted conveniently within its growing season without irrigation in Awun Basin. The present study might be helpful in explaining the plausible effects of present and future climate on crop water needs and better planning of agricultural water resources in Awun Basin.

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LIST OF ABREVIATIONS AND ACRONYMS

A2	Extreme/pessimistic carbon emission scenario
B1	Optimistic carbon emission scenario
BMN	Blaney Morin Nigeria model of evapotranspiration
DEM	Digital Elevation Model
ESP	Earth System Physics
ET_P	Potential Evapotranspiration
ET_C \ ET_{CROP}	Crop potential evapotranspiration/ Crop water requirements under standard conditions
ET_0	Crop reference evapotranspiration
FAO	Food and Agricultural Organization
GFDL	GCM (CM4) developed by the Geophysical Fluid Dynamics Laboratory
GIS	Geographical Information System
HS	Hargreaves and Samani model of evapotranspiration
HSG	Hydrologic Soil Group
HR	Hydrologic Ratio / Degree of dryness
HRUs	Hydrological Response Units
ICTP	International Centre for Theoretical Physics
IPCC	Intergovernmental Panel on Climate Change
LGAs	Local Government Area
LGP	Length of the Growing Period

LGS	Length of the Growing Season
LOCI	Local intensity scaling
MOS	Model Output Statistics
MPI	GCM (ECHAM4) developed by Max Planck Institute
NARCCAP	American Regional Climate Change Assessment Programme
NBS	National Bureau of Statistics
NCAR	National Centre for Atmospheric Research
NIMET	Nigeria Meteorological Agency
PP	Perfect Prognosis
PM	Penman-Montieth model
RCM	Regional Climate Model
RCP4.5	Representative Concentration Pathway Realistic Scenario
RCP8.5	Representative Concentration Pathway Pessimistic Scenario
RegCM4	Regional Climate Model system version 4
RH	Relative Humidity
SI	Seasonality Index
SRTM	Shuttle Radar Topography Mission

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background of the Study

Rainfed agriculture is a farming practice that rely on rainfall water. It is practised on about 80 % of the agricultural land area in a global scale (Wani, Rockström, and Oweis, 2009). According to Cooper *et al.* (2009), rainfed agriculture accounts for approximatively 70 % of the global staple foods production. This is the principal mode of production favoured by poor farmers in the developing world (Wani *et al.,* 2009). The support to global food supply from rainfed agriculture is forecasted to decline from 65 % to 48 % in 2030 (Bruinsma, 2003). In the Guinea Savannah zone of West Africa rainy-season farming is a major source of income for the rural population (Müller, Sanfo, and Laube, 2013). This way of using water allows climate to have an influence on crop water requirements or crop water needs which is defined by FAO (1998) as the amount of water required by the various crops to grow optimally.

Climate Change which refers to changes in climate characteristics, including rainfall, temperature, wind, humidity, and severe weather events over long term periods, is projected to have meaningful effects on conditions affecting agriculture. While some aspects of climate change such as longer growing seasons and warmer temperatures may bring benefits in cold regions, a range of adverse impacts, including reduced water availability, greater water need, and more frequent extreme weather in warm regions will occur. These effects may put agricultural activities at significant risk (AEA Energy and Environment, 2007; Eitzinger and Kubu, 2009). Furthermore, global climate change "is likely to decrease the level of rain in Guinea Savannah zones in West Africa and significantly increase rain variability across the continent" (World Bank, 2009).

Northern region of Nigeria is projected to experience more decrease in rainfall and an increase in temperature (Olusina and Odumade, 2012; BNRCC, 2011).So, the great challenge for the coming decades will be the task of increasing food production with water shortage due to climate change. In order to address the issue of poverty in Nigeria, relating to water availability for crops production, some authoritative studies have tried to optimize the crops water demand (Ufoegbune, Bello, Dada, Eruola, Makinde, and Amori, 2012; Odekunle, Orinmoogunje, and Ayanlade, 2007). A complementary assessment of the future crops water needs under climate scenarios in a local level will help to better tackle the issue.

1.2. Problem Statement

The agricultural activities in Kwara State, especially in Awun river basin, are mainly rainfed. However, the rainfall patterns in terms of length of growing season (LGS) have always been indeterminate due to high variability of onset and cessation of the growing season. In some years the rains commences early while in others it starts late. According to Mugalavai, Emmanuel, Kipkorir, Raes, and Rao (2008), the yearly variation makes the planning of sowing and the selection of the crop type and variety rather difficult. Generally yields may suffer significantly with either a late onset or early cessation of the growing season, as well as with a high frequency of damaging dry spells within the growing season. The ability to estimate effectively the actual start of the season therefore becomes vital (Mugalavai *et al.*, 2008). Thus, prediction of the onset dates are important in order to plan rainfed agriculture. There are many factors influencing crop production including soil, relief, and climate, low capital base of farmers, pests and diseases, among others. Nevertheless, climate is the most important factor that influences agricultural production (Efe, 2009). According to Ayoade (2004), agriculture largely rely on climate to perform, hence, precipitation, temperature, solar radiation, relative humidity, wind, and other climatic parameters affect the global distribution of crops and livestock as well as their yields. Therefore, any shift in climatic parameters can seriously affect the crops growth and yielding potential. Some parameters such as rainfall and temperature are the most important for crops because they influence the water available for crops. Unfortunately, rainfall is projected to likely decrease and temperature to likely increase by 2050s under B1 and A2 scenarios in the Tall Grass Guinea Savannah zone of Nigeria (BNRCC, 2011). It means that the amount of water available during the growing season may be affected. It is therefore important to be aware of how much water will be available for rainfed crops by quantifying the crop water requirements under several climate scenarios.

Many studies have been done to assess water availability for agriculture in Nigeria. Odekunle *et al.* (2007) has shown that inter-annual rainfall variability brings changes in water availability, thus, affects the rate of maize yield in Nigeria. Ufoegbune *et al* (2012) has shown that tomato, pepper and maize could perform conveniently during their growing season without the need for irrigation whereas cotton will need a complement of irrigation water in Aboekuta, Nigeria. However these studies were treating only the present effect of climate on crop water requirements. In a context of changing climatic conditions, more emphasis might be made towards future climate. Some previous studies have tried to use climate change scenarios in Nigeria (BNRCC, 2011; Olusina and Odumade, 2012). Nevertheless they were not using high resolution climate simulations up to 25 km spatial resolution. In Nigeria, especially in Kwara State, no study has tried to assess the present or future effects of climate change on water availability for crops. Also, no study has yet tried to predict water availability for rainfed crops using bias-corrected climate scenarios from RegCM4 in Kwara State. There is therefore a gap in the body of knowledge in terms of the assessment of agricultural water demand under present and future climate scenarios in Kwara State. This study seeks to fill the part of that gap by analysing the potential impact of present and future climate on water availability for only rainfed crops in Kwara State.

1.3. Justification of the Study

Having an overview of the present and future water conditions of Awun basin in terms of amount rainfall amount and characteristics (onset, spreading of the rainy season, degree of dryness), and potential crop evapotranspiration is imperative for soil and water management. Analysing the sensitivity of rainfed crops to climate change in terms of plausible water deficit in the present and in the future can raise the awareness on the need to optimize the water and can contribute to assess the suitability of an area for crop production. In fact, accurate prediction of rainfall patterns, especially the onset, is necessary to determine a less risky planting date or planting technique, or sowing of less risky varieties of crops in farming (Stewart, 1991). In order to optimize the use of available rainfall, the amount of probable rainfall and rainfall reliability with respect to meeting crop water requirements should be known (Gebremichael, Quraishi, and Mamo, 2014). Maize, sorghum, cassava and yam are the main food crops for most communities in Awun basin located in the agro-ecological zone C of Kwara State. They represent the main sugar energy sources for poor farmers. These crops have a relatively long growing cycle that requires also a long-lasting water supply. Climate change scenarios must be derived from climate model simulations, combine with observed to create future time horizon. This is the reason for using RCP4.5 (realistic scenarios) and RCP8.5 (pessimistic scenario).Thus, Model outputs cannot be used directly in Impact, Adaptation, and Vulnerability assessment. Although RCMs are powerful tools that can describe regional and even smaller scale climate conditions, they still contain severe systematic errors (Theme, Gobiet, and Leuprecht, 2011).The present study has the benefit of providing climate change impact based on high resolution climate scenarios and 40 years observed climatic parameters. This strong methodology used to downscaled future climate at a local scale (catchment level) could be used for other climate change impacts studies in future researches. Also, the communities will know, quantitatively, how the water available for food crops will be affected by climate change. That will further motivate NGOs, governments or privates to undertake some projects to mitigate a plausible water shortage for some specifics rainfed crops.

1.4. Scope and Limitation of the Study

In terms of scope, the present study is focused only on the common rainfed crops grown in the Kwara State such as Maize, Sorghum, Cassava, and Yam .But the crop water needs were computed for only the first three crops listed because crop factors for yam were not available. The work used regional climate model version 4 (RegCM4) runs extracted from simulations over West Africa and driven by only two global climate models (GCMs) outputs from Max Planck Institute (MPI) located Germany and the Geophysical

Fluid Dynamic Laboratory (GFDL) in United State of America. The climate scenarios were localized by downscaling correcting the simulations only two storylines, representative concentration pathways 4.5 and 8.5 namely RCP4.5 and RCP8.5 projected for the long-term period 2080-2100. For each crop in the area, only the common variety were considered because different variety of the same crop are affected differently by climate change, and hence the need for further disaggregation.

One of the limitation of this study is the mid-term (2030-2050) climate scenarios were not available in order to compare the baseline or present climate with mid-term and long-term climate. Another limitation in the methodology is that the stationarity of the model errors will be assumed. It means that the correction factors (scaling factors) for current climate conditions are assumed to also be valid for a time series of changed future climate conditions.

1.5. Aim and Objectives of Study

The aim of this study is to assess rainfall patterns and crop water requirements for rainfed crops under different climate scenarios. This is in view of determining whether each crop can be planted conveniently within its growing season with or without irrigation.

The objectives of the study are:

i. To assess the rainfed crop type, cropping patterns (total growing period, and growing stages) as well as farmers’ perception of water availability (baseline rainfall patterns) in the agro-ecological zone C located within Awun basin, Kwara State.

ii. To downscale climate scenarios (RCP4.5, RCP8.5) of future temperature, rainfall, and relative humidity simulated for 2080-2100 in Awun catchment, Kwara State.

iii. To assess rainfall characteristics (seasonality index, hydrologic ratio, start of growing season) based on the downscaled future climate scenarios and compare it with the baseline.

iv. To evaluate the crop water requirements (crop evapotranspiration) based on the downscaled future climate scenarios and compare it with the baseline.

In order to systematically achieve the objectives, the following research questions were used as guides:

i. What are rainfed crops types, the cropping patterns as well as farmer's perception of water availability (baseline rainfall patterns) in the agro-ecological zone C located within Awun catchment?

ii. What are the downscaled climate scenarios of temperature, rainfall, and relative humidity for 2080-2100 in Awun basin catchment?

iii. What are rainfall characteristics (start of the growing season, seasonality index, and degree of dryness) for the baseline and under the downscaled climate scenarios?

iv. What are the crop water needs for the baseline and under the downscaled climate scenarios for each rainfed crop?

1.6. Hypothesis

The selected variety of the common crop grown in Awun Basin could perform well during its growing season without irrigation under the baseline/present climate and future climate scenarios.

1.7. Description of Study Area

1.7.1. Location

The study took place in Awun river basin, Kwara State, Nigeria. A river basin is chosen because it is the most appropriate scale for management of water resources, (Sule, 2003). Awun river basin is specifically chosen because of the availability of data (watershed characteristics). Kwara State falls under the southern Guinea Savanna agro-ecological zone of Nigeria and its capital city is Ilorin with sixteen (16) Local Government Areas (LGAs). It is located between latitudes 8° 05’00’’N to 10° 05’00’’N and longitudes 2° 50’00’’E to 6° 05’00’’ E. The state has an elongated shape running from west to east and covering an area of about 32,500 km^2 and has river Niger as its natural boundary along its northern and eastern margins. Kwara state shares a common internal boundary with Niger State in the north, Kogi State in the east, Oyo, Ekiti and Osun States in the south and an international boundary with the Republic of Benin in the west. The entire Awun basin is located between Latitudes 8°28’00” North and 9°00’00”North and Longitudes 4°30’00”East and 4°45’00”East. The watershed has an area of 954 km^2. The LGAs of Kwara State which fall partially or totally within the Awun basin are: Ilorin West, Ilorin East, Ilorin South, Asa, Moro and Oyun. Thus, two of the four agro-ecological zones of Kwara State, defined by Kwara state Agricultural Development project (KWADP, 2007), are mainly found in the watershed: Zone C (Moro, Ilorin West, Ilorin East, Ilorin South, Asa) and Zone D (Oyun). Figure 1.1 shows the map of Awun Basin in Kwara State. The southern part of the Basin is located in Oyo state.

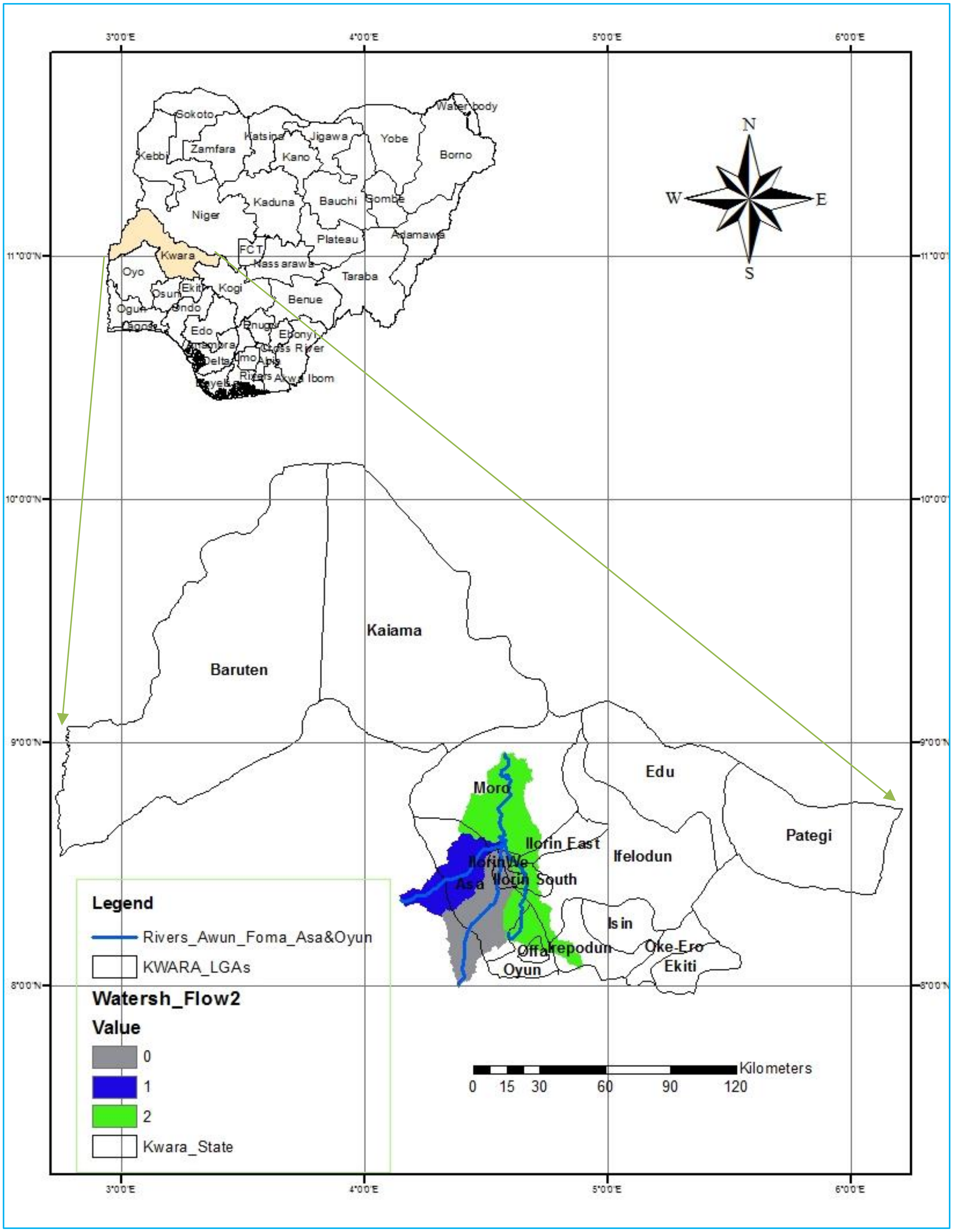


Figure 1.1: Kwara State Showing the Study Area

1.7.2. Climate

Awun River Basin is located in the tropical climate region which is typified a wet and dry seasons which have about six months for each (Olanrewaju, 2009). The annual range of rainfall in the watershed is 1000 mm to 1500 mm. The temperature ranges from 25^{o}C to 30^{o}C during the wet season from 33^{o}C to 34^{o}C during the dry season (NBS, 2009). The relative humidity ranges from 75 to 80% in the wet season and is about 65% in the wet season (NBS, 2009). The above climatic conditions, in no doubt, dictates the human activities in the state with various agricultural practices including rainfed agriculture.

1.7.3. Soil and Vegetation

Based on Food and Agricultural Organization (FAO) (1990) genetic soil classification system, there are three distinct soil types in Kwara State. These are ferruginous tropical soils, Ferrasols and and hydromorphic soils. They are found in almost all parts of the watershed (Hassan, Adeyemo, Isah, and Godwin, 2008). The textural class of the soil in the watershed is sandy loam, and it belongs to Hydrologic Soil Group B (HSG B), (Sule and Alabi, 2013). The Hydrologic Soil Group is an important parameter for determining of the runoff coefficient. The vegetation within the watershed is constituted of tall grass along with short dispersed trees. This characteristic explain further the involvement of Kwara State people in farming.

1.7.4. Geology

The geology map of Nigeria shows that Kwara State is underlain by Pre-Cambrian basement complex rocks. Generally very old and highly weathered rocks of basement complex of Pre-Cambrian age underlay the state. The relatively long period of metamorphic activities gave to the development of soil of medium to high productivity and such soils are cultivable (Hassan *et al.*, 2008).

1.7.5. Land Use and Cover

According to Sule and Alabi (2013), Awun River Basin, with a total area of 954 km^2, contains mainly four main land use types namely: the residential land with an area of 205 km^2, streets and roads land with an area of 174 km^2, a cultivated land with an area of 296 km^2 and a wood or forest land with an area of 279 km^2.

1.7.6. Topography and Drainage Patterns

The study site is on land that slopes 0.15% northward (watershed slope), the average canal slope is 0.12%, the maximum relief is 183 m, the main river length is 80.23 km, and the length along the main channel from the outlet to a channel point nearest the watershed centroid is 42.29 km, (Sule and Alabi , 2013). The land slope or watershed slope can be used, together with the HSG and the land use, to determine the runoff coefficient. In Kwara State, Awun River Basin is a combination of three basins namely: River Foma, River Asa and River Oyun. The water of the basin runs into Niger River (Figure 2).

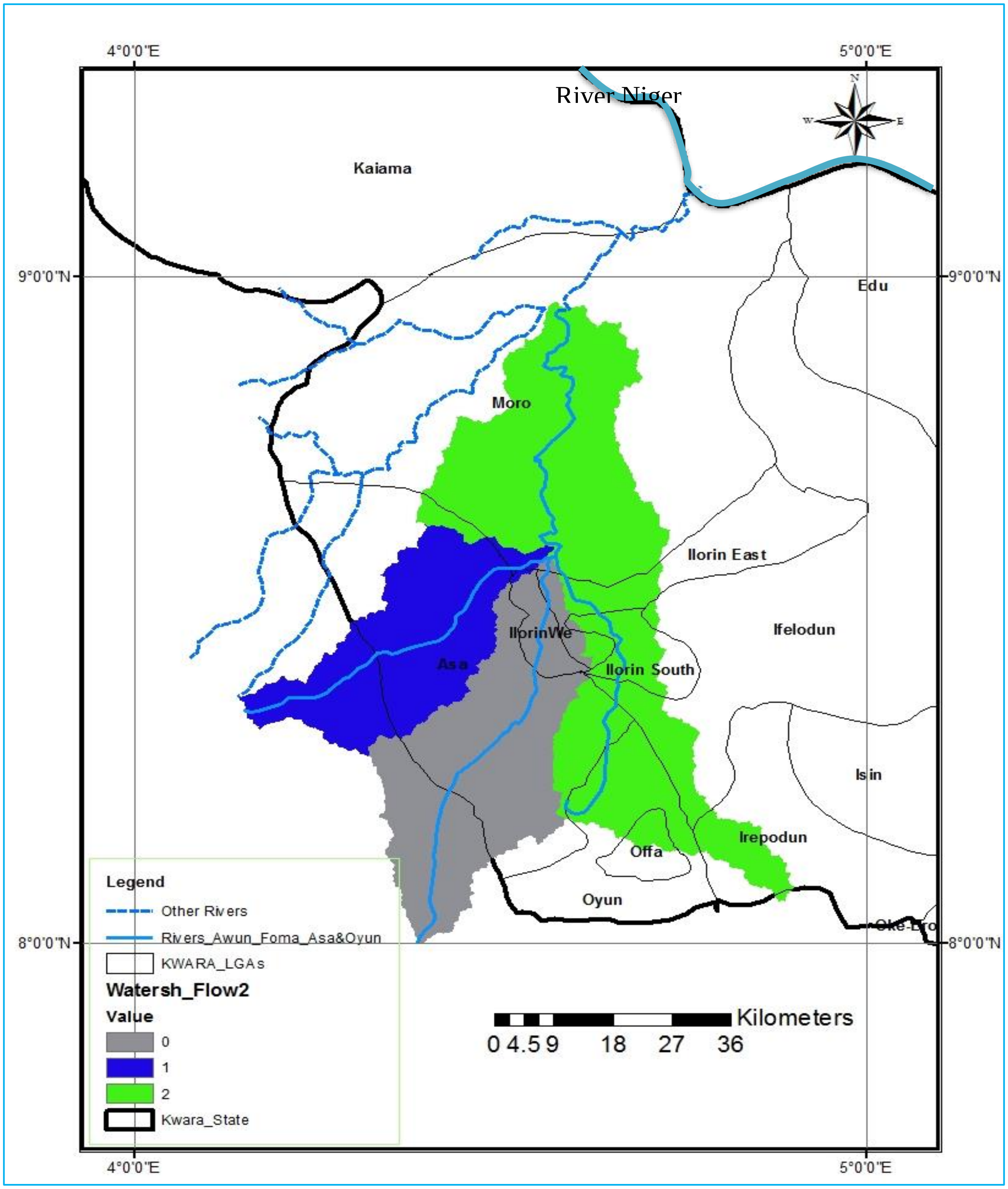


Figure 1.2: Drainage of Awun Basin, Kwara State

CHAPTER TWO

2.0. LITERATURE REVIEW

In this chapter some concepts such as climate change, regional climate model, emission scenario, climate projection, climate scenarios, statistical downscaling, crop water requirements, and water balance equation in agricultural land were reviewed. These concepts are very useful for the understanding of this study. Some relevant literatures for the present study were also reviewed. They encompass the estimation of availability for agriculture, the water insufficiency and failure of crop in Guinea Savannah of Nigeria, and future agricultural production under climate change. These literatures help in identifying the gaps in the body of the knowledge.

2.1. Conceptual Framework

2.1.1. Climate Change and Water Resources

Climate is average weather and occurs over long time frames (e.g. 30 years as defined by World Meteorological Organization (WMO)).Indeed, climate variability refers to variations in the mean state of the climate on all temporal and spatial scales (IPCC, 2007). Then, Climate change refers to changes in climate characteristics, including temperature, humidity, rainfall, wind, and severe weather events over long term periods due to natural variability or as a result of human activity (IPCC, 2001). Climate change therefore brings changes in all facets of hydrological cycle. At some places, it will result in heavy floods while in order places, regional drought. It is necessary to downscaled projections of climate change for the purpose of showing the effects of climate change on anthropogenic and natural systems (Fowler, Blenkinsop, and Tebaldi, 2007).

2.1.2. Regional Climate Model

A climate model is a numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties (IPCC, 2013). An example of such model is the RegCM which is maintained in the Earth System Physics (ESP) section of the International Centre for Theoretical Physics (ICTP) but was originally developed at the National Centre for Atmospheric Research (NCAR). The latest version of the model, RegCM4, is now fully supported by the ESP, while previous versions are no longer available. The model is simple, applicable to any region of the world with a spatial resolution can is up to about 10 km (Giorgi *et al*., 2012).The spatial resolution for the present study is 25 km.

2.1.3. Emission Scenario

Emission scenarios provide to the climate models by describing the future greenhouse gases, aerosols, and many other pollutants released into the atmosphere, and together with land use and land cover information (IPCC, 2013). In other words emission scenarios estimate future releases of greenhouse gases and aerosols to the atmosphere considering hypotheses relating to, for instance, the future technological and socioeconomic developments.

2.1.4. Climate Projection and Scenario

Climate projection is the response of the climate system, simulated based on an emission scenario or the concentration greenhouse gases and aerosols released in the future, usually obtained using models of the climate (IPCC, 2013). It is therefore an output of a climate model. The outputs are also called simulations or runs.

Climate scenario is a reasonable and probable future climate built to help understand and quantify potential effects of the anthropogenic climate change (Abu-Taleb, 2000; IPCC, 2001). There are several types of climate scenarios including three main classes: synthetic scenarios, analogue scenarios and scenarios based on outputs from global climate models (GCMs). According to IPCC-TGCIA (1999) each scenario is defined in the following way:

The synthetic scenarios describe methods where a specific climatic parameter is increased or decreased at an arbitrary quantity, but realistic, considering the change range of that parameter obtained using climate model runs of a region. For instance, the baseline temperature can be arranged by adding +1, 2, 3, 4°C and precipitation can be decreased or increased by 5, 10, 15, and 20 %. Indeed, these adjustments give the extent of change in the future of temperature and precipitation. They can be used considering the range of variation given by global or regional climate models (GCMs or RCMs). The synthetic scenarios are easily understood by policy makers or non-specialist. The weakness of such scenarios is the arbitrary choices applied.

The analogue scenarios in a region are built using records of similar future climate of another region which has close regimes of climate. The similarity of regimes can be obtained in a temporally or spatially scale. The advantage of the analogue scenarios is that they are relaying on climatic conditions which have already been experienced or observed. They are therefore free from models uncertainty. Analogue scenarios are useful for validation of the impact models. However, they have limitation, especially for quantity impact evaluation.

The scenarios based on general circulation models, called GCMs, give reliable estimation of future climate because they used strong tools to estimate the forthcoming response of climate to the radiative forcing. GCMs are appropriate in estimating future climate in a large or global scale whereas, in a regional scale, RCMs offer a good resolution. And because this work is a quantitative impact assessments, scenarios from the RCMs were considered. The GCMs or RCMs output are based on storylines. Every storyline correspond to a specific emission scenario. The previous storylines were designated as "marker scenarios" (IPCC, 2000) with A1 (with three groups A1FI, A1T and A1B), A2, B1 and B2. More recently, these were reviewed and new scenarios established by the IPCC AR5 (Moss *et al.*, 2008). The new storylines refer to as 'Representative Concentration Pathways' (RCPs).There are also four RCPs namely: RCP2.5, RCP4.5, RCP6.5 and RCP8.5. The present study will focus on the RCP4.5 (realistic scenario) and RCP8.5 (pessimistic scenario).

2.1.5. Statistical Downscaling

The statistical downscaling is the establishment of mathematical relationships between large scale climate variables (simulations) and local scale variables (observation or records). In other terms it is simply a regression between simulations and local scale observations including generally precipitation, temperature, and relative humidity. The downscaling of climatic parameters or variable can be done using several methods.

Maraun *et al*. (2010) classified the techniques as Perfect Prognosis (PP) approach, Model Output Statistics (MOS) technique, and Weather Generator method. PP establishes relationships between the GCM outputs (large scale variables) and the local scale observations. The MOS form relationships between the simulations and local scale observations for the aim of correcting either GCMs or the RCM biases or errors. Weather generators generate weather time series at the local scale using the statistical properties of observed times series. Then parameters are adjusted using GCMs or RCMs outputs.

The MOS method which corrects the RCM outputs was used for the present study by establishing a regression between the simulated variables and the observations. Teutschbein and Seibert (2012) has evaluated six approaches for correcting biases of RCMs simulations for input hydrological models: (i) no correction, (ii) the delta-change approach, (iii) linear scaling, (iv) local intensity scaling (LOCI), (v) power transformation, and (vi) distribution mapping. The linear scaling method of Lenderink, Buishand, and Van Deursen (2007) allows to downscale or correct RCM runs using scaling factor obtained from the relationship between mean monthly RCM control simulations and local scale corresponding observations or records. In that method, simulated precipitation and relative humidity are corrected with a multiplicative factor while temperature is corrected with an additive factor. According to Teutschbein and Seibert (2012), this method offer the advantage of correcting well the means. This approach, quite simple, is adequate for the present study as far as it deals only with the means of rainfall and temperature.

2.1.6. Onset, Seasonality Index, and Degree of Dryness/ Hydrologic Ratio

Onset of the growing season is the period when distribution of rainfall becomes sufficient for crop development (Odekunle, Balogun, and Ogunkoya, 2005). For rainfed agriculture, the start of growing season is quite important as yields may suffer if the onset is late. Indeed the prediction of onset is vital for farmers. There are several works done on onset prediction in in Nigeria. Some of the methods include (i) rainfall-evapotranspiration models (Kowal and Knabe, 1972; FAO, 1978; Benoit, 1977), and (ii) rainfall-based models which are based only on rainfall data (Olaniran, 1983; Ilesanmi, 1972a). According to FAO (1978) the onset of the growing season is the date when precipitation is greater than half of the potential evapotranspiration. The rainfall evapotranspiration model was used by Kowal and Knabe (1972) to compute onset date. They defined onset as ‘the decade in which the rainfall is greater than 25mm and where subsequent decade of rainfall are greater than 0.5 potential evapotranspiration’. Benoit (1977) defined the start of growing season in Northern Nigeria as the date when accumulated rainfall exceeds and remains greater than one half of potential evapotranspiration for the remainder of the growing season provided that no dry spell longer than five days occurs immediately after this date. Stern, Dennett, and Garbutt (1981), however, discussed that this method is complicated and proposed that the onset is the first occurrence of a specific amount of rain within two consecutive days. However in the context of climate change where there is an evident increase in temperature which may lead to more water losses more emphasis should be made toward rainfall-evapotranspiration models. The seasonality index (SI) measures the spread of the rainy season while the hydrologic ratio (HR) measures the degree of dryness of an area (Sawa and Adebayo, 2011).

2.1.7. Crop Water Requirements / Crop evapotranspiration

The widespread used equation for reference evapotranspiration (ET_0) computation is the Penman-Monteith equation. The Penman-Monteith (Allen, Pereira, Raes, and Smith, 1998) variation is recommended by the Food and Agriculture Organization (FAO). However this method needs many parameters (solar radiation, air temperature, humidity and wind speed) that are not always available. Hargreaves and Samani (1985) developed an alternative approach to estimate ETo where only mean maximum and mean minimum air temperature and extraterrestrial radiation are required (the Hargreaves-Samani method is referred to hereafter as HS).The simpler Blaney-Criddle (1950) equation was popular in the Western United States for many years and can be easily used to determine ET_0. However it over estimates the value of ET_0 (Kassam, and Smith, 2001). Another simple approach is the Blaney Morin Nigera (Duru, 1984) model which requires less variables and was found out to be the best model that can be applied to estimate ET_0 for several stations in Nigeria (Ati, Stigter, and Oladipoa, 2002; Ilesanmi, Oguntunde, and Olufayo, 2014). According to Ilesanmi, Oguntunde, and Olufayo (2014) BMN model has high correlation value with the values obtained from the recommended FAO56-PM model (Allen *et al*., 1998).

2.2. Review of other Related Studies

Ufoegbune *et al* (2012) conducted a study on estimating water availability for agriculture in Abeokuta, South Western Nigeria. The concerns of the study were to tackle problem of low development of agricultural production in Aboekuta. Since crop productivity is highly related to the amount of water available, it was therefore necessary to know whether the water available during the growing season is sufficient or not in order to solve the problem. Mean monthly parameters (Temperature, Solar Radiation, Relative humidity, Wind speed and Rainfall) were collected from Nigeria Meteorological Services (NIMET) for a period of twenty-one (21). The data were compiled and tabulated for proper coordination. The data analysis was done using Blaney-Criddle equation to determine the crop water requirement. This equation was chosen instead of Penman (1948) equation because it was simpler and also popular as Penman equation. The results reveal that tomato, pepper and maize could perform conveniently during their growing season without the need for irrigation whereas cotton will need a complement of irrigation water in Aboekuta, Nigeria. This study provides a simple, clear and detailed method for data collection and analysis to estimate water availability for some crops. However several limitations must be considered in interpreting the study findings. The Blaney-Criddle (1950) model is based on temperature only which is not appropriate since it’s generally overestimate the ET0. Also, the results are only reliable for the present conditions of climate. The climate change impact has not been considered in the study. A simple sift of temperature or precipitation may change the results. So, further studies must be undertaken to include future climate change scenarios.

Ziad and Sireen (2010) conducted a study on climate change impact and adaptation with regards to agricultural water demand in Palestine. The study was to address the issue of present and future of agriculture production projected to be reduced due to climate change. The research aimed to assess potential effects of changing climatic conditions on crop and irrigation water needs through using synthetic scenarios or incremental scenarios. The data collected for this study was a range climate change, crop data and meteorological data (temperature, solar radiation, relative humidity, wind speed and rainfall). The range of climate change was obtained from an existing study. For the analysis, reference crop evapotranspiration (ET_0) was computed using the recommended Modified Penman-Monteith method. The results indicate that the utmost threat on crops will occurs if temperature increases up to 3°C and precipitation decreases by 20%. And the corresponding increased irrigation water for that scenario is 2.9 MCM/Y. The results seem reliable for the present and future conditions of climate. This study is therefore a perfect example of how the impact of climate change on crop and irrigation water requirements. In fact, the use of Modified Penman-Monteith method in CROPWAT 8.0 model is appropriate since it recommended by FAO. However, model-based scenarios are more reliable than the incremental scenarios.

Yengoh, Brogaard and Olsson (2012) used model based climate scenarios to evaluate the crop water requirements Guinea Savannah zone of Cameroon. This study addresses the issue of poverty in rural sector. The research aimed at better understand climate change impacts on rainfed agriculture since this farming practice has a crucial social and economic implications. They considered the common rainfed crops which are Beans, Groundnuts, Maize and Sorghum. Mean monthly climatic data (rainfall, temperature, humidity, wind speed, and sunshine) were inputted into CROPWAT model in order to compute crop water requirements for 2050s. Three Special Report on Emissions Scenarios (SRES) storylines were used namely A1B (moderate or mid-level carbon scenario), A2 (higher or more extreme carbon scenario), and B1 (the more optimistic carbon scenario). The results show that crop water needs defer considering different crops and scenarios. The values increases for all the crops under the moderate A1B and the extreme A2 scenarios except Sorghum which decreases under A1B scenario compare to the baseline values. The study shows a good methodology for assessment though the use of CROWAT model necessitates complex inputs parameters. The present work has also considered the effect of future climate condition on crop water requirements. Therefore this study seems to be reliable for current and future conditions. However, no bias correction was applied to the simulations and the denomination of storylines are no longer used, the new emission scenarios are the ‘Representative Concentration Pathways (RCP)’ where RCP.4.5 is equivalent to A1B and RCP.8.5 is equivalent to A2.

Shrestha (2014) conducted a study on ‘Assessment of Water Availability under Climate Change Scenarios in Thailand’. RCMs runs or simulations were obtained using PRECIS (Regional Climates for Impact Studies). The runs were further bias corrected using ratio method (linear scaling method) derived from Braun, Caya, Frigon, and Slivitzky (2011) for A2 and B2 emission scenarios. A comparison was done between RCM and Bias Corrected precipitation. The rainfall anomalies projected by bias correction of the RCM dataset were calculated for dry and wet seasons separately. The results showed that, in the future, water available at different hydrologic response units (HRUs) is subject to variations during dry and wet seasons. This paper shows an interesting and logical way of assessing water availability under climate scenarios including the methodology and the discussions that can inspire future related studies.

Mourato, Moreira, and Corte-Real (2014) conducted a study on ‘Water Availability in Southern Portugal for Different Climate Change Scenarios Subjected to Bias Correction’. The aim of their study was to correct the time series of precipitation and temperature for the control (1961–1990) and the scenario (2071–2100) periods provided by regional climate models and use them to assess future water availability. The reason why this study was done was that temperatures were higher and precipitation lower than observations in the control period. Thus, the direct input of models data might has resulted in more severe scenarios for future water availability. Therefore, three bias correction techniques namely: Delta Change, Direct Forcing and Hybrid, were used and their performances in water availability impact studies were evaluated. The Delta Change technique assumes that the observed series variability is maintained in the scenario period and is corrected by the evolution predicted by the climate models. The Direct Forcing (linear scaling) technique maintains the scenario series variability, which is corrected by the bias found in the control period, and the Hybrid method maintains the control model series variability, which is corrected by the bias found in the control period and by the evolution predicted by the climate models .The results show that runoff reduces for all the methods but it reduces more with Delta Change technique. No conclusion was drawn with regards to the appropriate method to use but it was recommended to always use several climate scenarios and different bias correction methods to produce robust conclusions in impact studies. The methodology is quite appropriate for their study as well as future studies. However for reason of scope and limitations, with regards to the amount of simulations to manipulate, only the direct forcing (simple linear scaling) method was chosen and used the present study.

Leander and Buishand (2006) have studied the resampling of regional climate model output for the simulation of extreme river flow. The purpose of their work was to investigate whether resampling of the output from a regional climate model (RCM) can provide realistic long-duration sequences of precipitation and temperature for the simulation of extreme river flows. This was important for assessing the impacts of climate change on river flooding. In the methodology applied, a baseline period 1961-1990 of observations and simulations was used. A linear and non-linear scaling methods were used to correct daily precipitation as well as daily temperature. It was found that a simple nonlinear correction adjusting both the biases in the mean and variability led to a better reproduction of observed extreme daily and multi-day precipitation amounts than the commonly used linear scaling correction. They conclude that it is always advisable to correct the simulation from regional climate model. And the non-linear method correct better precipitation and temperature especially when the interest of the study is to assess extremes. However for the present, the interest is not on the extremes, so the simple linear scaling method is still acceptable.

Schaldach, Koch, Beek, Kynast, and Flörke (2012) studied ‘current and future irrigation water requirements in pan-Europe: An integrated analysis of socio-economic and climate scenarios’. The aim of their study was to determine the amount of irrigation water needed which is important for agricultural production. They computed irrigation water requirement for the baseline climate (2000s) and for future climate (2050s) using available IPCC 4th assessment climate change scenarios (GCMs outputs). The results showed that yearly irrigation water requirements were expanding due to socio-economic drivers and climate change. They show that adapting sowing dates to the changing climatic conditions might help to overcome seasonal water deficits. This study has the benefit of showing that the combination of agricultural management such as planting dates adjustment with climate models simulations can provide reliable information to develop water management strategies at regional scale. However the use of coarse spatial resolution runs (GCMs) does not warranty precise estimate of crop water needs compare to high resolution simulations (RCMs).

While an adequate amount of research has been conducted on water availability for agricultural, most of these studies did not integrate future conditions of climate (Ufoegbune *et al*., 2012, Odekunle *et al*, 2007). Few studies have tried to take into account the future climate change scenarios (Ziad and Sireen, 2010, Yengoh, *et al*, 2012). However, most of the studies done on the potential effects of the future climate change on crop and irrigation water requirements are not from Nigeria (Ziad and Jamous, 2010, Yengoh *et al*., 2012). In Kwara State, no research has tried to predict the future effects climate change on water availability for crops. For instance Ufoegbune *et al* (2012) has only estimated the current crop water needs and irrigation in Abeokuta, South Western Nigeria. Odekunle *et al* (2007) have tried to show the past effect of climate variability on water availability for crops in Guinean Savanna part of Nigeria. The gap is therefore the lack of knowledge in terms of agricultural water demand under present and future climate scenarios in Kwara State. Hence, this study is an attempt to fill this gap.

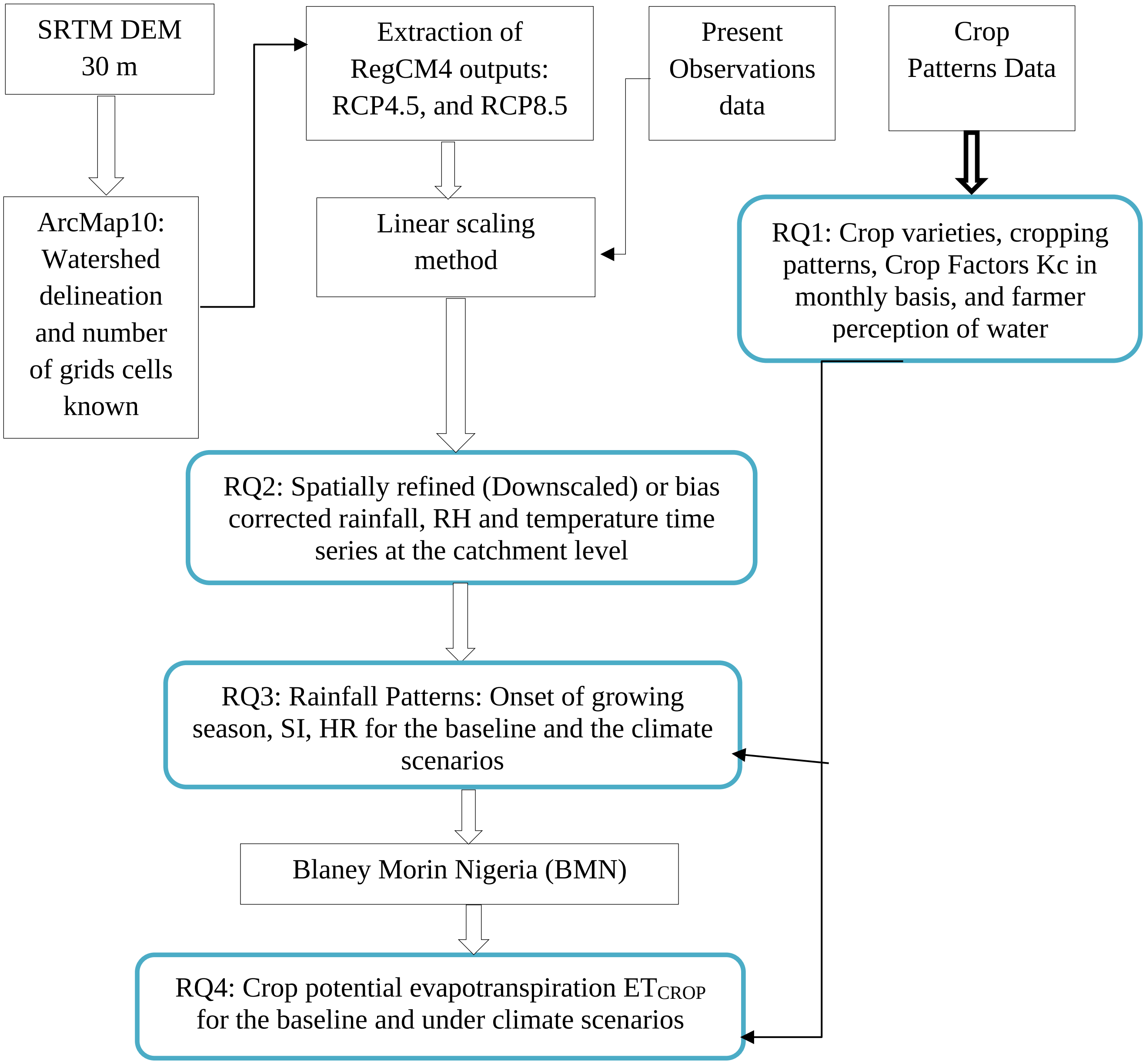
CHAPTER THREE

3.0. MATERIAL AND METHODS

This chapter clarify how data, from the field, was collected and the procedures used to analyse them in order to investigate the water availability for rainfed agriculture under different climate scenarios in Awun Catchment. Instruments that were used for the collection of the data are listed here and the flow chart leading to the answering of all the research questions of the study is shown. Microsoft Excel 2013, ArcMap 10.1 and STATA.11were used in analysing the data collected.

3.1. Methodological Framework Flow Chart

The flow chart in Figure 3.1 shows the steps by order that were considered to achieve the research word. It gives a brief summary of the data and techniques used to answer, by order, each research question.



RQ: Research Question

Figure 3. 1: Methodological Framework Flow Chart.

3.2. Data Collection

In this section, the study population, the sample and sampling procedure were first described. Then, the primary and secondary data collection were described. The primary data collection concerned crop types and cropping patterns and the secondary data collection concerned satellites images and climate scenarios.

3.2.1. Study Population, Sample and Sampling Procedure

The study population encompasses farmers growing some common crops in rainfed agriculture in one of the four (4) agro-ecological zones of Kwara within Awun river basin. These crops are maize, sorghum, yam and cassava. Only the common variety of each crop were taken into account in the area.

Awun basin falls mainly within the agro-ecological zone C of Kwara State. Zone C encompasses 5 LGAs. A multistage sampling was used to select the sample for the study. Three (3) LGAs potentially involved in farming were selected. For each of the four (4) crops, 25 farmers were chosen across the three LGAs considering the communities were the crop is potentially grown in rainfed, giving a total number of 100 farmers. These farmers were interviewed on the crop patterns, as well as their awareness about the impact climate change and water availability. Field observations and measurements (GPS) were also made in situ. The questionnaire administration were tested with KWADP agricultural agents who are also rainfed farmers. A sample of the questionnaire is in appendix A.

3.2.2. Primary Data Collection: Crop types and Cropping Patterns

Several common crops data can be found in the FAO (1998) publications; however, the most reliable crop data remain the data obtained from the local agricultural research stations. That is why a local survey was carried out to assess the crops grown in rainfed agriculture. The present cropping patterns were assessed through interviews with extension agents and farmers. The content of the questionnaire included the crop variety, first and last planting dates, the first and last harvesting dates, length of the growing period (LGP) and information about onset and cessation for the last 20 years. The information was confirmed by Kwara Agricultural Development Project (KADP). Since no research has been conducted to determine, for each crop, the total growing period, length of growing stages (LGSs) and the crop factor (Kc) in this area, these values were estimated using FAO56 (1998) tables.

3.2.3. Secondary Data Collection

3.2.3.1. Satellite Image

A Digital Elevation Model (DEM) is needed to delineate Awun watershed and this was done using the satellite imagery SRTM. The watershed characteristics (position and size) were determined in order to figure out the number of RegCM4 grid cells (25x25km^2 per grid) that are captured in this catchment. Since the RegCM4 runs for the whole West Africa Region, the simulated aerial rainfall and order climatic parameters were then extracted for the specific watershed.

3.2.3.2. Data Acquisition for Climate Scenarios

a. RegCM4 Outputs from WASCAL Competence Centre

Simulations from RegCM4 at 25km spatial resolution were requested from the WASCAL Competence Centre. The control dataset (1985-2004) and the future dataset (2080-2100) for two scenarios RCP4.5 and RCP8.5 were requested. The dataset include:

- **Control climate:** (Minimum Temperature, Maximum Temperature, Rainfall, and Relative Humidity (RH)) for the period 1985-2004 and for the RegCM4 driven by MPI and GFDL.
- **Future climate**: (Minimum Temperature, Maximum Temperature, Mean temperature, Rainfall, and Relative Humidity (RH)) for the period 2080-2100 and for the two scenarios (RCP4.5 and RCP8.5) driven by MPI and GFDL.

b. Meteorological Climate Data

The climatic data (observations) of synoptic station of Ilorin for a period of forty (40) years were acquired from the archives of Nigeria Meteorological Agency (NIMET), Abuja. These datasets include rainfall, minimum and maximum temperature, and relative humidity for the period 1985-2014. These dataset were used as baseline climate to correct the RegCM4 dataset future rainfall, temperature and relative humidity. The bias corrected data were then used to evaluate current and future start of rain, as well as crop water requirements (crop potential evapotranspiration).

3.3. Data preparation

All the collected data were compiled and tabulated in Microsoft Excel for proper coordination. The RegCM4 data from WACAL Competence centre were in NetCDF files (.nc) format that could not be used directly for the present study. This is because the plain text format (.csv for instance) was needed for importing raw numerical values of climatic parameters in excel, and for input in the potential evapotranspiration model. The conversion was done in window using the following steps: (i) Install NetCDF package (by downloading a pre-built Win32 binary version of the ncdump.exe from North American Regional Climate Change Assessment Programme (NARCCAP) website namely: netcdf-3.6-beta1-win32dll.zip), (ii) Install File Array Notation (FAN) package (by downloading a pre-built binary namely: fan-2.0.3.win32bin.zip from the same website, and (iii) Write the following programming code using Microsoft Window ‘s command prompt: ‘ncdump variable.nc > variable.csv’ . For example if the variable is pr_MPI_RegCM4_Historical_1985-2004_Awun, then the code is: ‘ncdump pr_MPI_RegCM4_Historical_1985-2004_Awun.nc > pr.csv ‘. The conversion was done for all the variables. It was found out that some variables in the CSV files present some blank rows all over the 20 years periods. The blanks were then remove using Microsoft Excel. Finally, the RegCM4 data (simulations) and the meteorological data (observations) were processed in Excel software to display the mean daily temperature (°C), daily rainfall (mm) as well as the mean monthly values over the baseline period as well as the future period for the two scenarios. Also mean monthly relative humidity (%) were displayed on tables.

3.4. Data Analysis

3.4.1. Crop Patterns Data Analysis

Information from the field work was combine with the FAO tables to determine crop factors. The values of crop factor (Kc) were given by FAO 56 (Allen *et al*., 1998) for each growing stage (initial stage, crop development stage, mid-season stage and late season stage). Since, the months and the growing stages were not always corresponding and in order to be able to calculate the crop evapotranspiration in a monthly basis, the Kc values per month were determined using simple interpolations. Microsoft Excel 2013 was used to summarize into percentages farmer responses.

3.4.2. Climate Scenarios Data Analysis

3.4.2.1. Delineation of the Awun River Bassin

The 30 m resolution digital elevation model (DEM) was downloaded from Shuttle Radar Topography Mission (SRTM) website: http://glcf.umd.edu/data/srtm/ .The DEM were imported into ArcGIS (ArcMap10) for analysis. The entire basin were delineated and overlain to the boundary of Kwara State. The number of RegCM4 grid cells within the basin were known, as well as the areal climatic parameters simulated.

3.4.2.2. Stationarity of RegCM4 and NIMET Dataset

The stationarity of the dataset (simulations and observations) was checked using the Philips Perron-Unit-Root Test in STATA11.0 at 95% and 90% confidence levels (α=0.05, α=0.10 respectively):

Null hypothesis (H0): The simulations and observations (Minimum Temperature, Maximum Temperature, Rainfall, and Relative Humidity) are not stationary at α=0.05 and α=0.10. Thus, the alternative hypothesis is (H1): The simulations and observations (Minimum Temperature, Maximum Temperature, Rainfall, and Relative Humidity) are stationary at 95% and 90% confidence level.

3.4.2.3.Downscaling of the RegCM4 Outputs to the Local Scale (Awun Basin)

a. Correction of the RegCM4 outputs Biases: the Linear Scaling Method

Developing a model that links the simulations and the observations was the statistical method used for the downscaling in the present study. The linear scaling method of (Hashino, Bradley, and Schwartz, 2007; Prudhomme, Wilby, Crooks, Kay, and Reynard, 2010; Newton, Dadson, Lafon, and Prudhomme, 2012), which is a regression method applied to downscale (correct) the simulated rainfall, relative humidity and temperature for the RCP4.5 and RCP8.5 to the local scale (Awun catchment). Figure 3.2 shows the flaw chart for correcting the errors of the model runs. The relative humidity is however truncated when the value is greater than 100 %.

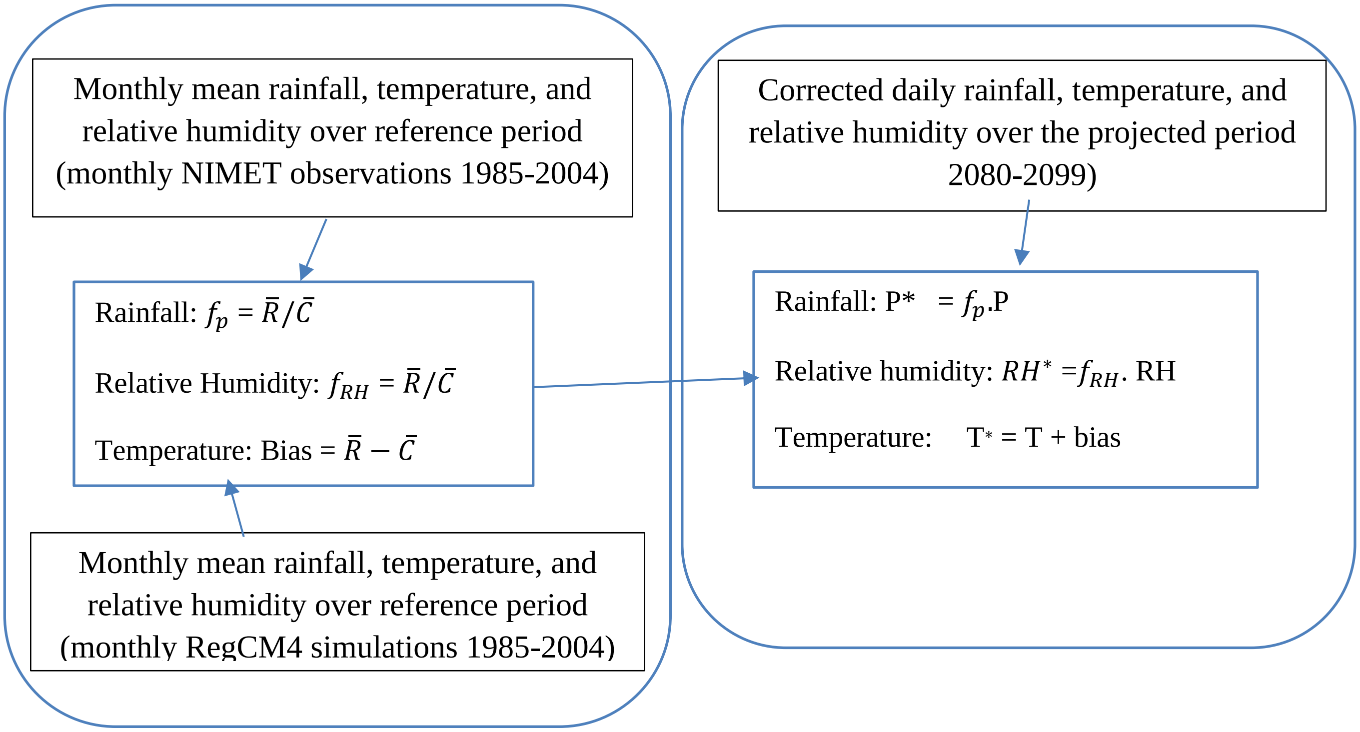


Figure 3. 2: Methodological Flow Chart for Bias Correction

Correction of Rainfall : the daily simulated rainfall P in the future was transformed into P^* such that $P^* = f_p.P$, using a scaling factor, $f_p = \bar{R}/\bar{C}$, where: $\bar{R}$ and $\bar{C}$ are the values of monthly mean observations rainfall from NIMET (over a period of 1985-2004) and simulations rainfall from RegCM4 (over the same period 1985-2004) respectively and for each grid 25km x25km. In other words the scaling factor f_p was then used to correct the future RegCM4 rainfall over the period of 2080-2099 in Awun Catchment, Kwara State.

Correction of Temperature: A linear scaling approach was carried out to correct the simulated daily mean air temperature. In contrast to precipitation amount, the bias of temperature were calculated as the difference of monthly mean values of simulated data

(C) and observed reference data (R) for each grid and over the control period 1985-2004: bias = $\bar{R} - \bar{C}$ and T* = T+ bias.

Correction of Relative Humidity: The bias correction of relative humidity (RH) is similar to that of rainfall because it is subject to positively constraints as rainfall and the RH values greater than 1 i.e 100% are simply truncated (Haerter, Hagemann, Moseley, and Piani , 2011) and (Piani , Haerter, and Coppola, 2010). Thus RH was bias corrected using the linear scaling approach as described above for rainfall.

b. Comparison between Model Outputs and Historical Records (Observations)

After correction, the model runs (rainfall, Tmin, Tmax, and relative humidity) were compared to the observations .The absolute and relative changes equations used by Leander and Buishand (2006) and Shrestha (2014) were applied. Equation 3.1 give gives the percentage of change between observations for a baseline period (1995-2014) and the corrected RegCM4 rainfall and relative humidity (2080-2100). Equation 3.2 gives the difference between observed and simulated rainfall.

$$\text{Relative change \%} = \frac{\bar{X}_{corrected\_RegCM4} - \bar{X}_{Obs}}{\bar{X}_{Obs}} \times 100, \qquad (3.1)$$

$$\text{Absolute change} = \bar{X}_{corrected\_RegCM4} - \bar{X}_{Obs} \qquad (3.2)$$

Where:

$\boldsymbol{\bar{X}_{Obs}}$ and $\boldsymbol{\bar{X}}_{corrected\_RegCM4}$ are respectively the mean monthly observations (temperature, rainfall, and relative humidity) from NIMET over the baseline 1995-2014 (20 years) and the RegCM4 outputs (rainfall, temperature, and relative humidity) over the scenarios period 2080-2099 (20 years). Clustered column charts were drawn to compare the values across the months.

3.4.3. Rainfall Characteristics for the Baseline and for the Future Scenarios

In this section, rainfall characteristics or patterns was determined based on some indices namely seasonality index (SI), onset of the growing season, and the hydrologic ration (HR). This was done for current and future climate.

3.4.3.1. Seasonality Index (SI)

Rainfall Seasonality Index (SI) was computed for the present and future climate. Seasonality Index measures the spread and steadiness of the rainfall during the wet season. Walsh and Lawler (1981) mathematically expressed seasonality index as the sum of the absolute deviations of the mean monthly rainfall from the overall monthly mean multiplied by the exponent of the mean annual rainfall given as in Equation 3.3:

$$\mathrm{SI} = \frac{\sum|\bar{X}_n - R/12|}{R} \qquad (3.3)$$

Where:

SI, R, and $\bar{X}_n$ represent respectively the seasonality index, the mean annual rainfall, and the mean rainfall of the month n

3.4.3.2. Start of the Growing Season in Awun basin, Kwara State

In a context of climate change (evident increase in temperature), the rainfall-evapotranspiration model of Benoit (1977), widely used by many studies in Nigeria (Jimoh and Egbareyba, 2003; Edoga, 2007) was adopted. According to Benoit (1977), onset is 'the date when accumulated daily rainfall exceeded 0.5 of the accumulated potential evapotranspiration i.e $\sum(rain - 0.5 * ET_p) > 0$ for the remainder of the season, provided that no dry spell longer than 5 days occurs immediately after that date'.

The ET_p was calculated using two models namely Blaney Morin Nigeria (Duru, 1984) and Hargreaves and Samani (1985) to make sure that onset prediction does not depend on the limitations of a particular ET_p model . These techniques were chosen instead of the recommended Penman-Monteith for their reliability in calculating ET_p in Nigeria when there are limited climatic parameters as experienced in the present study. Each method requires only three parameters which are described in Equation 3.4 and Equation 3.5 (Ilesanmi, Oguntunde, and Olufayo, 2014). According to Blaney Morin Nigeria (Duru, 1984) the daily potential evapotranspiration can be calculated as:

$$ET_p = r_f\,(0.45\mathrm{Ta} + 8)\,(520 - R^{1.31})/\,100 \qquad (3.4)$$

Where:

ETp = Daily potential evapotranspiration (mm/day)

r_f = Ratio of monthly radiation to annual radiation.

Ta = Mean daily temperature (^{0}C)

RH =Daily relative humidity (%)

And for Hargreaves and Samani (1985):

$$ET_p\ (\mathrm{mm\ /\ day}) = 0.0135\ K_{RS}.\ Ra.\ \sqrt{T_{max} - T_{min}}\ .\ (T_{mean} + 17.8) \qquad (3.5)$$

Where:

ET_p = Daily potential evapotranspiration (mm/day)

Tmean = Mean daily temperature (^{O}C)

Tmax = Daily maximum temperature (^{O}C)

Tmin = Daily minimum temperature (^{O}C)

Ra = Extra-terrestrial radiation (mm/day).

K_{RS} = Radiation adjustment coefficient (Hargreaves (1994) recommended using K_{RS} = 0.16 or "interior" regions and K_{RS} = 0.19 for coastal regions).

3.4.3.3. Hydrologic Ratio Indices

Hydrologic Ratio (HR) is the degree of wetness or dryness of a place. It is defined as the ratio of the mean annual rainfall (P) to the Potential Evapotranspiration (PE) (Adefolalu, 1998; Adebayo, 1997). The value indicates soil moisture deficiency or surplus. It is one of the best methods of estimating water availability as soil moisture. In this context, it is the most appropriate drought indicator, which not only gives an indication of the adequacy of rainfall but also serves as an empirical measure of the contribution of drought ‘tendency’ in the desertification process. It is the best indicator of the hydro-neutral zones (best zones for crop performance due to neither water logging nor deficient soil moisture content). This index helps in decision making in agriculture because it provides a guide to the best choice of the area where a particular type of crop will not only thrive well but reach optimum growth level and give high yield.

Hydrological ratio is obtained by using Equation 3.6:

$$HR = \frac{Rainfall}{PE} \qquad (3.6)$$

Where:

HR and PE are, respectively, the Hydrologic Ratio and the Potential Evapotranspiration. The higher the value of RH, the drier the wet season and vice versa.

3.4.4. Crop Water Requirements for the baseline and under the Climate Scenarios

3.4.4.1. Crop Reference Evapotranspiration for Baseline and the Climate Scenarios

In this research, Blaney Morin Nigeria model (BMN) has been adopted to estimate the monthly reference evapotranspiration. The BMN method requires only observed Tmin (˚C) and Tmax (˚C), relative humidity (%), the extra-terrestrial radiation Ra (MJ m^{-2}) for the estimation of ET_0 (mm/month). ET_0 is computed using Equation 3.7:

$$ET_0 = r_f\ (0.45Ta + 8)\ (520 - R^{1.31})/\ 100 \qquad (3.7)$$

Where:

ET_0 = Monthly reference evapotranspiration (mm/month)

r_f = Ratio of monthly radiation to annual radiation.

Ta = Mean monthly temperature (^{0}C) 1995-2014 (baseline) and 2080-2099 (scenarios)

R = Mean monthly relative humidity (%) 1995-2014 (baseline) and 2080-2099 (scenarios)

The use of BMN model for future scenarios requires the input of minimum and maximum temperatures, and relative humidity considering RCP4.5 and RCP8.5 scenarios. The model gave us the future crop reference evapotranspiration (ET_0) for the scenarios.

3.4.4.2. Crop Potential Evapotranspiration/ Crop water requirements

The crop potential evapotranspiration (ET_{CROP}) was determined using the relationship between the ET_0 and crop factors Kc (Equation 3.8). The formula is given as:

ET_{CROP} (mm) = $Kc \times ET_0$, (3.8).

Where:

Kc is the crop factor representing the relationship between the reference grass crop and the crop actually grown. Kc is determine in a monthly basis after the crops factors analysis.

Then a climatic water deficit or climatic water balance (difference between potential evapotranspiration and precipitation) was applied for the analysis. The climatic water deficit or climatic water balance for each crop is given by Equation 3.9.

Climatic Water Balance = $P - ET_{crop}$ (3.9)

Where:

P and ET_{crop} are the seasonal rainfall and the seasonal crop water needs respectively.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

This chapter contains the results of the analysis of data collected throughout the study to address the major objectives. The results were presented in a logical and meaningful way, according to the objectives. Discussions were simultaneously done on (i) crop types and cropping patterns as well as farmer's perception of water availability, (ii) downscaling of climate scenarios, (iii) rainfall characteristics, and (iii) crop water needs.

4.1. Crop types, Cropping Patterns and Farmers' Perception of Water Availability

4.1.1. Crop Types (Varieties) and Cropping Patterns in Awun Basin

The analysis of the questionnaire survey in Awun Basin (agro-ecological zone C) shows that the common food crops were as expected Maize, Sorghum, Cassava, and Yam. The main water use system adopted by farmers in the basin is rainfed. Several varieties for each crop can be found across Asa, Ilorin East, and Moro LGAs. Maize varieties are mainly yellow, white, hybrid, and sweet maize. The planting dates vary from April to June, and the harvesting dates from August to October. The length of the growing season is about 90 days. Maize is usually planted twice during the rainy season. Sorghum varieties are CS-95, red, white, hybrid, and sweet sorghum. Planting dates vary from May to July and harvesting dates from October to December. The estimated LGP is 4 to 7 months. Sorghum is only grown once. The varieties of cassava in zone C are mainly TMS-30555-0, TMS-30572, Oko Iyawo (local variety), TME 419, and TME 414. The planting dates for cassava vary from May to June and the harvesting dates from

November to May/June next year according to the variety. The estimated LGP is 6 to 12 months. Yam varieties are white yam, water yam, and hybrid. Planting dates vary from November to December and harvesting date from July to August of the following year with an estimated LGP varying from 7 to 10 months. The varieties of cassava and sorghum are drought resistant crops whereas those of yam and maize may not thrive well if there is drought (Olanrewaju, 2010).

4.1.2. Farmer' Perception of Water Availability in Awun Basin, Kwara State

According to the results shown in Figure 4.1 and Figure 4.2 farmers notice that the onset and cessation are likely to be early over the last 20 years. Figure 4.3 showed that the LGS over this period is likely to decrease. Also, Figure 4.4 showed that the frequency of dry spells are likely to increase in the area. The perception of farmers on the onset pattern was confirmed after analysis of the baseline onset date over the last 20 years.

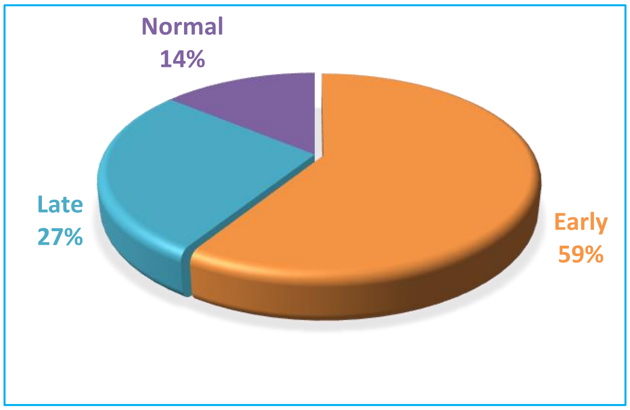


Figure 4. 1: Perception of Onset Evolution over the Last 20 years

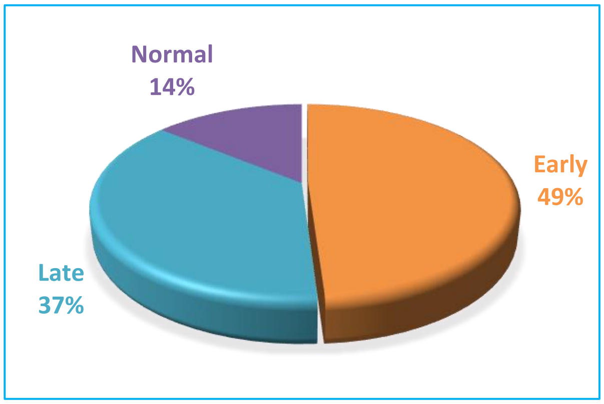


Figure 4. 2: Perception of Cessation Evolution over the Last 20 years

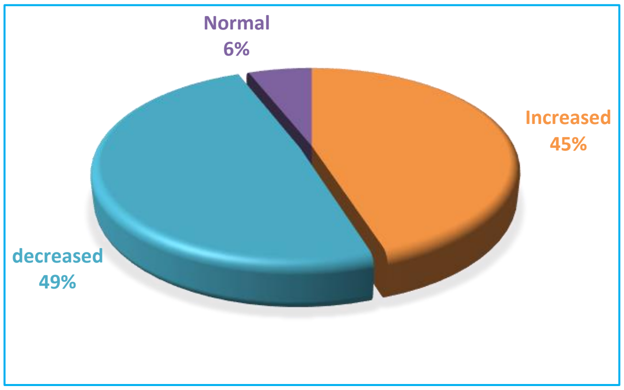


Figure 4. 3: Perception of Length of Growing Season Evolution over the last 20 years

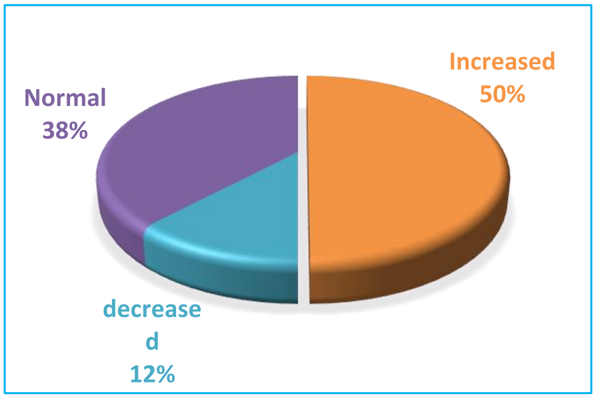


Figure 4. 4: Perception of Dry Spells Frequency over the last 20 years

4.2. Downscaling of Climate Scenarios in 2080-2099 at the Local Scale

The Stationarity of the dataset (annual rainfall, temperature and relative humidity) was checked before application of the linear scaling technique. The details of the computation are summarized in appendix D. The result from the analysis in STATA11.0 (appendix D) has shown that for all dataset, the Phillips-Perron unit root calculated value Z(t) is greater , in absolute value, than critical value at $\alpha = 0.05$ and $\alpha = 0.10$. This is confirmed by the Mackinnon approximate p-value for Z (t) which is closer to 0. The null hypothesis (H0) is then rejected at 95% and 90% confidence level meaning that all the dataset are stationary. The application of the linear scaling technique is detailed in appendix E. The correction factors or calibration factors were then used to correct the climate scenarios in order to bring rainfall, relative humidity and temperature at the local (Awun catchment) scale. Then future changes of rainfall, relative humidity, and temperature were shown in following paragraphs.

4.2.1. Changes in Rainfall Amount in the Future

After downscaling, on the one hand, Table 4.1 shows the expected changes in rainfall amount for the baseline and for the plausible future climate. The mean annual rainfall and the total rainfall over 20 years are computed for the baseline or present climate (1995-2014). The same variables are also computed over 20 years for future climate (2080-2099) represented for the RCP4.5 and RCP8.5 driven by the two GCMs namely MPI and GFDL. The table also shows the percentage of change with regards to the observations. The mean rainfall for the baseline period is 1226.5 mm and the expected means for the realistic scenario RCP4.5 are 1108.9 mm and 1066.3 mm for MPI and GFDL driven runs respectively. The corresponding changes (decrease) in the mean for that scenario are

9.6% and 13.1 % for MPI and GFDL driven runs. Under the pessimistic scenario RCP8.5 the expected mean rainfall depth are 1040.6 mm and 1009.6 mm for MPI and GFDL driven runs respectively. And the corresponding decrease in the mean rainfall is 15.2 % and 17.7 % for MPI and GFDL driven runs respectively. The same percentage of change are obtained with the total rainfall depth over 20years period. Thus, mean and total rainfall depths are expected to decrease under all plausible future climates. However the realistic scenario RCP4.5 projects less decrease in rainfall amount compare to the pessimistic scenario RCP8.5. Also the MPI driven run projects less decrease in rainfall depth compare to the GFDL driven runs. Thus, different GCMs driven runs project slightly different changes in rainfall as expected.

On the other hand, Figure 4.5 shows the annual cycle of rain over 20 years period for the baseline (1995-2014) and for climate scenarios (2080-2099). All scenarios (MPI_RCP4.5, GFDL_RCP4.5, MPI_RCP8.5, and GFDL_RCP4.5) exhibit lower mean monthly rainfall depth from January to June and in October as well as December but higher rainfall depth in August compared to observations. The low amount simulated in January, February and December may be due to the unusual phenomena that cannot be captured by the models (those amounts are not significant anyway since they are less than 10 mm) whereas from March to June it may be related to the delay in the start of the rainy season in the future. The low amount of rainfall depth observed in August can be attributed to the dry spells more 15 days observed in August throughout the baseline period specifically for the years 1997, 2001, 2003, 2005 and 2013. There was practically less than 60 mm threshold in August for the years 2001 and 2013. Koeppen and Geiger (1936) have classified the months of these years as ‘dry’ in the tropics. This classification based on 60 mm threshold is called absolute seasonality (Walsh and Lawler, 1981). From Figure 4.5 it is also clear that different models give different results with regards to MPI and GDFL (Mourato *et al.*, 2014).

Table 4. 1: Change in the rainfall amount for the present and future climate in Awun Basin

Statistics	Obs_Baseline1995-2014	pr_2080-2099_MPI_RegCM4_RCP4.5		pr_2080-2099_MPI_RegCM4_RCP8.5		pr_2080-2099_GFDL_RegCM4_RCP4.5		pr_2080-2099_GFDL_RegCM4_RCP8.5	
		Amount (mm)	% change	Amount (mm)	% change	Amount (mm)	% change	Amount (mm)	% change
Mean	1226.4	1108.9	-9.6	1040.6	-15.2	1066.3	-13.1	1009.6	-17.7
Sum	24527.2	22178.9	-9.6	20811.1	-15.2	21325.2	-13.1	20192.1	-17.7

Author’s Computation, 2015

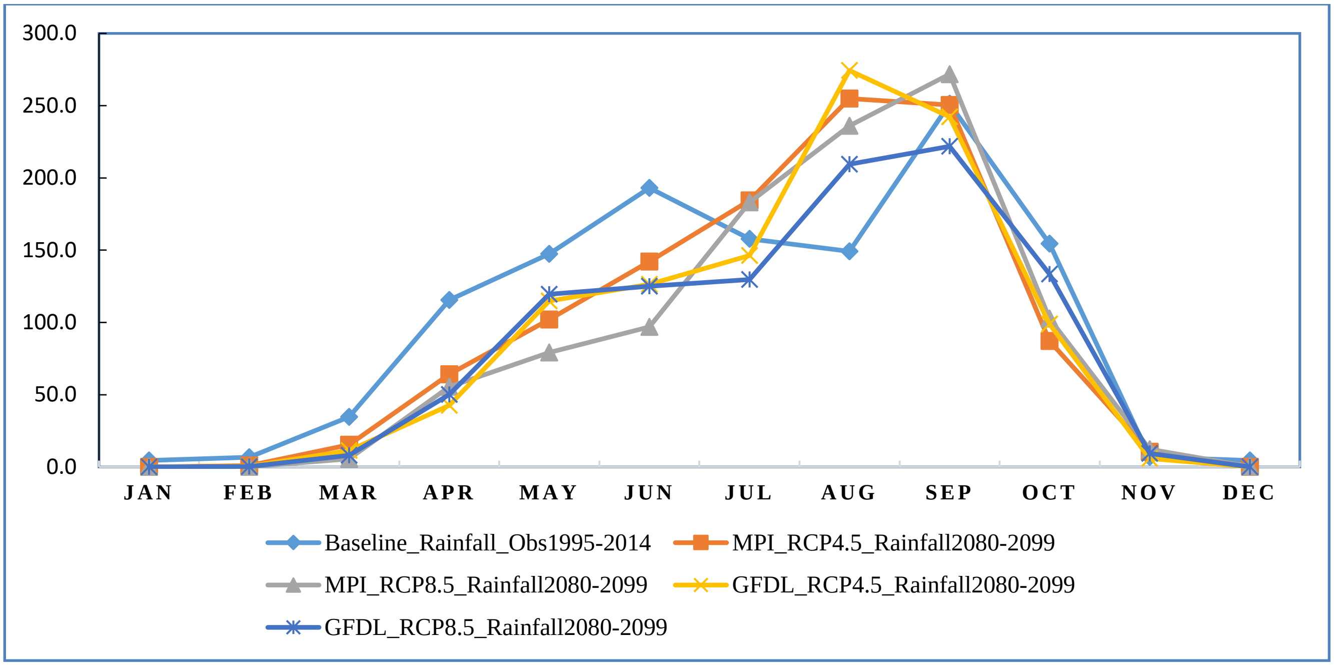


Figure 4. 5: Annual cycle of rainfall for the baseline and for the climate scenarios over 20 years after correction. The MPI-driven and GFDL-driven runs for the period 2080-2099 are compared with the observations 1995-2014.

4.2.2. Changes in Temperature and Relative Humidity in the Future.

In the future and under all scenarios the mean minimum and maximum temperatures are expected to increase (Table 4.2). Table 4.2 shows that this change varies from 1.5 ^{0}C to 2 ^{0}C for the realistic scenarios RCP4.5 and 3.1^{0}C to 4.0^{0}C for the more pessimistic scenario RCP8.5 respectively. Maximum temperature is expected to increase faster than minimum temperature for all scenarios. Figure 4.6 and Figure 4.7 show the annual cycle of minimum and maximum temperatures respectively. It is clear that maximum temperature is expected to increase drastically for all the months and for all scenarios while the minimum temperature will decrease for some months under the realistic scenario RCP4.5. Figure 4.6 shows that the decrease of minimum temperature will occur on January, February, March, October and December. It means the growing season period will experience a more increase in the minimum temperature compare to baseline. However, the mean relative humidity is projected to decrease about 10% (Table 4.3) for all scenarios. The annual cycle of relative humidity in Figure 4.8 shows that there is a decrease all over the year for all scenarios compare to the baseline period.

From the results (Table 4.1 to Table 4.3 and Figure 4.5 to Figure 4.7), rainfall is expected to vary, temperature will increase but relative humidity will decrease. And these changes in temperature and relative humidity will be accentuated under the pessimistic scenario compare to that of the realistic scenario. In other terms climate change will be severe under the pessimistic scenario.

Table 4. 2: Change in minimum and maximum temperatures for the present (1995-2014) and future climate (2080-2099) in Awun Basin

Statistics	Obs_Baseline1995-2014	MPI_RegCM4_RCP4.5 _2080-2099		MPI_RegCM4_RCP8.5_2080-2099		GFDL_RegCM4_RCP4.5_2080-2099		GFDL_RegCM4_RCP8.5_2080-2099	
		Value (^{0}C)	Change (^{0}C)	Value (^{0}C)	change (^{0}C)	Value (^{0}C)	Change (^{0}C)	Value (^{0}C)	change (^{0}C)
Mean Tmin	21.8	23.4	1.7	25.6	3.8	23.3	1.5	25.5	3.7
Mean Tmax	32.6	34.5	2.0	35.7	3.1	34.4	1.8	36.6	4.0

Author’s Computation, 2015

Table 4. 3: Change in relative humidity for the present (1995-2014) and future climate (2080-2099) in Awun Basin

Statistics	Obs_Baseline1995-2014	MPI_RegCM4_RCP4.5 _2080-2099		MPI_RegCM4_RCP8.5_2080-2099		GFDL_RegCM4_RCP4.5_2080-2099		GFDL_RegCM4_RCP8.5_2080-2099	
		Value (%)	Change (%)	Value (%)	Change (%)	Value (%)	Change (%)	Value (%)	change (%)
Mean RH	71.0	63.9	-10.1	63.4	-10.8	63.5	-10.6	64.6	-9.2

Author's Computation, 2015

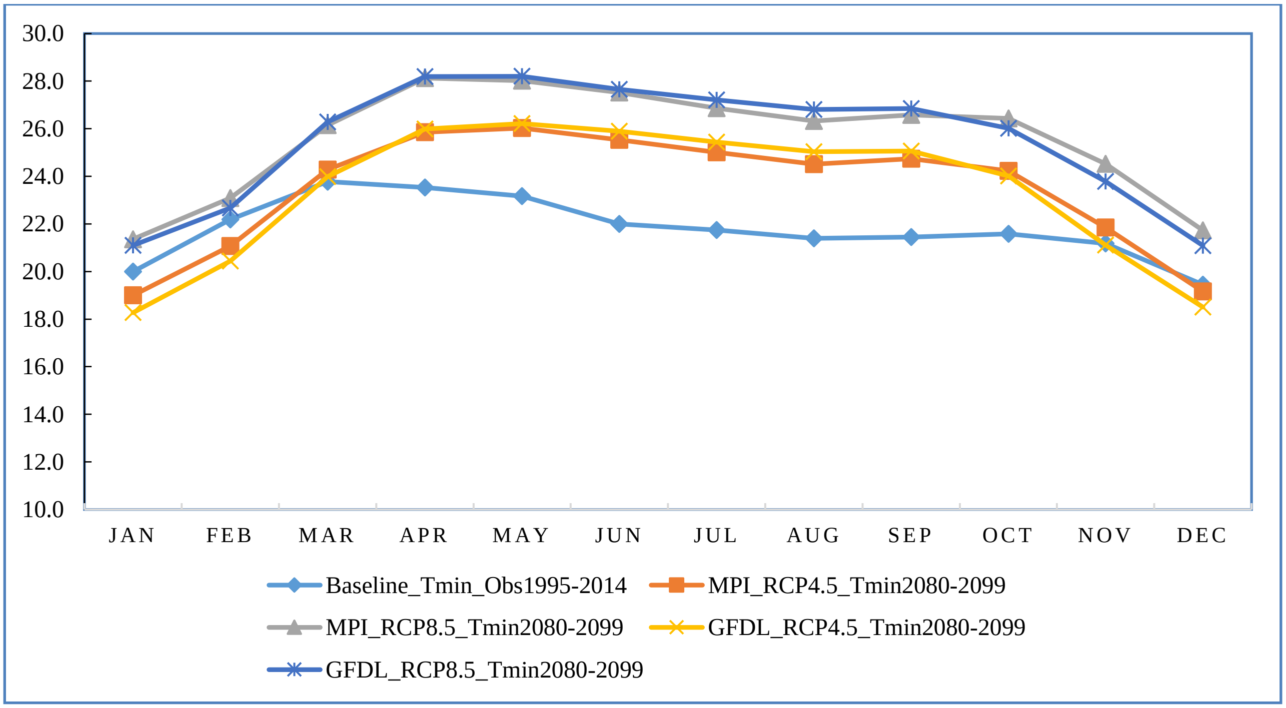


Figure 4. 6: Annual cycle of minimum Temperature for the baseline and for the climate scenarios over 20 years after correction. The MPI-driven and GFDL-driven runs for the period 2080-2099 are compared with the observations 1995-2014.

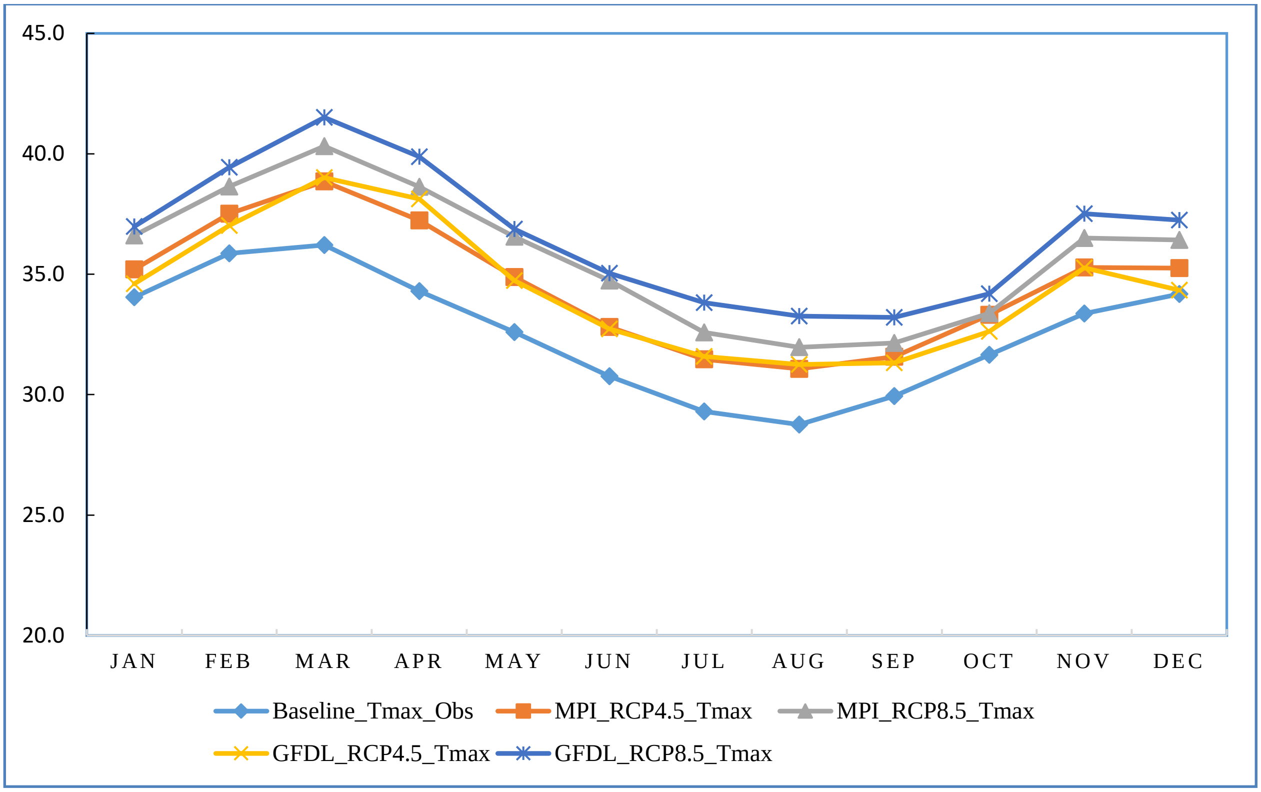


Figure 4. 7: Annual cycle of maximum Temperature for the baseline and for the climate scenarios over 20 years after correction. The MPI-driven and GFDL-driven runs for the period 2080-2099 are compared with the observations 1995-2014.

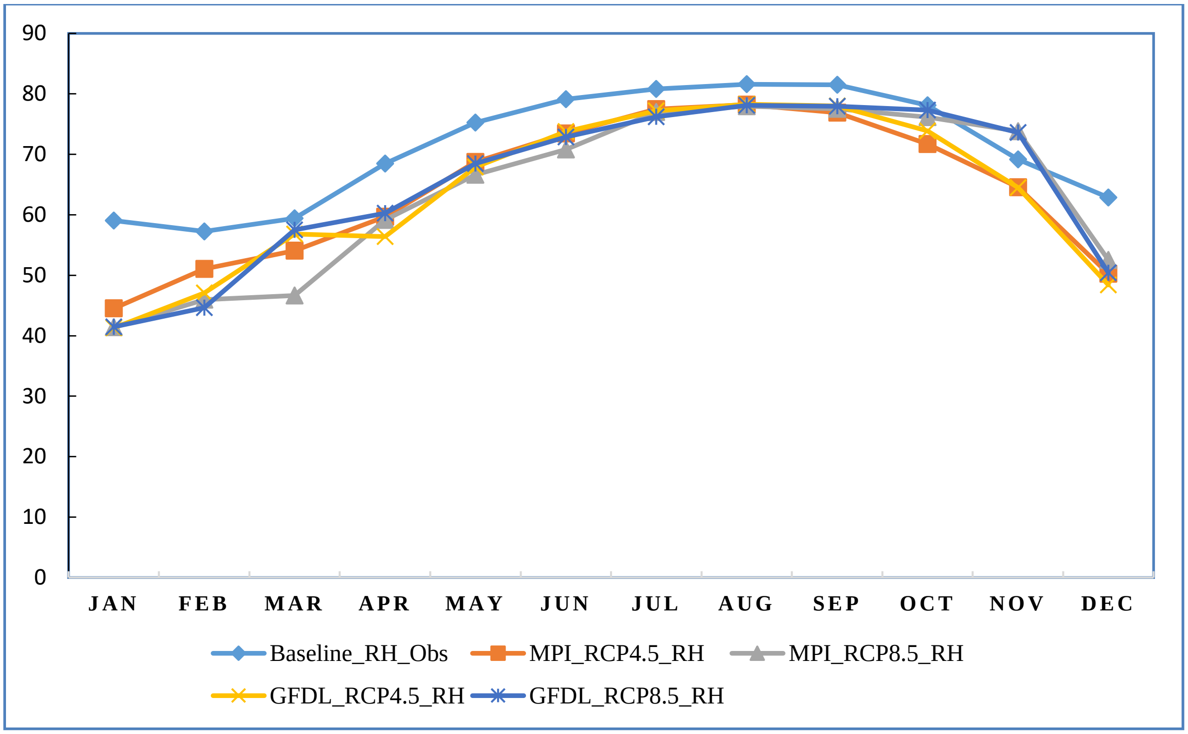


Figure 4. 8: Annual cycle of relative humidity for the baseline and for the climate scenarios over 20 years after correction. The MPI-driven and GFDL-driven runs for the period 2080-2099 are compared with the observations 1995-2014.

4.3. Rainfall Characteristics for the Baseline and under the Climate Scenarios

4.3.1. Onset of Growing Season for the Baseline and under the Climate Scenarios

In default of using the recommended Penman-Monteith method to compute ETp, because of some missing climatic parameters, two ETp models were chosen namely HS and BMN. This was also a way to ensure that results and inferences do not depend on the limitation of a particular ETp model since both methods are usually over estimating ETp compared to PM model (Ilesanmi, Oguntunde, and Olufayo, 2014). Table 4.4 shows the mean onset dates calculated with Benoit (1977) method for the baseline (1995-2014) and for the climate scenarios (2080-2099). From this table, for the baseline period, the start of the growing season safely begins in 6th May and 5th May using HS and BMN models respectively. The estimate are close to those obtained by Benoit (1977) for Mokwa, Olaniran and Summer (1989) for different parts of Nigeria as well as Jimoh and Egbareyba (2003) for Minna, Niger State. However the values still remains slightly high compare to the previous values found done in Kwara State (Olanrewaju, 2010) using only rainfall-related model. In the future, under the realistic scenario RCP4.5, the mean onset dates are 2nd June and 13th June for MPI and GFDL driven runs respectively when using HS model. With the same scenario, the onset dates are 23rd May and 2nd June for MPI and GFDL driven runs respectively with BMN model. For the pessimistic scenario RCP8.5, the onset dates are 30th June and 20th June for MPI and GFDL driven runs respectively when HS model is used, while with BMN the mean dates expected to be on 14th June and 5th June for MPI and GFDL driven runs respectively. It is clear that onset dates are expected to be late in the future compare to the present climate. These results based on high resolution climate simulations confirms the findings of BNRCC (2011). The authors of this paper have also shown that onset will be late in that part of Nigeria under the optimistic (B1) and pessimistic (A2) scenarios for 2100s.

Figure 4.9 shows the trend of onset dates for the baseline period 1995-2014 while Figure 4.10 and Figure 4.11 show the trend of onset dates for the future climate (2080-2100) period. The linear trend and trend line equation for the onset dates in the study area are displayed in these figures .It is obvious, from Figure 4.9, that the onset of the growing season for the baseline period is characterized by variation from year to year. This Figure clearly indicates a decrease trend line in the onset dates whereas Figure 4.10 and Figure 4.11 indicate an increase of the onset dates independently of the ETp model considered except for the realistic scenarios RCP4.5 driven by GFDL where it slightly decreases. The best fit line equation is negative for the baseline climate (y = -2.2303x + 4596.1 using BMN model for example) but positive for all future scenarios (y = 2.1767x - 4383.4, y = 0.9677x - 1866.3, and y = 2.0165x - 4069.9 for MPI_RCP4.5, MPI_RCP8.5, and GFDL_RCP8.5 respectively using BMN model). It means that there is a decreasing Julian days and implies that onset progressively starts earlier in recent times in the Awun basin for the baseline/ present climate. For future scenarios it means that Julian days are increasing and implies that onset of growing season progressively starts late towards the year 2099. The results for the baseline period confirms farmer's perception of onset evolution with regards to the fact that onset is likely to be early over the last 20 years.

Table 4. 4: Mean onset dates calculated for the baseline period 1995-2014 and for the future scenarios (2080-2099) using two ETp-models

Climate Scenarios	Baseline	MPI_RegCM4 _RCP4.5	MPI_RegCM4 _RCP8.5	GFDL_RegCM 4_RCP4.5	GFDL_RegCM4 _RCP8.5
HS ETp-model	6th May	2nd June	30th June	13th June	20th June
BMN ETp-model	5th May	23rd May	14th June	2nd June	5th June

Author's Computation, 2015

Figure 4. 9: Trend of the baseline 1995-2014 onset dates for Awun basin using two ETp models (HS and BMN).

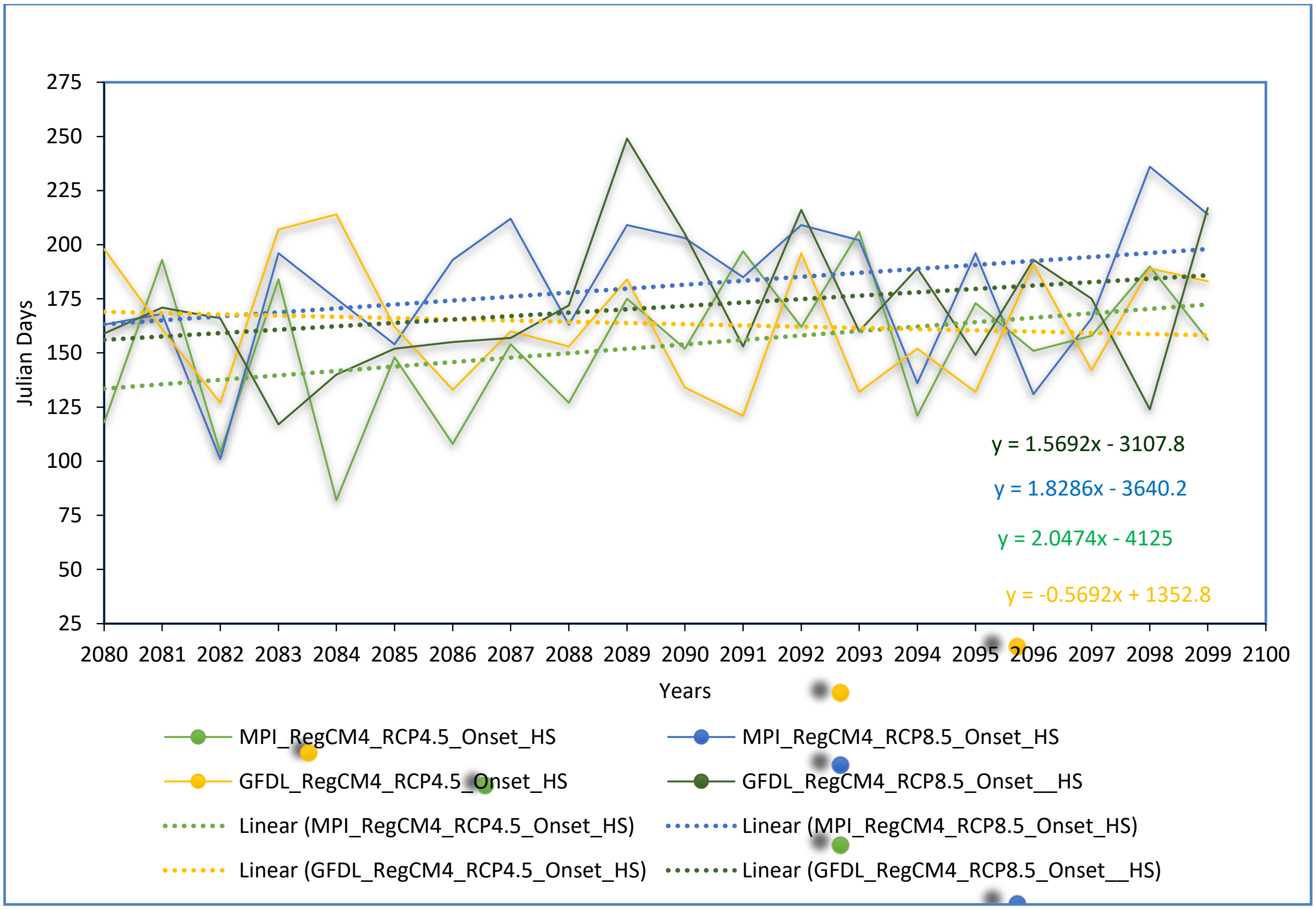


Figure 4. 10: Trend of the future climate scenarios onset dates for Awun basin, Kwara State using HS ETp model

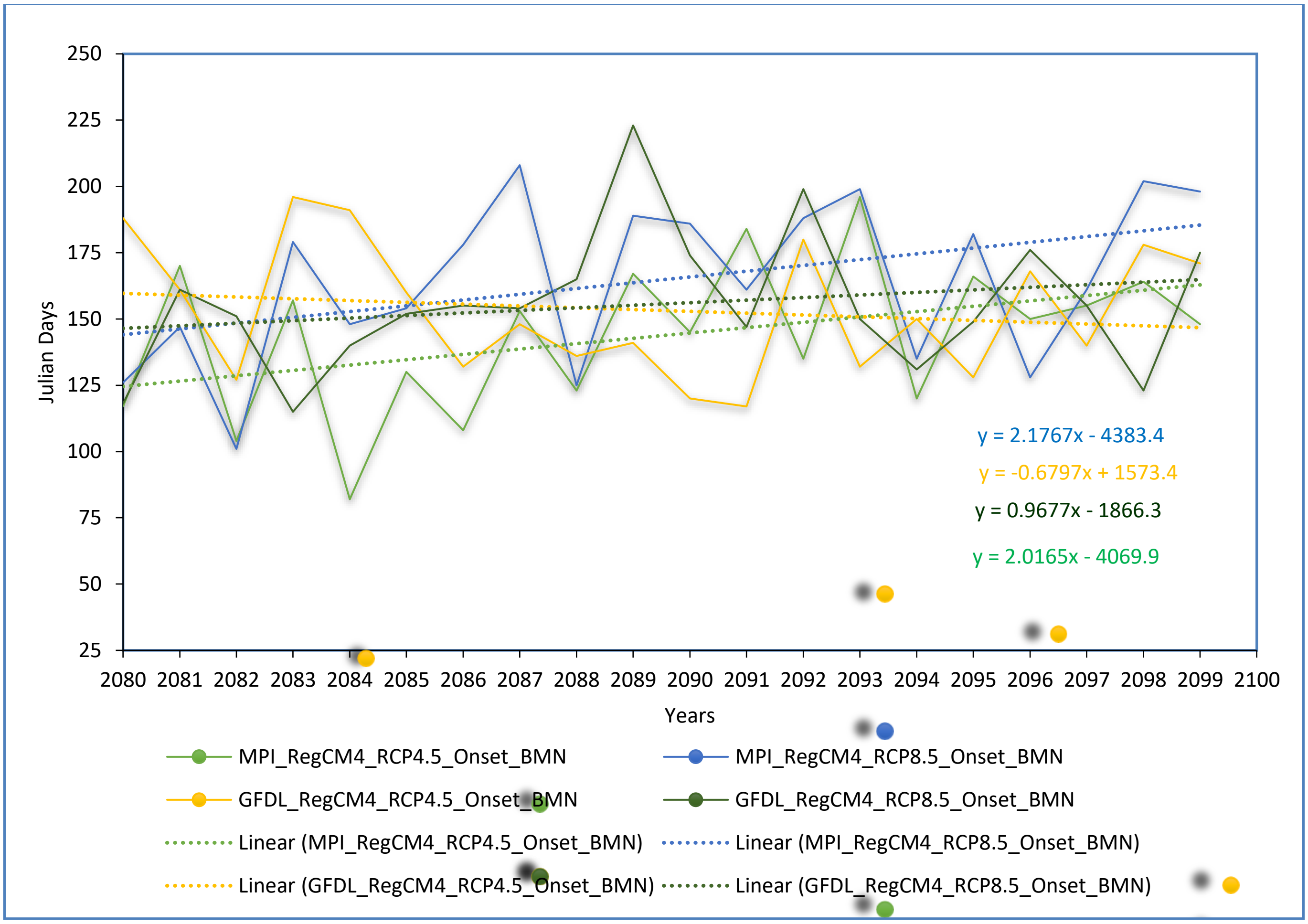


Figure 4. 11: Trend of the future climate scenarios onset dates for Awun basin, Kwara State using BMN ETp model.

4.3.2. Seasonality Index and hydrologic ratio for the Baseline and under the Climate Scenarios

The results of the analysis of the relative seasonality or seasonality index (SI) are summarized in Table 4.5. The mean spread of the rainy season is 0.74 meaning that the area falls within the Guinea Savanah climatic type. Walsh and Lawler (1981) have categorized this class of SI ($0.60 \leq SI \leq 0.79$) as seasonal (around 6 months of rainfall). That is the class between the (i) rather seasonal with short drier season and the (ii) markedly seasonal with long drier season. In the future and for the optimistic scenarios RCP4.5 the SI values are 0.85 and 0.89 for MPI and GFDL driven runs respectively while under the pessimistic scenarios the values are 0.87 for both MPI and GFDL driven runs respectively. It means that all future scenarios will fall within a markedly seasonal with long drier season as described by Walsh and Lawler (1981) i. e $0.80 \leq SI \leq 0.99$.

Table 4.6 shows that the average degree of dryness in the region is about 0.74 and 0.80 for the baseline period using HS and BMN ET models respectively. This result confirms that Awun basin is located in the wooded savannah zone but close to the rainforest area as categorized by Adefolalu (1988). The future scenarios project an important shift of the degree of dryness. For instance, under the realistic scenarios RCP4.5 the degree of dryness/ hydrologic ratios are 0.62 and 0.59 for the MPI and GFDL respectively using BMN model while, under the more pessimistic scenarios RCP8.5, the hydrologic ratios are 0.55 for both MPI and GFDL driven runs. It is clear that the degree of dryness will decrease in the future and the decrease will be more accentuated under the pessimistic scenarios. Since the lower the ratio the higher the dryness is (Adefolalu, 1988), it obvious that Awun Basin will get drier than it is today. The results confirms that climate change of Kwara State is toward aridity (Olanrewaju, 2010).

Table 4. 5: Seasonality Indices for the Present and Future Climate in Awun Basin

	Obs_Baseline 1995-2014	MPI_RCP4.5 2080-2099	MPI_RCP8.5 2080-2099	GFDL_RCP4.5 2080-2099	GFDL_RCP8.5 2080-2099
SI	0.74	0.85	0.87	0.89	0.87

Author's Computation, 2015

Table 4. 6: Degree of dryness or hydrologic ratio for the present (1995-2014) and future climate (2080-2099) in Awun Basin

	Obs_Baseline 1995-2014	MPI_RegCM4 _RCP4.5 2080-2099	MPI_RegCM4 _RCP8.5 _2080-2099	GFDL_RegCM4 _RCP4.5_ 2080-2099	GFDL_RegCM4 _RCP8.5_ 2080-2099
HR_HS	0.74	0.64	0.56	0.62	0.56
HR_BMN	0.80	0.62	0.55	0.59	0.55

Author's Computation, 2015

4.4. Crop Evapotranspiration for the baseline and under the climate scenarios

The crops water requirements were computed for the baseline period (1995-2014) and for the climate scenarios (2080-2099).An arbitrary planting date (1st May) was chosen since the crops water requirements are generally computed when planning for irrigation with a well-defined planting date. However 1st May was chosen based on the range of farmer' estimations. The same planting date was used to compute the crop water needs for maize, sorghum and cassava and for the present and future climate. Table 4.7 gives the lengths of the growing stages with the corresponding crop coefficients obtained from FAO 56 tables. Then crop factors were calculated on a monthly basis (appendix G).

Table 4.8 gives the summary of the seasonal values of crop water needs (ETcrop), the seasonal rainfall depths and the climatic water balance expected currently and in future for Awun basin, Kwara State. The details of the computation are found in appendix G. ETcrop of sweet maize, sorghum and cassava will increase in the future for all scenarios if they are planted in May. For instance, Table 4.8 shows that ETcrop of sweet maize are 340.1 mm, 387.2 mm, 383.3 mm 418.4 mm, and 404.9 mm for the baseline, the MPI_RCP4.5, the GFDL_RCP4.5, the MPI_RCP8.5, and the GFDL_RCP8.5 respectively. ETcrop of sweet sorghum are 414.0 mm, 471.8 mm, 465.1 mm, 506.0 mm, and 490.3 mm for the baseline, the MPI_RCP4.5, the GFDL_RCP4.5, the MPI_RCP8.5, and the GFDL_RCP8.5 respectively. Similarly ET_{CROP} of cassava are 1048.5 mm, 1226.2 mm, 1291.8 mm, 1237.1 mm, and 1269.6 mm for the baseline, the MPI_RCP4.5, the GFDL_RCP4.5, the MPI_RCP8.5, and the GFDL_RCP8.5 respectively. Figure 4.12, Figure 4.13, and Figure 4.14 clearly show that the future crop water needs of maize, sorghum, and cassava will increase more under pessimistic scenario RCP8.5 for both MPI and GFDL driven runs. The reason for the increase may be link to the pattern of future temperature which is projected to increase (confer section 4.5.1) for all scenarios but will increase more under the pessimistic ones. Since high temperatures lead to high water losses through evapotranspiration, therefore crop water requirements are expected to increase as well.

The results of the analysis of the climatic water deficit or climatic water balance are shown in Table 4.8 for the present and the future climate. From the table it is clear that the seasonal rainfall will compensate the seasonal crop water needs of sweet maize and sweet sorghum (since $P – ET_{CROP} > 0$) but will not be sufficient to compensate that of cassava (since $P - ET_{CROP} < 0$). In order words, based on the seasonal rainfall and crop water needs, sweet maize and sweet sorghum will perform well during their growing season without irrigation but cassava will not perform well without irrigation under all plausible future scenarios.

Table 4. 7: Lengths of various growing stages and the corresponding crop factors for maize, sorghum, and cassava.

Growth Stages		Init. stage	Dev. stage	Mid. stage	Late stage	Total
Sweet Maize	Lengths (days)	20	30	50	10	110
	Kc	0.3	0.73	1.15	1.05	-
Sweet Sorghum	Lengths (days)	20	35	45	30	130
	Kc	0.3	0.75	1.20	1.05	-
Cassava	Lengths (days)	150	40	110	60	360
	Kc	0.3	0.7	1.10	0.5	-

Source: FAO 56 and Field Work Information

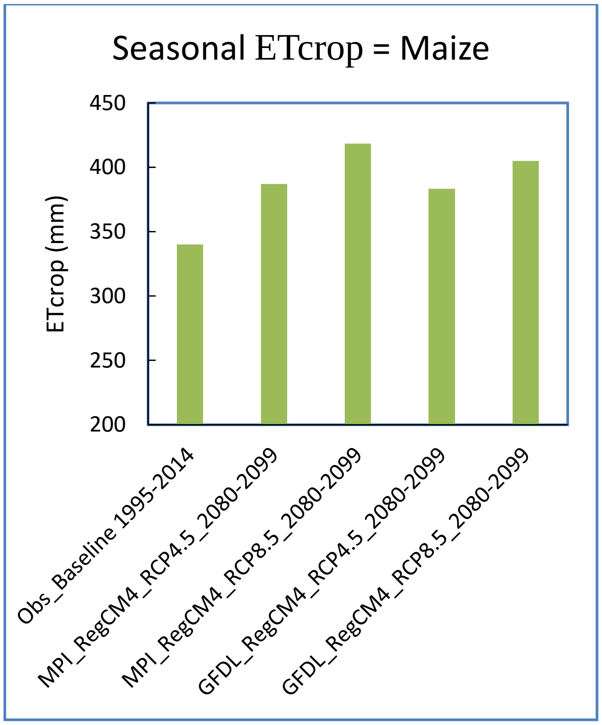


Figure 4. 12:Seasonal Crop Water Requirement of Maize

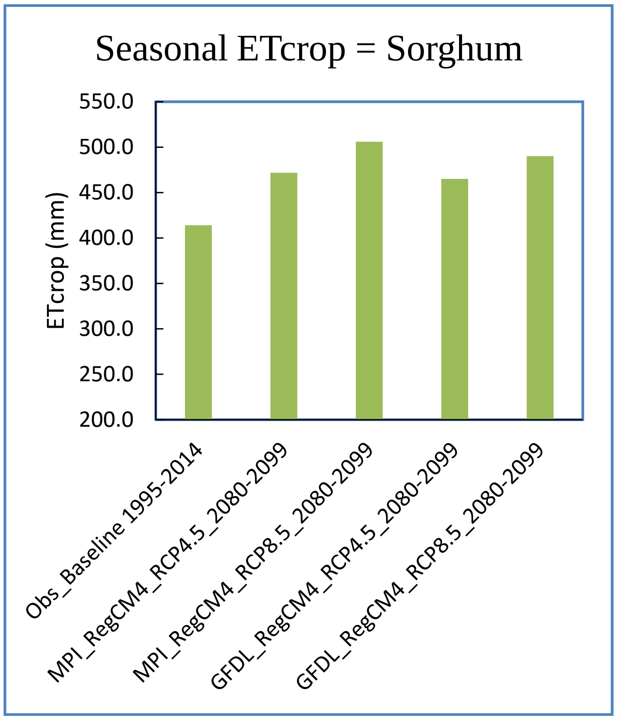


Figure 4. 13: Seasonal Crop Water Requirement of Sorghum

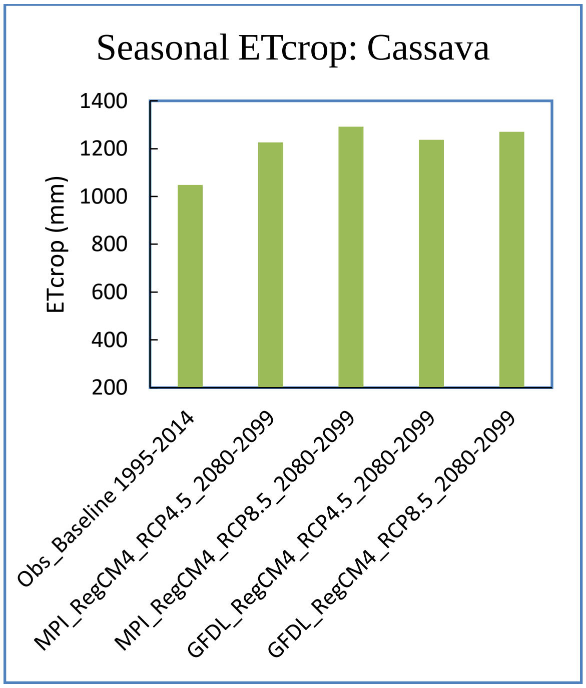


Figure 4. 14: Seasonal Crop Water Requirements of Cassava

Table 4. 8: Seasonal crop water needs for the baseline and the scenarios

Crops /Scenarios		Obs_Baseline1995-2014	MPI_RegCM4_RCP4.5_2080-2099	MPI_RegCM4_RCP8.5_2080-2099	GFDL_RegCM4_RCP4.5_2080-2099	GFDL_RegCM4_RCP8.5_2080-2099
Sweet Maize	ETcrop (mm)	340.1	387.2	418.4	383.3	404.9
	Seasonal rainfall	597.9	598.3	516.5	570.6	513.8
	Climatic balance	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$
Sweet Sorghum	ETcrop (mm)	414.0	471.8	506.0	465.1	490.3
	Seasonal rainfall	731.4	766.8	685.8	742.7	657.5
	Climatic balance	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$	$P-ET_C > 0$
Cassava	ETcrop (mm)	1048.5	1226.2	1291.8	1237.1	1269.6
	Seasonal rainfall	1226.4	1111.9	1043.4	1063.3	1006.8
	Climatic balance	$P-ET_C > 0$	$P-ET_C < 0$	$P-ET_C < 0$	$P-ET_C < 0$	$P-ET_C < 0$

Author’s Computation, 2015

CHAPTER FIVE

5.0. CONCLUSION AND RECOMMENDATIONS

This chapter dealt with the conclusions and recommendations of the research work. The purpose of the study was to analyse climate change projections on water availability for rainfed agriculture in Awun Catchment, Kwara State. Conclusions and recommendations were given according to the different objectives.

5.1. Conclusion

Famers, in Awun basin, cultivate several varieties of drought resistant crops (sorghum and cassava) but also non-drought resistant crops such as maize and yam. The latter may not thrive well if the area get drier.

The 25 km spatial resolution runs of RegCM4 have been downscaled/ bias corrected in Awun catchment for impact assessment using synoptic station data of the area. The analysis of changes in rainfall amounts (mean over 20 years) has shown that for the realistic scenario RCP4.5 mean rainfall will decrease by 9.6% and 13.1 % for MPI and GFDL driven runs. Under the pessimistic scenario RCP8.5 the expected decreases in the mean rainfall depth are 15.2 % and 17.7 % for MPI and GFDL driven runs respectively. The analysis of the patterns of temperature has shown that minimum and maximum temperatures will increase from 1.5 ^{0}C to 2 ^{0}C for the realistic scenarios RCP4.5 and from 3.1^{0}C to 4.0^{0}C for the more pessimistic scenario RCP8.5 respectively. However the mean relative humidity will decrease by 10% in 2100s. Onset dates for the present climate are 6th May and 5th May using HS and BMN models respectively. Under the realistic scenario RCP4.5, the mean onset dates are 2nd June and 18th July for MPI and GFDL driven runs respectively when using HS model. With the same scenario RCP4.5, the onset dates are 23rd May and 2nd June for MPI and GFDL driven runs respectively with BMN model. Under the pessimistic scenario RCP8.5, the onset dates are 30th June and 20th June for MPI and GFDL driven runs respectively when HS model is used, while with BMN the mean dates expected to be on 14th June and 5th June for MPI and GFDL driven runs respectively. The pessimistic scenario RCP8.5 projects late onsets dates compare to the optimistic scenario RCP.4.5 and the use of HS model in Benoit technique predict later dates compare to that of BMN model as expected since HS overestimate ET compare to BMN.

The assessment of the seasonality index has shown that current mean spread of the rainy season is 0.74, meaning that the area falls within the Guinea Savanah climatic type (around six months of rain). And for the optimistic scenarios RCP4.5 the SI values are 0.85 and 0.89 for MPI and GFDL driven runs respectively while under the pessimistic scenarios the values are 0.87 for both MPI and GFDL driven runs respectively. This class of SI for the future scenarios means that the rainy season will get shorter, but it will further short under the pessimistic scenario. From the study, it is shown that the degree of dryness or hydrologic ratio will decrease from around 0.74 for the baseline to 0.65 and 0.57 under the realistic scenario RCP4.5 and the pessimistic scenario RCP8.5 respectively; meaning that Awun Basin will get drier than it is today.

The study of crop water needs showed that the crop potential evapotranspiration of maize, sorghum, and cassava will increase under all future scenarios if they are planted in May. The analysis of the climatic water showed that sweet maize, and sweet sorghum will grow conveniently without need for additional water cassava will not.

To conclude, the present study has shown that rainfall amount will decrease in Awun basin under all scenarios but the decrease will be accentuated if the pessimistic scenario occurs. The mean minimum and maximum temperature is expected to increase for all plausible future mentioned in the present study but the mean relative humidity will decrease. The rainy season will get shorter in the future but much shorter for the pessimistic scenarios. The study showed that onset is projected to be late for both realistic and pessimistic scenarios but the delay will be severe if the pessimistic scenario occurs. Awun Basin will get drier than it is today for all scenarios. For the present and future climate, based on seasonal crop water needs, sweet maize and sweet sorghum will perform well during their growing period without irrigation. However, cassava will not perform conveniently during it growing period without irrigation under both realistic and pessimistic scenarios. The author findings highlight the importance of characterizing climatic water balance for understanding plant responses to climate change.

5.2. Recommendations

Based on the findings of the present study, many recommendations can be given. Suggestions concern the data and methodology of the work, the climate scenarios, the start of growing season, the spreading of the rainy season, the degree of dryness, and the crop water needs.

The evident increase in temperature and decrease in rainfall has been clearly confirmed in this study. In that context it is recommended that researchers should use the rainfall-evaporation model to predict the start of the growing season.

For the present climate, planting of crops should be encouraged in the month of May when the start of the growing season is set. This is a way to allow the rain to compensate water losses by evapotranspiration throughout the growing season. Hence the soil will keep enough moisture for crops and could encounter any plausible long dry spells which occurs during the growing season. In the future farmers of Awun basin should prepare for a shortening of the rainy season and an increase of the dryness by planning for irrigation.

The study showed that the occurrence of the pessimistic scenario will result in more severe shortening of rainy season, more dryness against an increased crop water needs in Awun Basin (compare to the realistic scenario). It is therefore necessary to make sure that the pessimistic scenario, corresponding to extreme greenhouse gases emission, does not occur in the future. Hence, it is recommended that Nigerian government together with private sector partnership should encourage practices (agricultural, industrial and domestic practices) which will not increase greenhouse gasses emission at that level. For instance, clean and environment friendly technologies for both supplied energy and consumption could be used.

Since cassava is projected to be in water stress under all plausible future studied, it is recommended that in the future, under rainfed agriculture, drought resistant varieties of cassava should be used in the area. For now, varieties of cassava with short growing period should be encouraged in Awun basin.

The present study only considered the implications of climate change for the long-term period (2080-2100). Further research works could be done in the same areas for a mid-term period (2031-2050). This will allow us to know the effects of climate change in Awun Basin and to investigate a near future scheduling and/or shifting of crop producing periods. Also, more weather stations, measuring all agrometeorological parameters should be established in the area to get more accurate crops water requirements as well as the irrigation water requirements using the recommended Penman-Monteith model (Allen *et al.*, 1998). Thus high resolution climate projections could be used in planning and designing irrigation systems for the near future.

REFERENCES

Abu-Taleb, M. (2000). Impact of global climate scenarios on water supply and demand in Jordan. *Water International*, 25(3), 457-463; DOI: 10.1080/02508060008686853

Adebayo, A.A. & E.F. Adebayo (1997). Precipitation effectiveness indices and upland rice yield in Adamawa State. *Annals of Borno, 13(14), 266-276*.

Adefolalu, D.O. (1998). Precipitation, evapotranspiration and the ecological zones in Nigeria. *Theoretical Applied Climatology*, 39, 81-89.

AEA Energy & Environment (2007). *Adaptation to climate change in the agricultural sector, Madrid* (1st ed.). AGRI-2006-G4-05. Retrieved from: http://www.ncat.org/attra-pub/sweet potato.html, on May 15, 2015.

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. (1998). *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56, ISBN 92-5-104219-5. Retrieved from http://www.intechopen.com/books/crop-production-technologies/ on May 2015

Ati, O.F, Stigter, C. J., & Oladipoa, E. O. (2002). Comparison of Methods to Determine the Onset of the Growing Season in Northern Nigeria. *International Journal of Climatology*, 22, 731–742; DOI: 10.1002/joc.712

Ayoade, J.O. (2004): *Introduction to Climatology for the Tropics. Revised edition*. Ibadan: Spectrum books limited.

Building Nigeria's Response to Climate Change (BNRCC) (2011). *Climate Change adaptation strategy Technical Reports - Nigeria*. (CCASTR) Ibadan, Nigeria: Nigerian Environmental Study/Action Team (NEST)

Benoit,P.(1977) "The Start of the Growing Season in Northern Nigeria," *Agricultural Meteorology*, 8(2), 91-99. doi:10.1016/0002-1571(77)90042-5

Blaney, H.F. & Criddle, W.D. (1950). *Determining water requirements in irrigation area from climatological and irrigation data*. Retrieved on 4th April, 2015, from IFAD website: www.ifad.org.

Braun, M., Caya, D., Frigon, A., Slivitzky M. (2011) Internal variability of the Canadian RCM's hydrological variables at the basin scale in Quebec and Labrador. *Journal of Hydrometeorol*ogy, 13, 443–462.

Bruinsma, J. (2003). *World agriculture: towards 2015/2030: an FAO perspective*. Retrieved from http://www.academicjournals.org/AJEST ISSN 1991-637X on January 2015.

Cooper, P., Rao, K., Singh, P., Dimes, J., Traore, P., Rao, K. & Twomlow, S. (2009). Farming with current and future climate risk: advancing a 'Hypothesis of Hope'for rainfed agriculture in the semi-arid tropics. *Journal of Semi-Arid Tropical Agriculture Research*. In press

Duru J.O. (1984). Blaney-Morin-Nigeria Evapotranspiration Model. *Journal of Hydrology*, 70, 71-83.

Edoga N. R., (2007). *Determination of Length of Growing Season in Samaru Using Different Potential Evapotranspiration Models*. Soil Science Department, Ahmadu Bello University. Zaria Nigeria.

Efe, S.I. (2009): Climate Change and Food Security in Africa: Delta State Nigeria Experience: In Anyadike, R.N.C., Madu, I.A. and Ajaero, C.K., (2010): *Conference Proceedings on Climate Change and the Nigerian Environment held at UNN.*

Eitzinge, J., & Kubu, G. (eds.) (2009) *Impact of Climate Change and Adaptation in Agriculture. Extended.* BOKU-Met Report 17, ISSN 1994-4179 (Print), ISSN 1994-4187. Retrieved from http://www.boku.ac.at/met/report, June 2015.

Food and Agriculture Organization (FAO) (1990). *Production Year Book*, 1989, Volume 43, Rome.

FAO (Food and Agriculture Organization) (1978). Report on the agro-ecological Zones Project. Volume1, Methodology and Results of Africa. Rome.

FAO (Food and Agriculture Organization) (1998). *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements: Guidelines for Computing Crop Water Requirements*. Retrieved on April 10, 2014 from www.wamis.org/agm/pubs/ SPI/WMO_1090

Fowler, H. J., Blenkinsop, S., & Tebaldi, C. (2007): Linking climate change modelling to impacts studies: recent advances in down-scaling techniques for hydrological modelling, *International Journal of Climatology*, 27, 1547–1578, doi:10.1002/joc.1556, 2007.

Giorgi, F., Coppola, E., Solmon, F., Mariotti, L., Sylla, M. B., Bi, X., & Brankovic, C. (2012). RegCM4: model description and preliminary tests over multiple CORDEX domains. *Journal of Climate Research*, 52, 7–29.

Gebremichael A., Quraishi, S., & Mamo, G. (2014). Analysis of Seasonal Rainfall Variability for Agricultural Water Resource Management in Southern Region, Ethiopia. *Journal of Natural Sciences research*, 4, 11, 234-245

Haerter J. O., Hagemann, S., Moseley, C. Piani, C. (2011). Climate model bias correction and the role of timescales. *Journal of Hydrology and Earth System Science*, 15, 1065–1079.

Hargreaves, G.H. (1994). *"Simplified coefficients for estimating monthly solar radiation in North America and Europe".* Departmental Paper, Department of Biology and Irrigation Engineering, Utah State University, Logan, Utah.

Hargreaves, G.H., & Samani, Z. (1985). "Reference Crop Evapotranspiration from Temperature," *Journal of Applied Engineering in Agriculture*, 1(2), 96-99.

Hashino, T., Bradley, A. A., and Schwartz, S. S., (2007): Evaluation of bias-correction methods for ensemble streamflow volume forecasts. *Journal of hydrology and Earth System Science*, 11, 939–950, doi: 10.5194/hess-11-939-2007, 2007.

Hassan, A.S., Adeyemo, A.A., Isah, H.J., Godwin, T.A. (2008). *Perspective on Nation-Building and Development in Nigeria: Environmental and Economic Issues*. Retrieved on April 10, 2014 from www.wamis.org/agm/pubs/ SPI/WMO_1090

Ilesanmi, O.O. (1972a). An Empirical Formulation of the Onset, Advance and Retreat of Rainfall in Nigeria. *Journal of Tropical Climatology*, 34, 17-24.

Ilesanmi, O. A., Oguntunde, P.G., & Olufayo, A.A. (2014). Evaluation of Four ETo Models for IITA Stations in Ibadan, Onne and Kano, Nigeria. *Journal of Environment and Earth Science,* 4, 5,456-471.

IPCC. (2013). *Climate Change 2013, the Physical Science Basis - Summary for Policymakers.* IPCC Working Group I Contribution to AR5.

IPCC-TGCIA. (1999): *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment.* Version 1. Prepared by Carter, T.R., M. Hulme, and M. Lal, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, 69pp.

IPCC Third Assessment Report. (2001): *Climate Change 2001: Impacts, Adaptation, and vulnerability*. Cambridge, United Kingdom. Press Syndicate of the University of Cambridge.

IPCC. (2007). *Climate Change 2007: Synthesis Report*. IPCC Secretariat, 7 bis Avenue de la Paix C. P. 2300 Geneva 2 CH- 1211 Switzerland.

Jimoh, O.D. & Edgharevba, N.A. (2003). Effect of Maize Yield in Minna (Norhern Nigeria). *Journal of Science, Technology and Mathematics Education (JOSTMED)*, 6 (1), 2003.

Kassam, A., & Smith, M. (2001). *"FAO Methodologies n Crop Water Use and Crop Water Productivity," Expert Meeting on Crop Water Productivity*. Rome, 3 to 5 December 2001, Paper No CWP-M07.

Koeppen, W. & Geiger, R. (1936). *Handbuch der Klimatologie*. Berlin, Gebruder Borntraeger.

Kowal J.M & Knabe D.T. (1972). *An Agroclimatological Atlas of the Northern States of Nigeria with Explanatory Notes*. Ahmadu Bello University: Zaria, Nigeria.

Kwara State Agricultural Development Project (KWADP) (2007). Ilorin, Nigeria.

Leander, R., & Buishand, T.A. (2006). Resampling of regional climate model output for the simulation of extreme river flows resampling of regional climate model output for the simulation of extreme river flows. *Journal of Hydrology*, 332, 487– 496.

Lenderink, G., A. Buishand, & W. Van Deursen (2007), Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrology Earth System Science*, 11(3), 1145–1159.

National Bureau of Statistics (NBS). (2009). *Commercial Agriculture Development Project* (CADP), (2009). NBS/CADP Baseline Survey Report.

Newton. G, Dadson. S, Lafon. T, & Prudhomme, C. (2012). *Science Report/Project Note* - SC090016/PN3

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., & Widmann, Eich, I. (2010). Precipitation Downscaling under Climate Change: Recent Developments to Bridge the Gap between Dynamical Models and the End User. Retrieve from http://www.academicjournals.org/AJEST ISSN 1991-637X, January 2015.

Mourato, S., Moreira, M., and Corte-Real, J. (2014).Water Availability in Southern Portugal for Different Climate Change Scenarios Subjected to Bias Correction. *Journal of Urban and Environmental Engineering*, 8(1), 109-11.

Moss, T., M. Babiker, S. Brinkman, E., Calvo, T., Carter, Edmonds, J., Zurek, M. (2008). *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies*. Retrieved from http://www.intechopen.com/books/crop-production-technologies/, May 2015

Mugalavai,E.M. , Emmanuel C., Kipkorir,E.C., Raes ,D., and Rao, M.S.(2008). Analysis of rainfall onset, cessation and length of growing season for western Kenya. *Journal of Agricultural and forest meteorology*, 148, 1123–1135.

Müller, M., Sanfo, S., and Laube, W. (2013). *Impact of Changing Seasonal Rainfall Patterns on Rainy-Season Crop Production in the Guinea Savannah of West Africa.* 2013 Annual Meeting, August 4-6, 2013, Washington, D.C. 151208, Agricultural and Applied Economics Association.

Odekunle,T.O, Balogun, E.E, and Ogunkoya, O.O. (2005). On the prediction of rainfall onset and retreat dates in Nigeria. *Theoretical Applied Climatology,* 81, 101–112; DOI 10.1007/s00704-004-0108-x.

Odekunle, T.O, Orinmoogunje, I.O.O and Ayanlade, .A. (2007). *Application of GIS to Assess Rainfall Variability Impacts on Crop Yield in Guinea Savannah part of Nigeria*.

Olaniran, O.J. (1983) “The Start and End of the Growing Season in the Niger River Basin Development Authority Area of Nigeria,” *Malaysian Journal of Tropical Geography*, 9, 49-58.

Olaniran.O.J. and Summer.G.N. (1989). A study of climatic variability in Nigeria based on the onset, retreat, and length of the rainy season. *International Journal .of Climatology*, 9, 253-269.

Olanrewaju, R. M. (2009). *Effect of Climate on Yam Production in Kwara State, Nigeria*. Environmental Issues, Department of Geography and Environmental Management, University of Ilorin, Ilorin, Vol. 3, No. 1

Olusina, J.O. and Odumade O.M. (2012). *Modelling Climatic Variation Parameters of Nigeria Using the Statistical Downscaling Approach*. TS07F - Task Force on

Surveyors and the Climate Change II, 6099. FIGURE Working Week 2012 knowing to manage the territory, protect the environment, and evaluate the cultural heritage Rome, Italy.

Piani C., Haerter, J. O., Coppola, E. (2010). Statistical bias correction for daily precipitation in regional climate models over Europe, *Theoretical Applied Climatology*, 99, 187–192.

PENMAN H.I (1948).Natural evapo-transpiration from open water, bare soil and grass. *Proceeding of Royal society of London, Series A*, 193, 120-145.

Prudhomme, C., Wilby, L. R., Crooks, S. M., Kay, A. L., and Reynard, N. S. (2010). Scenario neutral approach to climate change impact studies: application to flood risk. *Journal of Hydrology*, 390, 198-209, doi: 10.1016/j.jhydrol.2010.06.043.

Sawa, B.A. and Adebayo, A.A. (2011).The Impact of Climate Change on Precipitation Effectiveness Indices in Northern Nigeria. *Research Journal of Environmental and Earth Sciences,* 3(5), 481-486, 2011ISSN: 2041-0492

Schaldach, R., Koch, J., Beek,T. A., Kynast, E., and Flörke, M. (2012). Current and future irrigation water requirements in pan-Europe: An integrated analysis of socio-economic and climate scenarios. *Global and Planetary Change,* 94, 33–45.

Shrestha, S. (2014). Climate Change Impacts and Adaptation in Water Resources and Water Use Sectors. *Journal of* Springer *Water*, 65-68, DOI 10.1007/978-3-319-09746-6_2

Stern, R.D.; Dennett, M.D.; and Garbutt, D.J. (1981). The start of the rains in West Africa. *Journal of Climatology*, 1, 59-68.

Stewart, J.I. (1991). *Principles and performance of response farming*. In: Ford, W., Muchow, R.C., Bellamy, Z.A. (Eds.), Climatic Risk in Crop Production. Model and Management for the Semi-arid Tropics and Sub-tropics. CAB International, Wallingford.

Sule B.F (2003). Water Security: *Now and the Future, Sixty-fifth Inaugural Lecture of University of Ilorin, Ilorin, Nigeria*.

Sule B. F. and Alabi S. A., (2013). Application of synthetic unit hydrograph methods to construct storm hydrographs. *International Journal of Water Resources and Environmental Engineering,* 5(11), 639-647, 2013; DOI 10.5897/IJWREE2013.0437 ISSN 2141-6613

Teutschbein, C. and Seibert, J. (2012). Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. *Journal of Hydrology,* 45, 12-29; doi:10.1016/j.jhydrol.2012.05.052

Theme, M.J., Gobiet, A., and Leuprecht, A. (2011). Empirical-statistical Downscaling and Error Correction of Daily precipitation from Regional Climate Models. *International Journal of Climatology,* 31, 1530–1544 (2011); DOI: 10.1002/joc.2168

Ufoegbune, G.C., Bello, N.J., Dada, O.F, Eruola, A.O.Makinde, A.A., & Amori, A.A. (2012). Estimating Water Availability for Agriculture in Abeokuta, South Western Nigeria. *Global Journals Incorporated USA Research* Online ISSN: 2249-4626 & Print ISSN: 0975-5896.

Wani, S., J. Rockström, and T. Oweis. (2009). Rainfed Agriculture: unlocking the potential. *CABI Publishing*.

World Bank (2009): *Awakening Africa's Sleeping Giant: Prospects for Commercial Agriculture in the Guinea Savannah Zone and beyond*. Washington DC: World Bank and FAO.

Yengoh G.T., Brogaard. S., and Olsson. L. (2012). Crop Water Requirements in Cameroon's Savannah Zones under Climate Change Scenarios and Adaptation Needs. *INTECH open science, Crop Production Technologies*, ISBN: 978-953-307-787-1. Retrieved from http://www.intechopen.com/books/crop-production-technologies/, May 2015

Ziad A. M., and Sireen A.J. (2010).Climate change and agricultural water demand: Impacts and adaptations. African *Journal of Environmental Science and Technology,* 4(4), 183-191, 2010. Retrieve from http://www.academicjournals.org/AJEST ISSN 1991-637X, January 2015.

APPENDICES

Appendix A: Questionnaire Administration

Questionnaire for Variety and Crop Patterns Inventory: crop X = Maize, Sorghum, Cassava, or Yam

Section 0: General Information about the Community

Questionnaire Number……………... Date of Interview………………………….

LGA……………………………….. Time of Interview………………………….

Village/Community………………… Lat ……………….

Long………………….

Section 1: Socio-Economic Characteristics of the Respondents

1. Gender of the respondent : Male ☐ Female ☐
2. Highest Education Level: Primary ☐ Secondary ☐ Tertiary ☐ Non ☐ formal No ☐ formal edu.
3. Religion: Christianity ☐ Muslim ☐ Traditional ☐ Others (Specify)……………………..
4. Other occupation (except faming): Trading ☐ Handiwork ☐ ☐ Professional/Service Others (Specify/details)………..……………………………………………….…….

Section 2: Crop Data Patterns for Maize

1. How long have you been farming crop X in this area? :

    a. l-5 years ☐ b. 5-10 years ☐ c. >10 yea☐

2. Which water use system are you practicing for crop X? :

    a. Rainfed ☐ b. Irrigation ☐ c. Both rainfed and irrigation ☐

3. What variety of crop X are you growing in rainfed agriculture exclusively? :

    ….…………………………………………………………………………………..…

    …

4. How many times do you grow crop X during the rainy season? :

    a. Once ☐ b. Twice ☐ c. Three times or more ☐

5. What are the indicators that you based on to start sowing the first time? :

    a. Information from agricultural extension agents ☐

    b. Other (specify):

        …………………………………………………………...………..

6. What are the planting and harvesting dates for crop X (in 2014)? :

    a. Planting date (dd /mm):

        …………………………………………………..…….

    b. Harvesting date (dd /mm):

        …………………………………………………...

7. How long do you estimate the total growing period of crop X? (months and/or days)

    :

    ……………………………………………………………………………………

    …..

Section 3: Crop X Farmer's Perception of Climate Change and Water Availability

1. Are you aware or heard that climate has changed or is changing?

   a. Yes ☐ b. No ☐ c. Do not know ☐

2. If yes, from where have you heard about climate change?

   a. own observation ☐ b. radio ☐ c. NGO working in the area ☐

   e. told by neighbours/friends/family ☐ (f) others specify……………………

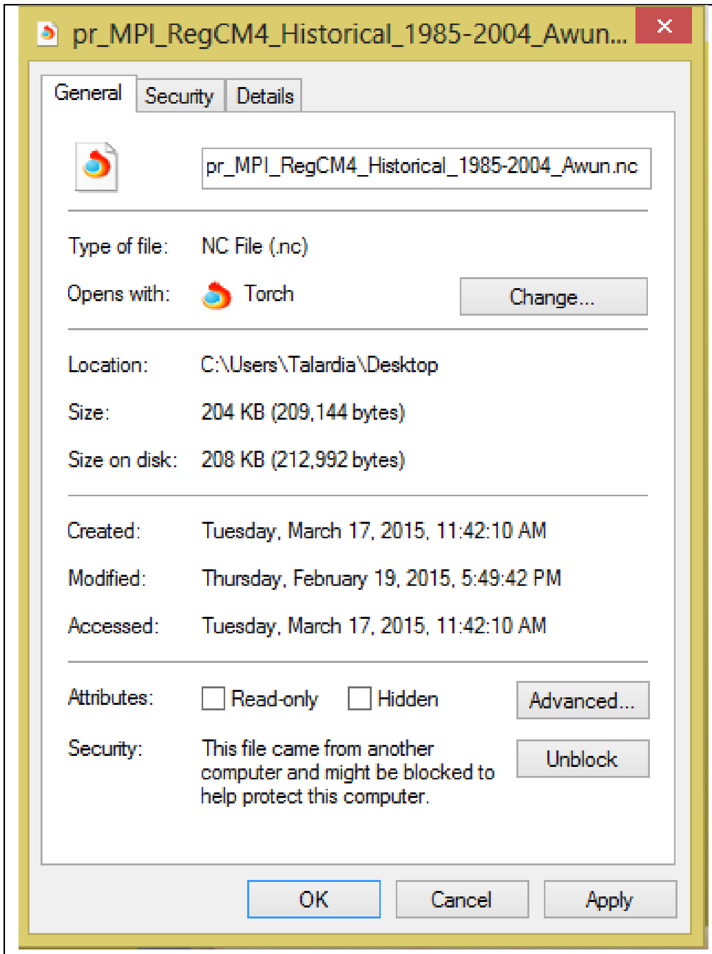
3. What are your observations about the following climatic parameters for the past 20years?

Rainfall amount	Increased ☐	Decreased ☐	The same ☐	Don't know ☐
Onset of rainfall	Early onset ☐	Late onset ☐	Normal ☐	Don't know ☐
Cessation of rainfall	Early ☐	Late ☐	Normal ☐	Don't know ☐
Length of growing season	Increased ☐	Decreased ☐	The same ☐	Don't know ☐
Temperature	Increased ☐	Decreased ☐	The same ☐	Don't know ☐
Frequency of prolonged dry spells	Increased ☐	Decreased ☐	Normal ☐	Don't know ☐

Appendix B: Photo during the field work

Plate I: Meeting KADP’s agricultural agents for the questionnaire survey

Appendix C: Programming code for conversion of NetCDF files (nc.) to plaint text format (CSV.)



pr_MPI_RegCM4_Historical_1985-2004_Awun.nc

Type of file: NC File (.nc)

Opens with: Torch

Location: C:\Users\Talardia\Desktop

Size: 204 KB (209,144 bytes)

Size on disk: 208 KB (212,992 bytes)

Created: Tuesday, March 17, 2015, 11:42:10 AM

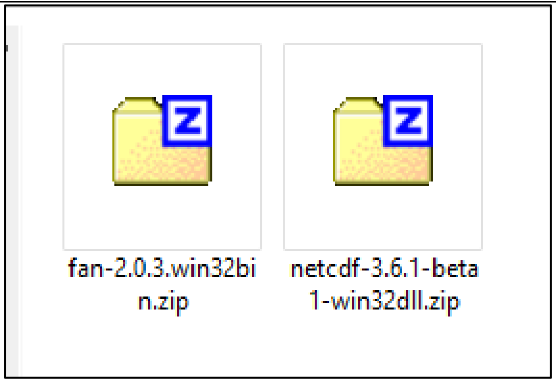
Modified: Thursday, February 19, 2015, 5:49:42 PM

Accessed: Tuesday, March 17, 2015, 11:42:10 AM

Attributes: ☐ Read-only ☐ Hidden

Security: This file came from another computer and might be blocked to help protect this computer.

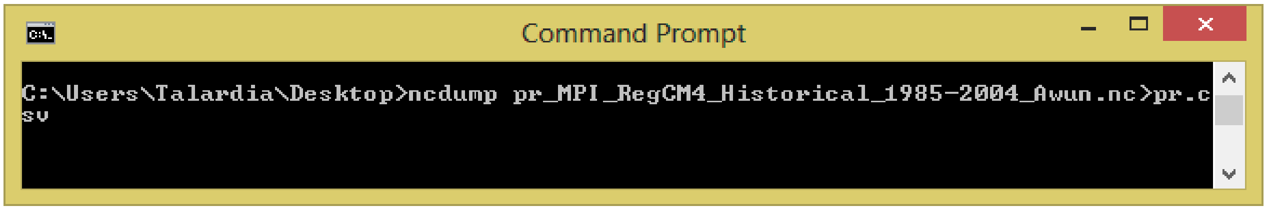
Figure 1: An example of raw RegCM4 file format.



fan-2.0.3.win32bin.zip

netcdf-3.6.1-beta1-win32dll.zip

Figure 2: FAN and NetCDF packages to be installed in window 8



```
C:\Users\Talardia\Desktop>ncdump pr_MPI_RegCM4_Historical_1985-2004_Awun.nc>pr.c
sv
```

Figure 3: Example extraction code in window command prompt

Appendix D: Details of Normality and Stationarity Test

Table 1: Results of the stationarity test at 5% and 10% significance level

Time series / Z(t) test		Z(t) Calculated value	Z(t) 5% Critical value	Z(t) 10% Critical value	Mackinnon approximate p-value for Z(t)	Conclusion: at 5% significance level
Rainf-all (pr)	Pr_Observations	-3.103	-3.000	-2.630	0.0263	Ho rejected at 5%
	Pr_MPI_RegCM4	-3.305	-3.000	-2.630	0.0147	Ho rejected at 5%
	Pr_GFDL_RegCM4	-4.627	-3.000	-2.630	0.001	Ho rejected at 5%
Tmin	Tmin_Observations	-3.420	-3.600	-3.240	0.0487	Ho rejected at 10%
	Tmin_MPI_RegCM4	-4.278	-3.600	-3.240	0.0034	Ho rejected at 5%
	Tmin_GFDL_RegCM4	-3.922	-3.600	-3.240	0.0113	Ho rejected at 5%
Tmax	Tmax_Observations	-4.129	-3.600	-3.240	0.0057	Ho rejected at 5%
	Tmax_MPI_RegCM4	-4.028	-3.600	-3.240	0.0080	Ho rejected at 5%
	Tmax_GFDL_RegCM4	-3.245	-3.600	-3.240	0.0759	Ho rejected at 10%
RH	RH_Observations	-3.500	-3.600	-3.240	0.0394	Ho rejected at 10%
	RH_MPI_RegCM4	-6.692	-3.600	-3.240	0.000	Ho rejected at 5%
	RH_GFDL_RegCM4	-4.561	-3.600	-3.240	0.0012	Ho rejected at 5%

Author’s Computation, 2015

Appendix E: Details of the Application of the Linear Scaling Technique to Bias-Correct Rainfall, Temperature and Relative Humidity.

- ✓ Rainfall

The application of the linear scaling technique has given the following results:

$\overline{\boldsymbol{R}}$ (Monthly mean observations over 1985-2004) = 97.1 mm

$\overline{\boldsymbol{C}}$ (Monthly mean simulated rainfall driven by MPI over 1985-2004) = 101.4 mm

$\overline{\boldsymbol{C}}$ (Monthly mean simulated rainfall driven by GDFL over 1985-2004) = 88.80 mm

f_p (Scaling factor for Rainfall_MPI_RegCM4) = 97.10 / 101.4 = 0.96

f_p (Scaling factor for Rainfall_GDFL_RegCM4) = 97.10 / 101.4 = 1.09

- ✓ Temperature

The application of the linear scaling technique has given the following results:

$\overline{\boldsymbol{R}}$ (Mean monthly observations Tmin over 1985-2004) = 21.58 ^{o}C

$\overline{\boldsymbol{C}}$ (Mean monthly simulated Tmin driven by MPI over 1985-2004) = 20.95 ^{o}C

$\overline{\boldsymbol{C}}$ (Monthly mean simulated Tmin driven by GDFL over 1985-2004) = 20.23 ^{o}C

$\boldsymbol{Bias}$ (Scaling factor for Tmin_MPI_RegCM4) = 21.58 – 20.95 = 0.63

$\boldsymbol{Bias}$ (Scaling factor for Tmin_GDFL_RegCM4) = 21.58 – 20.23 = 1.36

$\overline{\boldsymbol{R}}$ (Mean monthly observations Tmax over 1985-2004) = 32.38 ^{o}C

$\overline{\boldsymbol{C}}$ (Mean monthly simulated Tmax driven by MPI over 1985-2004) = 30.95 ^{o}C

$\overline{\boldsymbol{C}}$ (Monthly mean simulated Tmax driven by GDFL over 1985-2004) = 30.35 ^{o}C

$\boldsymbol{Bias}$ (Scaling factor for Tmax_MPI_RegCM4) = 32.38 – 30.95 = 1.44

$\boldsymbol{Bias}$ (Scaling factor for Tmax_GDFL_RegCM4) = 32.38 – 30.35 = 2.04

- ✓ **Relative Humidity (RH)**

$\overline{\boldsymbol{R}}$ (Monthly mean observations over 1985-2004) = 64.23 %

$\overline{\boldsymbol{C}}$ (Monthly mean simulated rainfall driven by MPI over 1985-2004) = 50.40 %

$\overline{\boldsymbol{C}}$ (Monthly mean simulated rainfall driven by GDFL over 1985-2004) = 49.26 %

f_{RH} (Scaling factor for Rainfall_MPI_RegCM4) = 64.23 / 50.40 = 1.27

Table 1: Summary of mean annual scaling factors

Scaling factors / Scenarios	MPI_RegCM4	GDFL_RegCM4
f_p	0.96	1.09
f_{RH}	1.27	1.30
$Bias\_Tmin$	0.63	1.36
$Bias\_Tmax$	1.44	2.04

Author's Computation, 2015

Table 2: Summary of monthly scaling factors for correction of the climate scenarios

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
f_pr_MPI	2558.01	220.48	2.89	1.17	1.40	1.34	0.74	0.62	0.76	1.07	1.97	78.26
f_pr_GFDL	1360.57	38.58	6.98	1.37	1.17	1.23	0.90	0.64	1.05	1.47	2.50	1585.52
f_Tmax_MPI	1.87	1.84	0.63	0.90	1.50	1.46	0.97	0.70	1.23	1.93	1.99	2.23
f_Tmax_GFDL	2.99	2.36	0.65	1.05	1.99	1.94	1.51	1.40	1.92	2.39	2.68	3.56
f_Tmin_MPI	2.98	3.38	1.91	0.06	-0.74	-1.28	-0.93	-1.02	-1.47	-0.47	2.28	2.89
f_Tmin_GFDL	4.15	4.16	2.74	0.38	-0.38	-0.86	-0.49	-0.47	-0.82	0.31	3.35	4.22
f_RH_MPI	3.25	2.84	1.49	1.10	1.05	1.03	1.04	1.05	1.05	1.12	1.60	2.76
f_RH_GFDL	3.37	3.07	1.68	1.14	1.06	1.03	1.03	1.05	1.05	1.16	1.76	2.99

Author’s Computation, 2015

Appendix F: Details of Onset Dates

Table 1: Baseline dates of onset of the growing season from each of the two ET methods, for Awun basin, Kwara State (1995–2014). Julian days give the number of the day of the Julian calendar of that year.

Years	Baseline_Onset Dates	Baseline_Onset Junian days_HS	Baseline_Onset Dates_BMN	Baseline_Onset Junian days_BMN
1995	1st May	121	1st May	121
1996	25th May	149	29th May	150
1997	26th April	116	26th April	116
1998	2nd May	122	7th May	127
1999	12th May	132	25th May	145
2000	1st June	155	1st June	155
2001	12th May	132	12th May	132
2002	26th June	177	3rd July	184
2003	28th June	148	1st June	152
2004	15th May	136	30th May	151
2005	20th April	110	20th April	110
2006	8th May	129	27th April	117
2007	12th April	102	29th March	88
2008	1st April	92	1st April	92
2009	12th April	102	12th April	102
2010	15th June	166	6th June	157
2011	7th June	158	***	***
2012	24th April	115	24th April	115
2013	14th April	105	30th March	89
2014	7th April	97	7th April	97

Author’s Computation, 2015

*: years with missing relative humidity to compute onset using BMN ETp model

Table 2: Scenario MPI_RegCM4_RCP4.5 dates of onset of the growing season for Awun basin (2080–2099) using HS ETp model

Years	MPI_RegCM4_RCP4.5_Onset dates_HS	MPI_RegCM4_RCP4.5_Onset_Junian days_HS	MPI_RegCM4_RCP8.5_Onset dates_HS	MPI_RegCM4_RCP8.5_Onset_Junian days_HS
2080	27th April	118	11th June	163
2081	4th July	193	16th June	168
2082	14th April	104	11th April	101
2083	3rd July	184	15th July	196
2084	22nd March	82	23rd June	175
2085	28th May	148	3rd June	154
2086	18th April	108	12th July	193
2087	3rd June	154	31st July	212
2088	6th May	127	11th June	163
2089	24th June	175	28th July	209
2090	1st June	152	22th July	203
2091	16th July	197	4th July	185
2092	19th June	162	27th July	209
2093	25th July	206	21st July	202
2094	30th April	121	16th May	136
2095	22nd June	173	15th July	196
2096	30th May	151	10th May	131
2097	7th June	158	15th June	166
2098	9th July	190	24th August	236
2099	5th June	156	2nd August	214

Author’s Computation, 2015

Table 3: Scenario MPI_RegCM4 RCP4.5 and RCP8.5 dates of onset of the growing season for Awun basin (2080–2099) using BMN ETp model

Years	MPI_RegCM4_ RCP4.5_Onset dates_BMN	MPI_RegCM4_RCP4.5_Onset_Junian days_BMN	MPI_RegCM4_ RCP8.5_Onset dates_BMN	MPI_RegCM4_ RCP8.5_Onset_Junian days_BMN
2080	26th April	117	5th May	126
2081	18th June	170	26th May	147
2082	14th April	104	11th April	101
2083	6th June	157	28th June	179
2084	22nd March	82	27th May	148
2085	10th May	130	3rd June	154
2086	18th April	108	27th June	178
2087	2nd June	153	27th July	208
2088	2nd May	123	4th May	125
2089	16th June	167	8th July	189
2090	25th May	145	5th July	186
2091	3rd July	184	10th June	161
2092	14th May	135	6th July	188
2093	15th June	196	18th July	199
2094	29th April	120	14th May	135
2095	15th June	166	29th June	182
2096	29th May	150	7th May	128
2097	4th June	155	10th June	161
2098	13th June	164	21st July	202
2099	28th May	148	17th July	198

Author's Computation, 2015

Table 4: Scenario GFDL_RegCM4 RCP4.5 and RCP8.5 dates of onset of the growing season for Awun basin (2080–2099) using HS ETp model

Year	GFDL_RegCM4_RCP4.5_Onset dates_HS	GFDL_RegCM4_RCP4.5_Onset_Junian days_HS	GFDL_RegCM4_RCP8.5_Onset dates_HS	GFDL_RegCM4_RCP8.5_Onset_Junian days_HS
2080	16th July	250	7th June	239
2081	9th June	213	19th June	221
2082	7th May	174	15th June	226
2083	26th July	258	27th April	174
2084	1st August	217	17th May	195
2085	11th June	238	1st June	234
2086	13th May	248	8th June	225
2087	9th June	216	6th June	228
2088	1st June	228	20th June	231
2089	3rd July	246	6th September	**
2090	14th May	229	24th July	268
2091	1st May	237	2nd June	252
2092	14th July	233	3rd August	239
2093	12th May	210	9th June	257
2094	1st June	239	8th July	229
2095	12th May	227	29th May	262
2096	9th July	247	11th July	235
2097	22nd May	225	24th June	250
2098	8th July	236	5th May	247
2099	2nd July	229	5th August	270

Author’s Computation, 2015

Table 5: Scenario GFDL_RegCM4_RCP4.5 dates of onset of the growing season for Awun basin (1995–2014) using BMN ETp model

Year	GFDL_RegCM4_RCP4.5_Onset dates_BMN	GFDL_RegCM4_RCP4.5_Onset_Junian days_BMN	GFDL_RegCM4_RCP8.5_Onset dates_BMN	GFDL_RegCM4_RCP8.5_Onset_Junian days_BMN
2080	6th July	188	27th April	118
2081	9th June	161	10th June	161
2082	7th May	127	31st June	151
2083	15th July	196	25th April	115
2084	9th July	191	17th May	140
2085	9th June	160	1st June	152
2086	12th May	132	4th June	155
2087	28th May	148	2nd June	154
2088	15th May	136	13th June	165
2089	21st May	141	11th August	223
2090	31st April	120	23th June	174
2091	27th April	117	27th May	147
2092	28th June	180	17th July	199
2093	12th May	132	30th May	150
2094	30th May	150	11th May	131
2095	8th May	128	29th May	149
2096	16th June	168	24th June	176
2097	20th May	140	4th June	155
2098	27th June	178	4th May	123
2099	20th June	171	25th June	175

Author’s Computation, 2015

Appendix G: Details on the computation of crop water needs

- ✓ Maize (Crop Potential Evapotranspiration)

Table 1: Baseline (1995-2014) water needs for maize

Scenarios	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Baseline_BMN_ETO(mm/day)	4.8	5.5	5.8	4.9	4.1	3.6	3.4	3.4	3.4	3.6	4.1	4.4
Kc per month					0.44	0.87	1.15	1.10				
ETcrop (mm/day)					1.8	3.1	3.9	3.7				
ETcrop (mm/month)					55.1	93.8	117.2	74.0				
Seasonal ETcrop (mm)					340.1							

Author’s Computation, 2015

Table 2: Scenario MPI_RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for Maize

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MPI_RCP4.5_BMN_ETO(mm/day)	6.1	5.9	6.2	6.2	4.9	4.1	3.8	3.8	3.9	4.7	4.8	5.1
Kc per month					0.4	0.9	1.2	1.1				
ETcrop (mm/day)					2.2	3.6	4.3	4.2				
ETcrop (mm/month)					65.8	107.2	130.1	84.1				
Seasonal Etcrop (mm)					387.2							
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MPI_RCP8.5_BMN_ETO(mm/day)	6.6	6.6	7.2	6.6	5.4	4.6	4.0	4.0	4.0	4.5	4.3	5.2
Kc per month					0.4	0.9	1.2	1.1				
ETcrop (mm/day)					2.4	4.0	4.6	4.4				
ETcrop (mm/month)					72.0	120.1	137.9	88.5				
Seasonal Etcrop (mm)					418.4							

Author’s Computation, 2015

Table 3: Scenario GFDL _RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for Maize

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GFDL_RCP4.5_BMN_ETO(mm/day)	6.1	6.2	6.1	6.7	5.0	4.1	3.7	3.7	3.8	4.6	4.7	5.2
Kc per month					0.4	0.9	1.2	1.1				
ETcrop (mm/day)					2.2	3.5	4.3	4.1				
ETcrop (mm/month)					66.4	106.2	128.3	82.3				
Seasonal Etcrop (mm)						383.3						

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GFDL_RCP8.5_BMN_ETO(mm/day)	6.5	6.7	6.3	6.6	5.1	4.3	4.0	3.9	3.9	4.5	4.2	5.4
Kc per month					0.4	0.9	1.2	1.1				
ETcrop (mm/day)					2.3	3.8	4.6	4.3				
ETcrop (mm/month)					68.4	113.1	137.3	86.1				
Seasonal Etcrop (mm)						404.9						

Author’s Computation, 2015

- ✓ Sorghum (Crop Potential Evapotranspiration)

Table 4: Baseline (1995-2014) water needs for sorghum

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Baseline_BMN_ETO(mm/day)	4.8	5.5	5.8	4.9	4.1	3.6	3.4	3.4	3.4	3.6	4.1	4.4
Kc per month					0.45	0.83	1.20	1.10	1.05			
ETcrop (mm/day)					1.87	2.97	4.08	3.70	3.59			
ETcrop (mm/month)					56.0	89.0	122.3	110.9	35.9			
Seasonal Etcrop (mm)							414.0					

Author’s Computation, 2015

Table 5: Scenario GFDL_RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for sorghum

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

MPI_RCP4.5_BMN_ETO(mm/day)	6.1	5.9	6.2	6.2	4.9	4.1	3.8	3.8	3.9	4.7	4.8	5.1
Kc per month					0.45	0.825	1.2	1.1	1.05			
ETcrop (mm/day)					2.2	3.4	4.5	4.2	4.1			
ETcrop (mm/month)					66.8	101.7	135.8	126.1	41.4			
Seasonal Etcrop (mm)							471.8					
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MPI_RCP8.5_BMN_ETO(mm/day)	6.6	6.6	7.2	6.6	5.4	4.6	4.0	4.0	4.0	4.5	4.3	5.2
Kc per month					0.45	0.825	1.2	1.1	1.05			
ETcrop (mm/day)					2.4	3.8	4.8	4.4	4.3			
ETcrop (mm/month)					73.1	113.9	143.9	132.7	42.5			
Seasonal Etcrop (mm)							506.0					

Author’s Computation, 2015

Table 6: Scenario MPI_RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for Sorghum

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GFDL_RCP4.5_BMN_ETO(mm/day)	6.12	6.20	6.06	6.70	4.99	4.07	3.72	3.74	3.77	4.60	4.70	5.18
Kc per month					0.45	0.825	1.2	1.1	1.05			
ETcrop (mm/day)					2.2	3.4	4.5	4.1	4.0			
ETcrop (mm/month)					67.3	100.8	133.9	123.5	39.5			
Seasonal Etcrop (mm)							465.1					
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GFDL_RCP8.5_BMN_ETO(mm/day)	6.5	6.7	6.3	6.6	5.1	4.3	4.0	3.9	3.9	4.5	4.2	5.4
Kc per month					0.45	0.825	1.2	1.1	1.05			
ETcrop (mm/day)					2.3	3.6	4.8	4.3	4.1			
ETcrop (mm/month)					69.5	107.3	143.3	129.1	41.2			
Seasonal Etcrop (mm)							490.3					

Author’s Computation, 2015

- ✓ Cassava (Crop Potential Evapotranspiration)

Table 7: Baseline (1995-2014) water needs for cassava

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Baseline_BMN_ETO(mm/day)	4.8	5.5	5.8	4.9	4.1	3.6	3.4	3.4	3.4	3.6	4.1	4.4
Kc per month	1.2	1.2	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.7	0.97	1.2
ETcrop (mm/day)	5.8	6.6	2.9	2.5	1.2	1.1	1.0	1.0	1.0	2.5	4.0	5.3
ETcrop (mm/month)	172.9	199.0	86.7	74.1	37.3	32.3	30.6	30.3	30.7	76.2	120.2	158.2
Seasonal Etcrop (mm)	1048.5											

Author's Computation, 2015

Table 8: Scenario MPI_RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for cassava

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

MPI_RCP4.5_BMN_ETO(mm/day)	6.1	5.9	6.2	6.2	4.9	4.1	3.8	3.8	3.9	4.7	4.8	5.1
Kc per month	1.2	1.2	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.7	0.97	1.2
ETcrop (mm/day)	7.3	7.1	3.1	3.1	1.5	1.2	1.1	1.1	1.2	3.3	4.6	6.1
ETcrop (mm/month)	219.4	213.3	93.6	93.7	44.5	37.0	33.9	34.4	35.5	98.8	138.5	183.5
Seasonal Etcrop (mm)	1226.2											
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MPI_RCP8.5_BMN_ETO(mm/day)	6.6	6.6	7.2	6.6	5.4	4.6	4.0	4.0	4.0	4.5	4.3	5.2
Kc per month	1.2	1.2	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.7	0.97	1.2
ETcrop (mm/day)	8.0	8.0	3.6	3.3	1.6	1.4	1.2	1.2	1.2	3.2	4.2	6.3
ETcrop (mm/month)	238.8	238.7	108.6	99.2	48.7	41.4	36.0	36.2	36.4	94.9	125.0	187.8
Seasonal Etcrop (mm)	1291.8											

Author’s Computation, 2015

Table: Scenario GFDL_RegCM4 RCP4.5 and RCP8.5 Crop Water Requirements (2080–2099) for cassava

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

GFDL_RCP4.5_BMN_ETO(mm/day)	6.1	6.2	6.1	6.7	5.0	4.1	3.7	3.7	3.8	4.6	4.7	5.2
Kc per month	1.2	1.2	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.7	0.97	1.2
ETcrop (mm/day)	7.3	7.4	3.0	3.3	1.5	1.2	1.1	1.1	1.1	3.2	4.5	6.2
ETcrop (mm/month)	220.3	223.2	90.9	100.5	44.9	36.6	33.5	33.7	33.9	96.7	136.3	186.6
Seasonal Etcrop (mm)	1237.1											
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GFDL_RCP8.5_BMN_ETO(mm/day)	6.5	6.7	6.3	6.6	5.1	4.3	4.0	3.9	3.9	4.5	4.2	5.4
Kc per month	1.2	1.2	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.7	0.97	1.2
ETcrop (mm/day)	7.8	8.0	3.1	3.3	1.5	1.3	1.2	1.2	1.2	3.2	4.1	6.4
ETcrop (mm/month)	232.8	241.4	94.4	99.4	46.3	39.0	35.8	35.2	35.3	94.6	122.3	193.0
Seasonal Etcrop (mm)	1269.6											

Author’s Computation, 2015