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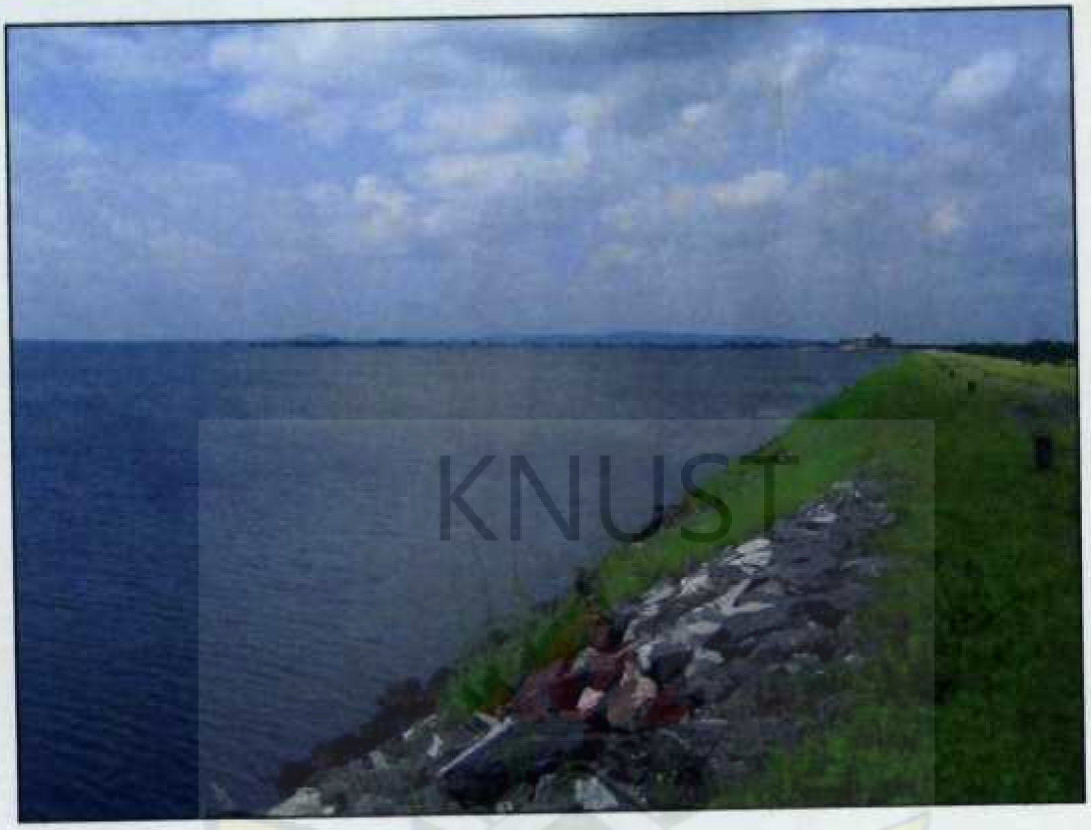

Assessing the Potential Impacts of Climate Change on Irrigation Water Use in Upper East Region of Ghana: A case study of Tono and Vea Irrigation Projects

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ASSESSING THE POTENTIAL IMPACTS OF CLIMATE ON IRRIGATION WATER USE IN UPPER EAST REGION OF GHANA: A CASE STUDY OF TONO AND VEA IRRIGATION PROJECTS

by

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Technology

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in

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College of Engineering

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CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Dr. S. N. Odai **(Principal Supervisor)**	.... Signature	May 7 2009 Date
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Prof. S. K. Ampadu **(Head of Department)**	.... Signature	10/05/2009 Date

Dedication

To my Mama and Papa

Abstract

Climate change is a global phenomenon associated with the emission of greenhouse gases into the atmosphere with the resultant effect of raising the global mean temperatures. Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. The people in Upper East Region (UER) are mostly engaged in Agriculture which is mostly dependent on irrigation water provided by medium and small reservoirs. With increase in population and the need to meet food security under Ghana's poverty reduction strategy, more lands are envisaged to be put under irrigation. It is therefore imperative to look into the impacts of climate change on irrigation water use of the two medium reservoirs in the region, Tono and Vea irrigation projects.

Historical water abstraction from Tono and Vea reservoirs were estimated. The irrigation needs of four major crops (rice, tomato, pepper and onion) grown during the dry season were computed using the CROPWAT model. Future climatic conditions for the year 2020, 2050 and 2080 were determined for the UER based on synthetic and general circulation models climate scenarios. Future irrigation needs were also computed based on future climatic conditions. Climate change adaptation measures were identified and reviewed by interviewing institutions who have a stake in climate change.

Historical water abstraction from the Tono and Vea reservoirs for the cultivation of the four crops were far less than their maximum storage capacity. Historical water abstraction for the cultivation of the four crops for dry season farming ranged from 9.66 Mm^3 to 27.67 Mm^3 and 1.82 Mm^3 to 8.88 Mm^3 for Tono and Vea reservoirs respectively. The irrigation requirements of rice, tomato, pepper and onion based on climatic baseline (1977 - 2006) are 871.5 mm, 680.1 mm, 558.9 mm and 441.8 mm respectively. The net irrigation water requirements of the four crops will increase by about 0.6 – 9% due to climate change depending on the climate change scenarios and time slices. Climate change will not have significant impact on Tono irrigation project because future irrigation abstraction when maximum land areas between 1985 and 2006 are cultivated will be about 33 – 35 % of the maximum storage of the reservoir. Future irrigation abstraction when the total irrigable area at Tono is cultivated with rice, will be about 44% to 47% of the maximum storage capacity between 2020 and 2080 and therefore the total irrigable area of 2490 ha could be utilized for the cultivation of rice and other water demanding crops since there is abundance of water. Climate change will have a minimal impact on Vea reservoir but coupled with an increase in domestic abstraction, the stored water in the reservoir may not be adequate for both irrigation (when maximum land areas between 1985 and 2006 are cultivated in the future) and domestic use for 2050 and beyond. Furthermore, when the total irrigable area is cultivated, the stored water will be adequate for the cultivation of tomato, pepper and onion in 2020 with the exception of rice. The Vea reservoir could supply enough water for the cultivation of pepper and onion on the total irrigable area in 2050 because their irrigation abstractions are about 63% and 49% of the maximum storage capacity. In 2080, the Vea reservoir cannot supply enough water (over 51% of total reservoir capacity) needed for the cultivation of each of the four crops on the total irrigable area because domestic abstraction will be about 52% of the maximum storage capacity.

Climate change adaptation measures such as planting of crop varieties tolerant to adverse climatic conditions, efficient water management, and application of organic matter fortified with inorganic fertilizer if implemented can help farmers cope with climate change.

Key words: Climate change, irrigation water requirement, climate scenarios, adaptation

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List of Abbreviations and Acronyms

AEZs	Agro-ecological Zones
AOGC	Coupled Atmosphere-ocean Models
AR4	Fourth Assessment Report
CRU	Climatic Research Institute
EPA	Environmental Protection Agency
ECHO-G	Hamburg Atmospheric – Ocean Coupled Circulation Model
FAO	Food and Agricultural Organization
GCMs	General Circulation Models
GIDA	Ghana Irrigation Development Authority
GIR	Gross Irrigation Requirement
IPCC	Intergovernmental Panel on Climate Change
MAGICC	Model for Assessment of Greenhouse gas Induced Climate Change
MDGs	Millennium Development Goals
MRI	Meteorological Research Institute of Japan Model
NIR	Net Irrigation Requirement
SCENGEN	Spatial Climate Change Scenario Generator
SRES	Special Report on Emission Scenarios
UEA	University of East Anglia
UER	Upper East Region
WVR	White Volta River

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CHAPTER ONE

1 INTRODUCTION

1.1 Background

Climate change is a global phenomenon associated with emission of greenhouse gases into the atmosphere with the resultant effect of raising the global mean temperatures. Since the beginning of the Industrial Revolution in 1750, global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a consequence of human activities such as burning of fossil fuels, agriculture, deforestation, etc. (IPCC, 2007a). The levels of emission depend on the degree of industrialisation of the country and available technology among other factors. However, the impacts of climate change on the natural resources of a region depend on the changes or modifications in the atmospheric circulation over the area induced by the changes in global atmospheric chemistry.

The Intergovernmental Panel on Climate Change (IPCC) has demonstrated that an increment in CO_2 concentration of about 90ppm has occurred between the periods 1750 to 2000. Over the years anthropogenic activities have lead to an increase in global mean surface temperature of approximately 0.6°C during the 20th century (IPCC, 2001). Based on a range of several current climate models, IPCC in 2001 predicted that the mean annual global surface temperature is projected to increase by 1.4 to 5.8°C over the period of 1990 to 2100, with changes in the spatial and temporal patterns of precipitation (Soutworth et.al, 2000; Räisänen, 2001). Climate change can have very serious negative effects on the socio-economic development of the country if the potential impacts are not identified for appropriate adaptive measures to be put in place. A number of sectors such as water resources, coastal zone resources, agriculture, human health, energy, industry, forestry, fisheries and wildlife can be impacted by climate change (Andah et.al, 2002).

Climate change has very great significance for sustainable development plans, life and livelihoods in Ghana. Climate change is regarded generally in Ghana as a development issue and might be a contributory factor that will exacerbate a number of existing problems such as land degradation, urban migration and food insecurity. However variety in agro climatic regions across the country from savannah grassland to tropical rainforest with varying degrees of temporal variability makes climate change discussions challenging. Ghana, just like many African countries is neither able to cope with current climate variability nor adapt to the medium and long term impacts of projected climatic changes (Kuuzegh, 2007). The Fourth Assessment Report (AR4) of the IPCC confirms that African countries are likely to suffer most from the negative impacts of climate change since African countries have the least capacities to adapt to the impacts of climate change. Not only African countries are vulnerable to climate change but also other developing countries because of the predominance of agriculture in their economies, warmer baseline climates and heightened exposure of extreme events. Without taking stringent measures and actions to adapt to climate change, it is imminently going to be a good recipe for failing to achieve the millennium development goals (MDG(s).

Historical climate data observed by the Ghana Meteorological Agency across the country between 1960 and 2000, (a forty-year period), show a progressive and discernible rise in temperature (about 0.4^{o}C) and a concomitant decrease in rainfall of about 10% in all agro-ecological zones of the country (EPA, 2000 and Kuuzegh, 2007).

Variations in the earth's climate and likely future changes not only present a serious threat to human society in general but more in particular to the water sector, bringing consequences and implications that will affect the future management of water resources (HM Government, 2006). These variations raise concern for irrigated agriculture which is the largest user of the world's water resources.

1.2 Problem statement

Agriculture in the Upper East Region (UER) of Ghana is dependent on irrigation water provided by medium and small reservoirs. Agricultural sustainability in this semi-arid region is thus primarily determined by water supply being adequate to meet demand. Several studies have predicted responses to global warming as increased temperatures, altered precipitation patterns and changes in the amount of precipitation, all of which will have an impact on the crop water supply-demand relationship (Neilsen et al, 2001). If water requirements for agriculture increases, competition among various users for the same resource may further limit supply to agriculture especially when many of the reservoirs that supply irrigation water are also used for domestic water supply as well as livestock watering and construction purposes. This realization should be of grave concern to all development oriented organizations and individuals owing to the fact that this region already endures long dry spell periods and low rainfall. With increasing population and the need to meet food security under Ghana's poverty reduction strategy, more lands are envisaged to be put under irrigation. However, it is not known whether there will be enough water for the anticipated extension, both presently and future wise. This would deepen the woes of irrigated agriculture if the possibilities of a reduction/increase rainfall and temperature due to climate change are not incorporated into our present development framework.

1.3 Justification

Irrigation water over the years has enabled farmers to increase crop yields by reducing their dependence on rainfall, thus boosting the average crop production while decreasing the interannual variability (Tuibiello, 2005; Diamond et.al, 1997). Semi-arid areas already suffering from limited availability of water under current conditions are likely to be most affected by climate change, while (sub-) humid areas may be less adversely affected, (Yano, et.al, 2007; Brumbelow and Georgakakos, 2001; Fuhrer 2003). Current emerging trends of events necessitate the need for a step towards evaluating how much water will be needed for irrigation in the future, by quantifying how the threats of climate change will affect irrigation water requirements, especially in water stress areas such as the UER of Ghana.

Despite the susceptible nature of the UER to climate change due to its long periods of droughts and uni-modal rainfall pattern, relatively few studies have tried to quantify the possibility of a potential damage to its agricultural base, especially on irrigation water use, using local data. Climate change has become a global issue and therefore calls for such studies to be undertaken in the UER since the livelihood of the people is likely to be hit.

1.4 Objectives

The aim of this study is to assess the potential impacts of climate change on irrigation water use in Upper East Region of Ghana

Specific Objectives

1. To establish an irrigation water abstraction baseline for Tono and Vea irrigation projects.
2. To create a set of future climatic conditions for Upper East Region by using the climate scenarios.
3. To assess the impacts of climate change on irrigation water needs for different species of crops grown in the region.
4. To identify potential adaptation measures to deal with climate change in the region.

1.5 Organization of thesis

The thesis is organized into six chapters. Chapter 1 gives a background to the thesis, the problem statement and justification to allow readers get a better understanding of the topic. Then, the aims and objectives also follow. Chapter 2 reviews literature: climate change scenarios, climate change impacts on water resources, water supply and demand, plant responses to stress and irrigation. Chapter 3 describes the study area. Chapter 4 outlines the materials and method used for the study. Chapter 5 presents the results and discussion of the study. Chapter 6 presents conclusions of the findings and also gives recommendations.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Climate change and Climate Variability

Climate change refers to the regional or global-scale changes in historical climate patterns arising from natural and/or man-made causes and resulting in both intermittent but increasingly frequent, extreme impacts (e.g. large storms and heat waves) and slow on-set, pervasive cumulative effects (e.g. extinction of life forms and sea level rise (Simon, 2007 cited in Training manual for Trainers, 2008). Climate change involves the interactions of many systems such as the atmosphere, hydrosphere, cryosphere, biosphere, as well as the human system. Climate change could occur due to natural variability or anthropogenic conditions. In other words, climate change may be due to internal processes and/or external forcings. The natural variability of the climate system is due to some external influences such as changes in solar radiation and volcanism which occur naturally. Emission of greenhouse gases into the atmosphere as result of human activity that began with the industrial revolution is the other external changes which have caused change in composition of the atmosphere. Internal variability is present on all time scales. Atmospheric processes that generate internal variability are known to operate on time scales ranging from virtually instantaneous (e.g., condensation of water vapour in clouds) up to years (e.g., troposphere-stratosphere or inter-hemispheric exchange). Other components of the climate system, such as the ocean and the large ice sheets, tend to operate on longer time scales. These components produce internal variability of their own accord and also integrate variability from the rapidly varying atmosphere (Hasselmann, 1976). In addition, internal variability is produced by coupled interactions between components, such as is the case with the El-Niño Southern

Oscillation (ENSO). Distinguishing between the effects of external influences and internal climate variability requires careful comparison between observed changes and those that are expected to result from external forcing. Döll (2002) also defined climate change as changes in the long-term averages of precipitation and temperature only.

2.2 Climate Scenarios

There exists much confidence among scientists that increased atmospheric greenhouse gas concentrations from human activities will increase global temperatures. Their confidence begins to lessen as to how climate will change at a regional scale (Giorgi et al., 2001). Climate change will specifically be felt at regional or local level such as at the scale of farm, river basin or even an individual organism. However, no method yet exists of providing confident predictions of climate change at these scales; an alternative approach is to specify a number of plausible future climates. These are termed climate scenarios (IPCC-TGICA, 2007).

Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and other pollutants and with our understanding of the effect of increased atmospheric concentrations of these gases on global climate (IPCC-TGICA, 2007). A variety of scenarios can be used to identify the sensitivity of an exposure unit to climate change and to help policy makers decide on appropriate policy responses. Unlike weather forecasts which make use of enormous quantities of information on the observed state of the atmosphere and calculate, using the laws of physics, how this state will evolve during the next few days, producing a prediction of the future - a forecast; climate scenario is a plausible indication of what the future could be like over decades or centuries, given a specific set of assumptions. These assumptions include future trends in energy demand emissions of greenhouse gases, land use change as well as assumptions about the behaviour of the climate system over long time scales. The uncertainties surrounding these assumptions normally determine the range of possible scenarios (IPCC-TGICA, 2007). The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (Smith and Hulme, 1998). It follows that the selection of scenarios can also be controversial, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis.

2.2.1 Criteria for selecting climate scenarios

Smith and Hulme (1998) suggested four criteria that climate scenarios should meet if they are to be useful for impact assessment by researchers and policy makers. IPCCIPCC-TGICA (2007) also suggested an additional criterion to make it five.

- Criterion 1: Consistency with global projections. They should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases.
- Criterion 2: Physical plausibility. They should be physically plausible; that is, they should not violate the basic laws of physics.
- Criterion 3: Applicability in impact assessments. They should describe changes in a sufficient number of variables on a spatial and temporal scale that allows for impact assessment.

- Criterion 4: Representative. They should be representative of the potential range of future regional climate change.
- Criterion 5: Accessibility. They should be straightforward to obtain, interpret and apply for impact assessment.

2.2.2 Types of climate scenarios

There are three main classes of climate scenarios. These are: synthetic scenarios, analogue scenarios and scenarios based on outputs from General Circulation Models (GCMs).

2.2.2.1 *Synthetic scenarios*

Synthetic scenarios describe techniques where particular climatic (or related) elements are changed by a realistic but arbitrary amount, often according to a qualitative interpretation of climate model simulations for a region. For example, adjustments of baseline temperatures by +1, 2, 3 and 4°C and baseline precipitation by ±5, 10, 15 and 20 per cent could represent various magnitudes of future change.

The advantages of synthetic scenarios are:

1. They are simple to apply by impact analysts, transparent and easily interpreted by policy makers and non-specialists
2. They capture a wide range of possible changes in climate, offering a useful tool for evaluating the sensitivity of an exposure unit to changing climate. Since individual variables can be altered independently of each other, synthetic scenarios also help in identifying thresholds or discontinuities of response that might occur under a given magnitude or rate of climate change.

3. Different studies can readily apply the same synthetic scenarios to explore relative sensitivities of exposure units. This is potentially useful for comparing and synthesizing the potential effects of climate change over different sectors and regions.

The major disadvantage of synthetic scenarios is their arbitrary nature. They rarely present a realistic set of changes that are physically plausible, commonly representing adjustments as being uniform over time and space and inconsistent among variables. Moreover, some scenarios may be inconsistent with the uncertainty range of global changes (criterion 1). However, this limitation can be overcome if the selection of synthetic scenarios is guided by information from GCMs.

2.2.2.2 *Analogue scenarios*

Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. These records can be obtained either from the past called temporal analogues or from another region at the present known as spatial analogues.

2.2.2.3 *Scenarios from general circulation model outputs*

General circulation models also known as Global Climate Models (GCMs) or numerical models, representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response. According to IPCC (1994), only GCMs, often in conjunction with nested regional models or other downscaling methods have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis.

GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans (as shown in figure 1).

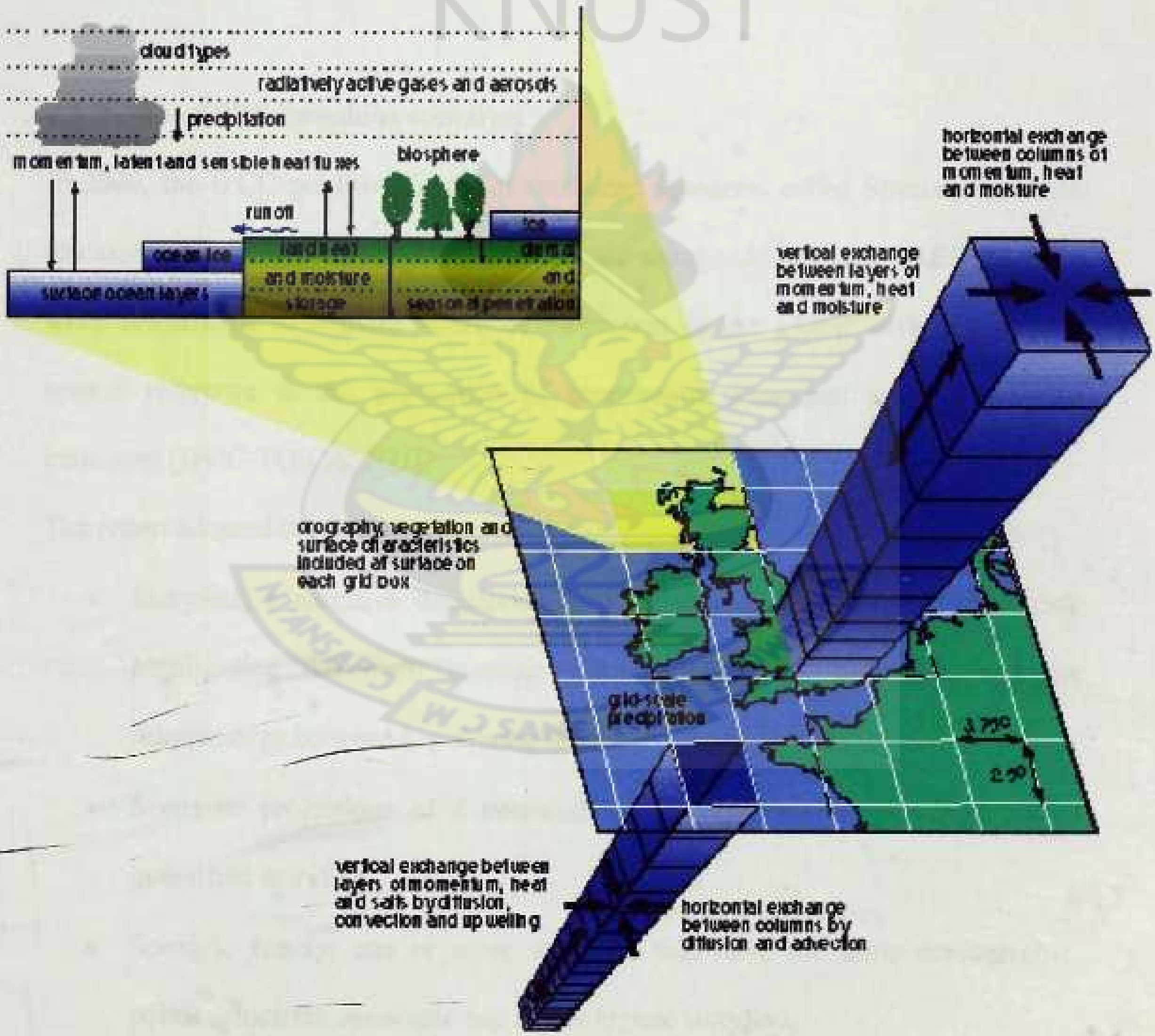

Figure 2.1: Conceptual structure of a coupled atmosphere-ocean general circulation model

Source: Viner and Hulme (1997)

Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments. GCM-based simulations of future climate cannot properly model many physical processes, such as those related to clouds which occur at smaller scales and various feedback mechanisms in models concerning, for example, water vapour and warming, clouds and radiation, ocean circulation and ice and snow albedo. GCMs for this reason may simulate quite different responses to the same forcing; simply because of the way certain processes and feedbacks are modelled. These are sources of uncertainties in GCM-based simulation models

2.3 The SRES emissions scenarios

In 2000, the IPCC published a set of emissions scenarios called Special Report on Emissions Scenarios – SRES for use in climate change studies. The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions (IPCC-TGICA, 2007)

The report adopted the following terminology:

- Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.
- Scenario: projections of a potential future, based on a clear logic and a quantified storyline.
- Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

The SRES team defined four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. The four storylines combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization.

Nakicenovic et al., (2000) summarized the storylines as follows:

***(a) A1 storyline and scenario family*:**

This scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. This family is divided into three groups that are distinguished by their technological emphasises: fossil intensive (A1FI), resulting in atmospheric CO_2 concentration increasing from the present 370 ppm to almost 1000 ppm by the year 2100; non-fossil sources (A1T), atmospheric CO_2 550 ppm in 2100; and balance (A1B), atmospheric CO_2 700 ppm in 2100.

(b) A2 storyline and scenario family:

This scenario describes a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

(c) B1 storyline and scenario family:

This scenarios describes a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resource efficient technologies.

(d) B2 storyline and scenario family:

This scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

2.4 Climate change impacts on water resources

Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation (IPCC, 2001). However, the impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

Water resources in Ghana are essential for socio-economic development. Impacts of climate change on the water resource can put the country at risk. EPA, (2000) assessed the impacts of climate change on water resources in Ghana by selecting a basin each from the three hydroclimatic zones. The basins are Pra from the South-Western basin system, Ayensu from the Coastal basin system and the White Volta from the Volta basin system. Findings from the study show that there was observed increase in temperatures of about 1°C over a 30 year period and reductions in rainfall and runoff of about 20 and 30% respectively in the historical data sets. Using synthetic scenario they found out that runoffs or discharges in all the representative basins are sensitive to changes in precipitation and temperature and thus to climate change. A 10% change in precipitation and a 1°C rise in temperature can cause a reduction in runoff of not less than 10%. Simulations using GCM-based climate scenarios indicated reduction in flows between 15-20% and 30-40% for the year 2020 and 2050 respectively in all the basins. They also found out that climate change can cause reduction in groundwater recharge between 5 and 22% by the year 2020. Reductions for the year 2050 are projected to be between 30 and 40%.

Matondo and Msibi, (2001) found out that in Swaziland, climate change would affect flow regimes and water resources through impact on rainfall distribution patterns, magnitude and intensity of individual precipitations, evaporation arising from temperature and radiation changes, and alternations in vegetation response.

2.5 Climate change impacts on water supply and water demand

Domestic water demand is driven to a large extent by the population growth and the industrial water demand by expansion of industries for socio-economic development.

Studies conducted by EPA, (2000) show that the direct impact of climate change, in terms of temperature and precipitation changes, on water demand by most industries is envisaged to be very small. The climate change impacts, with rise in temperatures, may be on cooling processes. They found out that residential water demand is inversely correlated with precipitation and positively correlated with average temperature. They could not investigate the impacts of climate change on domestic water demand due to lack of data. However, findings indicate that both surface and groundwater resources will decrease across the country in the year 2020 and 2050. It is therefore predicted that water demand will increase in general due to increase in population and the need for improvement in socio-economic conditions.

2.6 Plant responses to water stress

High temperatures lead to high evapotranspiration rates which induce water stress and yield reduction. Physiologically, high temperatures induce higher rate of growth but the overall growing period becomes shorter. The shortened reproductive stages due to high temperatures limit carbohydrate accumulation resulting in overall yield reduction. According to Hsiao et al, (1976) the most obvious effect of water stress is growth reduction. Since plants show a marked acclimation to water stress, water deficits can greatly modify plant development and morphology (Jones, 1992). Bisgrove and Hadley (2002) described how plants will adapt to water stress. These adaptations are;

- In the longer term (days, weeks, months), early flowering, compact plants with thicker leaves and resources oriented to root development.

- In the very long term (centuries, millennia), plants will develop adaptive mechanisms such as hairiness, waxiness, water shortage tissues or specialized metabolisms.

Nevertheless, the effects of water stress are dependent on the extent of the water deficit and are different for the different plant species (Griffths and Parry, 2002).

2.7 Impacts of climate change on soils and water regime

Climate change may manifest itself in changes in rainfall, temperature and atmospheric CO_2. These changes will affect soil ecology and organic matter in turn affecting soil structure and finally water regime and plant growth. Organic matter improves the structure of the soil and its water holding capacity. Climate change will lead to accelerated loss of soil organic matter and therefore tend to release nutrients in large quantities (Bisgrove and Hadley, 2002). Decreasing amount of organic matter as a result of climate change will incite negative effect on the structural stability of soil, reducing it water holding capacity (Bisgrove and Hadley, 2002; Diaz, 2007). Higher temperatures as a result of climate change will increase evaporative demand and affect the soil moisture content needed by plants for growth. Extreme rainfall intensities may result in serious soil erosion and overall land degradation. Prolonged drought conditions will adversely affect the entire hydrological regimes of the study area, which will result in a threat of desertification. Much less rainfall and increasing intra- and inter-annual variability could lead to less dry-matter production and hence, in due course, lower soil organic matter contents. Periodic leaching during high-intensity rainfall with less standing vegetation could desalinize some soils in well-drained sites, increased runoff in others, and lead to soil salinization in depression sites or where the groundwater table is high.

In assessing the impact of climate change on irrigation water use, the modification of the soil as a result of climate should be critically looked into. This is because the soil ability to hold water for plant growth will determine the amount of irrigation water that should be applied. The soil should be properly managed to avoid water wastage and other environmental problems such as water-logging in heavy soils and its concomitant problem of pest and disease infestation.

2.8 Climate change Impacts on irrigation

Agriculture is the largest user of water among human activities. According to Fischer et al. (2006), irrigation water withdrawals are 70% of the total anthropogenic use of renewable water resources – about 2630 Gm^3/year out of 3815Gm^3/year. As part of impacts, vulnerability and adaptation to climate change and Ghana's initial communication to UNFCC, EPA (2000) assessed the impacts of climate change on irrigation demand. The CROPWAT model was used to determine the net irrigation water requirements using the temperature and precipitation scenarios for the base period, 2020 and 2050 period as inputs. The net irrigation water demand was converted to the gross water demand by dividing by the local efficiency factor of 0.54. The gross water demands in the Pra, Ayensu and White Volta basins (selected from the three hydroclimatic zones) were determined for the year 2020 based on planned area to be put under irrigation by Ghana Irrigation Development Authority (GIDA), without consideration to climate change and then with climate change. For the year 2050, the areas to be irrigated were estimated based on population increase from 2020 to 2050. The results from the study are enumerated as follows. Water demand in the Pra basin for the year 2020 will increase by 551% and 510% with and without respectively from the base period of about 4,200,416 m^3. Furthermore, water demand in the Pra basin for 2050 will increase by 922% and 771% with and without climate change respectively. Water demands for the years 2020 and 2050 in the Ayensu basin for climate change alone are 141% and 652% respectively of the base value of 48,128 m^3. The water demands in the White Volta basin for the years 2020 and 2050 for climate change alone are 278% and 1,206% respectively of the base value of 6,056,400 m^3. It can be envisaged that the changes in area put under cultivation from the years 2020 to 2050 in all cases were slightly less than 50%. The changes in the water demand due to climate change were found to be about four (4) times (EPA, 2000).

Results by Fischer et al (2006) indicate that climate change is likely to increase water scarcity around the globe, mostly in regions that already suffer under present conditions, such as the southern Mediterranean, the Middle East, and Sub-Saharan Africa. Other studies have been carried out to deal with future regional and global changes in irrigation water for agriculture. Döll and Siebert (2001) worked on global modelling of irrigation requirements. They developed a global irrigation model by integrating simplified agro-ecological and hydrological approaches. Döll (2002) investigated global impacts of climate change and variability on agricultural water irrigation demand by comparing the impacts of current and future climate on irrigated cropland using the framework developed in 2001. Results by Döll (2002) show that changes in precipitation, coupled with increases in evaporative demands, increase the need for irrigation worldwide, with small relative changes in total, about +5 to 8% by 2070 – depending on the general circulation model (GCM) projection – and larger impacts, about +15%, in Southeast Asia and the Indian subcontinent.

2.9 CO_2 impacts on plant water use

CO_2 concentration is predicted to increase in future as a result of anthropogenic factors. Studies on irrigation water use should look at the impact of CO_2 concentration on plant water use. Climate change may cause water stress and its effects but analysis of the effect of rising CO_2 concentrations is proving differently. Allen et al (1990) and Diaz (2007) report that interaction of elevated CO_2 concentrations and water stress showed that plants growing in elevated CO_2 were able to withstand stress better and often showed a delay in the onset of the stress because of the decrease in stomatal conductance and transpiration. Water use efficiency increases as a result of decrease in stomatal conductance and transpiration. In subtropical and other sub-humid or semi-arid areas, the increased productivity and water-use efficiency due to higher CO_2 would tend to increase ground cover, counteracting the effects of higher temperatures. Higher atmospheric CO_2 concentration increases growth rates and water-use efficiency of crops and natural vegetation in so far as other factors do not become limiting. The higher temperature optima of some plants under increased CO_2 would tend to counteract adverse effects of temperature rise, such as increased night time respiration. The shortened growth cycle of a given species because of higher CO_2 and temperature would be compensated for in natural vegetation by adjustments in species composition or dominance (Brinkman and Sombroek, 1996).

CHAPTER THREE

3 STUDY AREA

3.1 Geographical location and population

The Upper East Region (UER) is located at the north-eastern corner of Ghana between latitudes 10°30' and 11°15' North and longitudes 0° and 1°30' West. It is bordered to the north by Burkina Faso, the east by the Republic of Togo, the west by Sissala in Upper West and the south by West Mamprusi in Northern Region. The total land area is about 8,842 sq km, which translates into 3.7 per cent of the total land area of the country. There are nine administrative districts: Bawku Municipal, Bawku West, Bolgatanga Municipal, Bongo, Builsa, Garu-Tempane, Kassena Nankana, Talensi-Nabdam and Kassena-Nankana West as shown in figure 3.1. Bolgatanga is the regional capital of Upper East region.

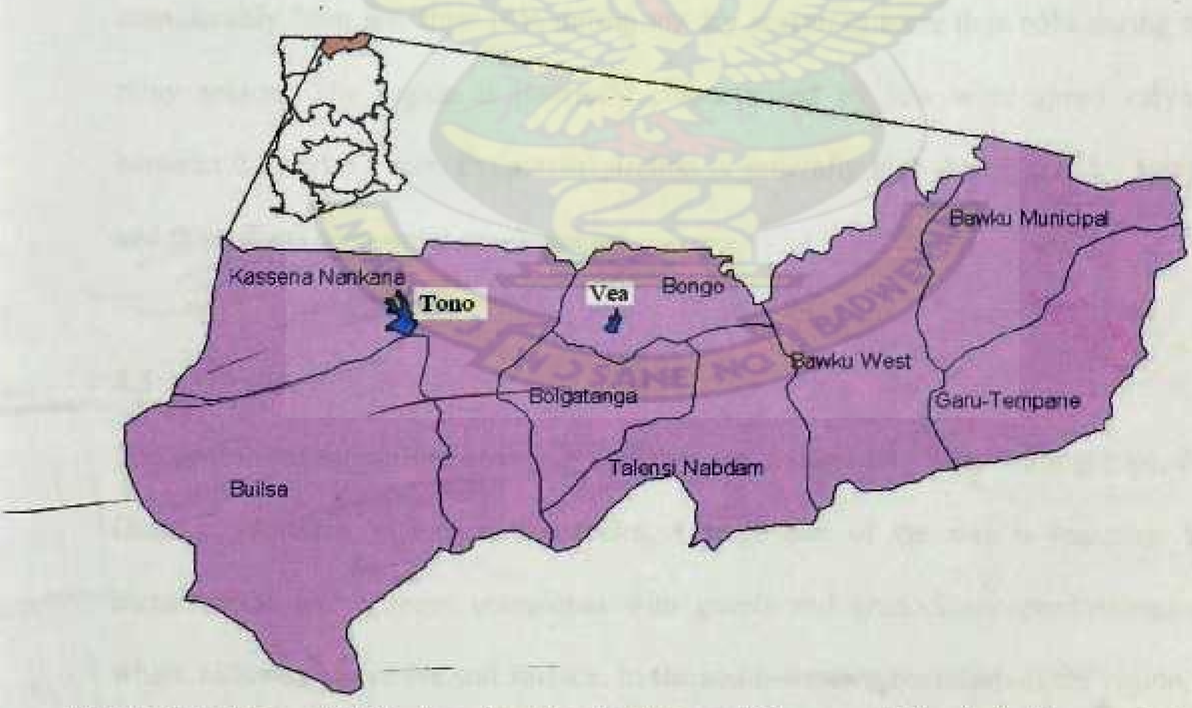

Figure 3.1: Map of UER showing the districts and Tono and Vea irrigation projects

The region has a population of 920,089 which is made up of 442,492 males and 477,597 females (GSS, 2005). The major ethnic groups are the Bimoba, Bissa, Buli, Frafra, Kantosi, Kasem, and Kusasi.

3.2 Climate

The region is within the inter-tropical convergence zone where the movement of the two air masses- the harmattan or North East (NE) trade winds and the southwesterly monsoon winds determines its climate. Rainfall in the region is uni-modal which is erratic and spatially distributed starting from April/May and ending in September/ October with a dry period of 6 – 7 months. Average annual rainfall ranges between 700 and 1100 mm. Temperatures in the region are consistently high, with the hottest month being March or April (40-42°C) and coolest month being August (26°C). Mean annual temperatures are around 28-29°C (Mdemu, 2008). Relative humidity fluctuates considerably from less than 10% during the dry season to more than 65% during the rainy season. The region is generally characterized by low wind speed varying between 0.4 and 2.5 m/s. Evapotranspiration is generally high during the dry season and this affects crop water requirements.

3.3 Geology

The geological formations covering the UER are divided into three main groups, the Granitic, Voltaian, and Birrimian rocks. A large part of the area is underlain by metamorphic and igneous complexes with gnesis and granodiorite predominating; where hills rise above the soil surface. In the south-western boundary of the region, a substantial band of sandstone, grit and conglomerate parallels the boundary and the course of the White Volta River. There are small areas of intrusive diorite in the north-west of the region. Laterite has been formed by fluvial processes in the flat lands adjacent to present and past water course and occur over large areas. Sand occurs at local deposits and along most of the major river courses.

3.4 Soil

Soils in UER are generally formed by the weathering of the bedrock which are mainly granite, although some drift of soil transported by wind and water is also found (Adwubi, 2007) They belong to luvisols, cambisols, greysols, regosols, vertisols, plinthosols and fluvisols developed from granites, birimian rocks and alluvia of mixed origin (Quansah, 2005). The soils have predominately light textured surface horizons, shallow and low in soil fertility, weak with low organic matter content, and predominantly coarse textured. Erosion is serious problem on these soils. Soils in the valley bottoms are heavy textured. Valley areas have soils ranging from sandy loams to salty clays. They have higher natural fertility but are more difficult to till and are prone to seasonal waterlogging and floods.

3.5 Relief

The relief of the area is generally flat, gently undulating with slopes ranging from 1 to 5% except in a few uplands where slopes are about 10% (Adwubi, 2007). According to Adu (1969), the relief of the UER is related to the geology, where a range of Birrimian greenstone hills rising up to 457 m above sea level dominate north of Bawku and Zebilla along the border with Burkina Faso and in the southwest along the White Volta River (WVR). The granite areas are generally of low, gently rolling relief ranging from 122 m to 260 m above sea level. The relief under Voltain rocks has similar characteristics to granites, with few escarpments rising above 518 m near the border with Togo in the east. The mean elevation for the region is 197 m above sea level (Liebe, 2002).

3.6 Vegetation

The UER belongs to the Guinea and Sudan Savannah Agro-Ecological Zones (AEZs). The Guinea Savannah covers large parts of the UER in the western half and southern part of the region, while the Sudan Savannah covers the north-eastern part. The natural vegetation in both zones is that of the savannah woodland characterized by short scattered drought-resistant trees and grass that gets burnt by bushfire or scorched by the sun during the long dry season. The natural vegetation has been modified by human activities resulting in near semi-arid conditions. The most common economic trees are the sheanut, dawadawa, boabab and acacia. Common grasses include *Andropogen gayyanus* in the less eroded areas and *Hyperrhenia spp.*, *Aristida spp.* and *Heteropogen spp.* in the severely eroded areas.

3.7 Drainage

The area is mainly drained by the WVR and its major tributaries, the Red Volta, the Sisili River, Atankwidi River and Tono River. The drainage basin of the WVR within the UER starts from northeast along the border with Burkina Faso draining all areas along Bawku East and West down south. On the edges of the Gambaga escarpment, the WVR drainage turns southwest, separating the UER from the Northern Region. In the west, the region is drained by the Sisili River, which joins the WVR in the southwest corner of the UER. Areas between Bongo and Zebilla on the western side of the WVR are drained by the Red Volta River, which joins the WVR on the edges of the Gambaga escarpment as the WVR turns southwest. The areas north of

Bolgatanga and large parts of Navrongo are drained by the Atankwidi sub-catchment, while the Tono sub-catchment drains areas northwest and west of Navrongo. All tributaries south of the WVR in the Gambaga escarpment drain southward away from the WVR (Liebe, 2002). Most of the subcatchments in the UER have developed inland valleys of different sizes and shapes. Small and medium-sized reservoirs have been constructed (Liebe, 2002) in these inland valleys to supply water for crop irrigation, livestock and domestic, fishery and other uses during the dry season.

3.8 Socio-economic activities

Agriculture, hunting and forestry are the main economic activities in the region. About eighty per cent of the economically active population engages in agriculture. The main produces are millet, guinea-corn, maize, groundnut, beans, sorghum and dry season tomatoes and onions. Livestock and poultry production are also important. Irrigation schemes in the area are vital for increasing food security and rural income by providing water for dry season farming, livestock and fishery. Industrial activity in the region is generally low, with two industries in operation at the moment. These are the newly built cotton ginnery at Pusu-Namongo (near Bolgatanga) and the Northern Star Tomato at Pwalugu. Other existing industries are the Meat Processing Factory (GIHOC) at Zuarungu and the Rice Mills at Bolgatanga.

3.9 Description of Tono and Vea Irrigation Projects

The Tono Irrigation Scheme is located at Navrongo in Kassena-Nankana District of the UER. The scheme was constructed between 1975 and 1985 by Taysec, a British engineering company and it's being managed by the Irrigation Company of Upper Region. The Tono project covers a gross area of 3,860 hectares with about 2,490 hectares developed for irrigation. The scheme consists of reservoir with a maximum surface area of 1860 hectares and a maximum storage volume of 93 Mm^3. The reservoir is filled by collecting runoff from a catchment area of about 650 km^2. The scheme has road networks and two main canals serving the right and left banks with a total length of about 120 km and 42 km respectively. The soils in the scheme have light top soils varying in texture from coarse sands to loams, and sub-soils varying from coarse sandy loams to clays with variable amounts of gravel (Boateng and Ayamga, 1992).

The Vea irrigation project is located at Vea in the Bongo District of UER. The project was started in 1965 and completed in 1980. It has a gross project area of 1,197 hectares with about 850 hectares developed for irrigation. The project has a reservoir with a maximum surface area of 405 hectares and maximum storage of 17 Mm^3. The maximum storage of the reservoir consists of live storage of 16 Mm^3 and dead storage of 1 Mm^3. The reservoir has a total crest length of 1,585 metres. The reservoir is built along the course of River Yaragatanga and it is also filled by collecting runoff from a catchment area of 136 km^2. The project has a network of roads and canals with a total length of the main road and main canal of about 18 km and 21 km respectively. The project is divided into upland and lowland. In the upland, tomato, onion, pepper, sorghum, millet, groundnut, etc, are cultivated using furrow system. Rice is cultivated using basin flooding in the lowland. The Vea irrigation project has fish ponds which covers about 3.2 hectares.

CHAPTER FOUR

4 MATERIALS AND METHODS

The following materials and methods were used for this study.

4.1 Site selection

There are more than one hundred and sixty small reservoirs used for irrigation in the Upper East region (van de Giesen et al. 2002). However the two medium reservoirs, Tono and Vea were selected for the study as shown in figure 3.1. These sites were selected based on the following criteria.

- Reservoirs that do not dry up during the dry season
- Availability of data necessary for the study

4.2 Data collection

Data were collected from both primary and secondary sources. Secondary data were historical meteorological data such as rainfall, temperature, relative humidity, wind speed, and sunshine hours for the study area collected from the Ghana Meteorological Agency regional office in Bolgatanga and used as the baseline data for climate.

The different types of crops under irrigation and areas of land cultivated each year were obtained from official records of Irrigation Company of Upper Region (ICOUR).

Relevant literature such as peer reviewed journals, text books were obtained through internet and library search. The CROPWAT and MAGICC (Model for Assessment of Greenhouse gas Induced Climate Change) models were downloaded from the internet.

The primary data were obtained by interviewing various stakeholders such as the project manager of ICOUR, regional director of Environmental Protection Agency (EPA), the basin officer of White Volta Basin (WVB) and the regional director of Ministry of Food and Agriculture (MoFA).

4.3 Assessing Current Irrigation demand

Historical irrigation patterns represent the current irrigation demand for predicting future conditions. Historical water abstractions from the Tono and Vea reservoirs could show how irrigation water use varies over the years. Historical water abstractions from Tono and Vea reservoirs were to be collected from ICOUR. However, there are no records of water abstractions from Tono and Vea reservoirs. Historical water abstractions were therefore estimated based on the crops cultivated, areas of land cultivated and the irrigation efficiency. Irrigation needs of four major crops (rice, tomato, pepper and onion) which are grown at Tono and Vea irrigation schemes were computed. These crops were selected because they are cash crops which are irrigated during the dry season. Water abstractions from the reservoirs are used for irrigating these crops during the dry season.

CROPWAT model by Food and Agriculture Organization (FAO) was used to estimate net crop irrigation water requirements (NIR). NIR is defined as the amount of water in addition to available soil moisture from precipitation that crop plants on irrigated land must receive to grow without water stress. The CROPWAT model used the equation below to compute NIR.

$$NIR = k_c \times ET_o - P_{eff} \quad (1)$$

where, NIR = net irrigation requirement [mm/d]; k_c = Crop coefficient [dimensionless], ET_o = potential evapotranspiration [mm/day]; P_{eff} = Effective precipitation [mm/month]

Crop coefficient, *kc* is a function of the crop type and the day of the growing season. P_{eff} is the fraction of the total precipitation, (*P*) that is available to the crop and does not run off.

Potential evapotranspiration, ET_o is calculated using FAO Penman-Monteith equation (Allen et al., 1998) below with parameters of temperature, relative humidity, sunshine hours, and wind speed.

$$ET_o = \frac{\Delta \frac{(R_n - G)}{\lambda_w} + \rho_a C_p \frac{(e_s - e_a)}{\lambda_w}}{\Delta + \gamma_a \left(1 + \frac{r_c}{r_a}\right)} \quad (2)$$

where: ET_o is potential evapotransipiration [mmd-1], R_n is the net radiation [$MJm^{-2}d^{-1}$], G is soil heat flux [$MJm^{-2}d^{-1}$], (e_s-e_a) represents the vapour pressure deficit of the air [kPa], ρ_a is the mean air density at constant pressure [kgm^{-3}], *cp* is the specific heat of the air [$MJkg^{-1}$ $°C^{-1}$], Δ represents the slope of the saturation vapour pressure-temperature relationship [$kPa°C^{-1}$], λ_w is the latent heat of vaporization [$MJkg^{-1}$], γ_a = psychrometric constant [$kPa°C^{-1}$], r_c is crop resistance [sm^{-1}], and r_a is aerodynamic resistance [sm^{-1}].

The CROPWAT model requires input data below to compute NIR.

- Climatic data – mean monthly maximum and minimum temperatures (°C), monthly rainfall (mm), relative humidity (%), sunshine duration (hours) and wind speed (m/s)
- Crop data – the crop type and planting date

The net irrigation requirement is computed using the climatic data for the period 1985 to 2006 and the present-day long-term average climatic conditions, 1977-2006 (baseline climate). Long term average irrigation requirement is also calculated.

The gross agricultural water withdrawal for irrigation, popularly known as gross irrigation requirements (GIR) is then estimated from NIR via an irrigation efficiency parameter (Irr_{eff}), an indirect proxy of irrigation water loss.

$$\text{GIR} = \frac{NIR}{Irr_{eff}} \qquad (3)$$

Volumetric irrigation demand which represent abstraction from the reservoirs is computed by multiplying the gross irrigation water withdrawals for irrigation with the areas of land under cultivation, A.

4.4 Climate change scenarios generation

Two well defined climate scenarios were used to create a set of future climatic conditions. In the first one, synthetic scenarios were developed by uniformly increasing or decreasing the historical data sets. Temperatures of the baseline were increased by 1°C, 1.5°C or 2°C and rainfall decreased by 10%, 15% or 20% of the base values. In the second method, the output of General Circulation Models was used. The method takes into account the consequences of anthropogenic interference with the climate system through the emission of Greenhouse Gases into the atmosphere and the cooling effect of anthropogenic sulphate aerosols on future global and regional temperature. A simple climate model known as MAGICC (Model for Assessment of Greenhouse gas Induced Climate Change) developed at the Climatic Research Centre (CRU) of the University of East Anglia (UEA) is used. MAGICC is a climate model that drives a spatial climate change scenario generator known as SCENGEN which allows user defined emission scenarios, choice of atmospheric sensitivity and choice of GCM results. This makes it possible to compare the global warming potential of different GCMs under the same greenhouse gas forcing specifications.

Model selection and validation

MAGICC has currently 20 models with full set of data required for use in SCENGEN. A standard method for selecting models is on the basis of their ability to accurately represent current climate, either for a particular region and/or for the globe. All the models in SCENGEN data base are ranked by the manufacturer's using annual precipitation as shown in appendix D. In choosing the appropriate models for this study, the first four ranked models (CCCMAS, MRI-2.3.2, ECHO-G and HadCM3) and model which has been used in similar studies (CSIRO) were selected and used to model mean monthly temperature and rainfall values of Navrongo for the period 2000 to 2005 using the climatic normal of 1961 – 1990. The modelled temperature and rainfall values of Navrongo by each model for the period 2000 to 2005 were plotted against the actual measured mean monthly temperature and rainfall for the same period. The graphs were critically analyzed to determine which models were close to true measured temperature and rainfall values for the period 2000 – 2005. The co-efficient of determination, R^2 of the graphs shown in appendix E were used to select the appropriate model which is close to measured mean monthly temperature and rainfall for the period 2000 – 2005. On the basis of the co-efficient of determination, R^2 two models – MRI-2.3.2 and ECHO-G were close to measured temperature and rainfall values for the period 2000-2005. MRI-2.3.2 A and ECHO-G were selected for this study.

Two outputs of GCMs, the MRI-232A (the Meteorological Research Institute of Japan model) and ECHO- G (the Hamburg Atmospheric-Ocean Coupled Circulation model) with atmospheric sensitivity of 3°C were used in the construction of the climate change scenarios. MAGICC parameter and aerosol effect were set at mid-range value. The greenhouse emission scenario known as A1FI was used (Nakicenovic et al, 2000). Temperature and rainfall changes were extracted from the MRI-232A and ECHO-G for the Upper East Region for the year 2020, 2050 and 2080. The changes in temperature and rainfall were applied to baseline climate (1977 -2006) to develop climate change scenarios. The observed monthly temperature and rainfall values of the baseline were scaled by climate change as computed by the two GCMs- MRI-232A and ECHO-G. In the case of temperature, the observed values of the baseline were scaled by adding to them the changes determined from the two models. With respect to rainfall, the observed values of the baseline were scaled by applying the percentage changes to them.

4.5 Future climatic conditions

The results from the climate change scenarios represent future climatic conditions for the Upper East Region. Temperature and rainfall values for the year 2020, 2050 and 2080 determined from the climate change scenarios.

4.6 Future Irrigation water demand

Future irrigation water demand were estimated based on future climatic conditions generated with the same procedure and formulae used for the current irrigation demand described above.

4.7 Climate change adaptation strategies.

Project manager of ICOUR, regional director of EPA, regional director of MOFA and the basin officer of White Volta Basin were interviewed to know potential climate adaptation measures that can be implemented in the region to cope with climate change. Adaptation strategies implemented in other countries were also reviewed to know those that can be implemented in the region.

CHAPTER FIVE

5 RESULTS AND DISCUSSION

5.1 Historical water abstraction baseline

The Tono and Vea reservoirs can store water of about 93 Mm^3 and 16 Mm^3 respectively. The reservoirs were constructed mainly for irrigation during the dry season; however the reservoirs now supply domestic water. The Vea reservoir supply domestic water to Bolgatanga Township while Tono reservoir supplies water to ICOUR Township 1 and 2 and some villages within its catchment. In 2008, about 1,454, 000 m^3 of domestic water was abstracted from Vea reservoir for Bolgatanga Township. However, there are no records on domestic water abstracted from Tono reservoir. The largest abstractions from the reservoirs are mainly for irrigation during the dry season while in the wet season supplementary irrigation is practiced. Water abstractions were estimated by considering the four major crops (rice, tomato, pepper and onion) which are grown during the dry season. Irrigation requirements for the four major crops cultivated during the dry season were computed using the climatic data for the period 1985 to 2006 and the areas of the land occupied by the crops and the irrigation efficiency. The Tono and Vea irrigation schemes were designed with an irrigation efficiency of 65%. However, the schemes have deteriorated due to poor maintenance and are now operating with an irrigation efficiency of about 40%. In the estimation of irrigation abstraction, an irrigation efficiency of 50% was chosen to be a representative of the efficiencies that the schemes operated from 1985 to 2006. Table 5.1 shows the quantity of water abstracted from Tono and Vea reservoirs for dry season irrigation from 1985 to 2006.

Table 5.1: Water abstraction from Tono and Vea reservoirs for dry season farming

Year	Irrigation abstraction (Mm^3)	
	Tono Reservoir	Vea Reservoir
1985 - 86	9.68	4.71
1986 - 87	13.96	6.91
1987 - 88	18.85	7.45
1988 - 89	19.72	2.51
1989 - 90	13.03	8.88
1990 - 91	11.86	4.65
1991 - 92	12.28	3.61
1992 - 93	14.72	2.71
1993 - 94	12.72	4.77
1994 - 95	18.02	2.54
1995 - 96	19.86	6.28
1996 - 97	23.40	4.83
1997 - 98	11.30	4.30
1998 - 99	23.58	5.32
1999 - 00	21.77	4.12
2000 - 01	27.67	4.60
2001 - 02	19.91	5.79
2002 - 03	19.83	5.74
2003 - 04	17.50	1.91
2004 - 05	21.40	1.82
2005- 06	9.66	2.39
Average	17.18	4.56

Abstractions ranged from 9.66 Mm^3 in 2005/2006 season to 27.67 Mm^3 in 2000/2001 season for Tono reservoir and 1.82 Mm^3 in 2004/2005 season to 8.88 Mm^3 in 1989/1990 season for Vea reservoir. The average quantity of water abstracted from Tono and Vea reservoirs for the cultivation of the four crops is 17.18 Mm^3 and 4.56 Mm^3 respectively.

The quantity of water abstracted from the reservoir during a season depends on the weather conditions and the area of land cultivated. If there are high temperatures during a particular season, more water is abstracted from the reservoir because evapotranspiration increases with high temperatures. The estimated abstractions from the reservoirs for the cultivation of the four crops as shown in Table 5.1 are far less than the maximum storage capacity of 93 Mm^3 and 16 Mm^3 for Tono and Vea respectively, provided enough water is stored during the wet season. It can be deduced from Table 5.1 that the stored water in the reservoirs were sufficient for irrigation of the four crops because the areas under cultivation shown in appendix C were less than the total irrigable area of Tono and Vea irrigation schemes of about 2490 hectares and 850 hectares respectively which the schemes were designed for. However, possible increase in irrigation water use as a result of climate change and extension of land under cultivation and increase in domestic water supply as a result of population growth might lead to the reservoirs not being able to supply the required water needed for irrigation if the planned irrigable areas are to be cultivated.

5.2 Current irrigation needs

The theoretical irrigation requirements of the four major crops were computed to serve as a baseline. The irrigation requirements were calculated based on planting dates of these crops determined by interviewing farmers and extension officers and the climatic conditions for the period 1985 to 2006. Table 5.2 provides details of the growing periods of the crops

Table 5.2: Growing periods of crops

Crop type	Growing period
Rice	November 5 –April 4
Tomato	October 20 – March 14
Pepper	October 20 – February 27
Onion	December 5- March 10

The other crop characteristics such as depletion factors, crop coefficients, and maximum root depth were taken from FAO Manual 56 (Allen, et al. 1998) which has been incorporated into the CROPWAT model. The model has a database[1] of these parameters which are long time averages for different crops. The Ministry of Food and Agriculture and Ghana Irrigation Development Authority also in the calculation of irrigation requirements adopt these crop characteristics from FAO manual 56. The irrigation requirements of pepper for the period 1985 to 2006 and long term average irrigation requirements, LTA, and temperature are shown in Figure 5.1

[1] The database contains crop coefficients which depend on crop height, albedo (reflectance) of the crop-soil surface, canopy resistance and evaporation from soil, especially exposed soil.

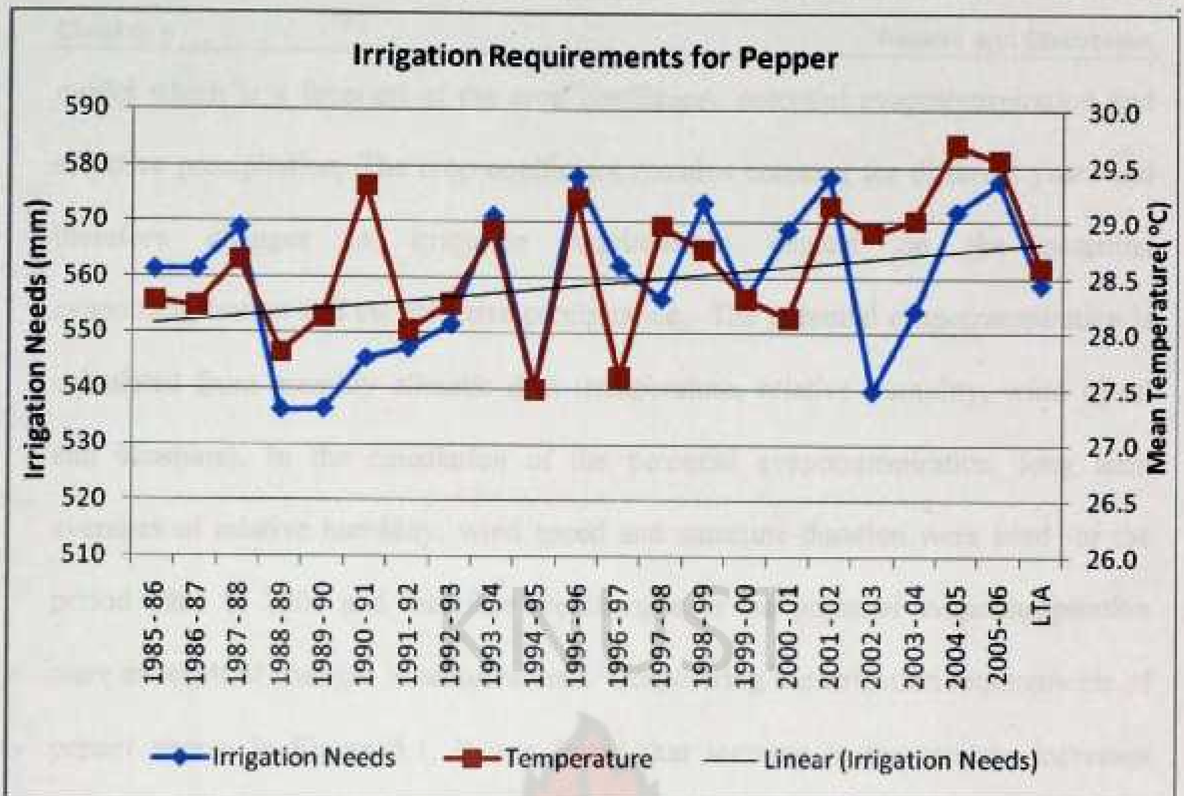

Figure 5.1: Irrigation requirements of pepper

The irrigation requirement of the crops between different years varies. The irrigation requirement of rice ranges from 823.2 mm/period to 905.5 mm/period with long time average (LTA) of 871.5mm/period. The irrigation requirement of tomato ranges from 657.2 mm/period to 702.9 mm/period with long time average of 680.1 mm/period and that of pepper ranges from 536.2 mm/period to 578.2 mm/period with long time average of 558.9 mm/period. The irrigation requirement of onion ranges from 417.7 mm/period to 457.4 mm/period with long time average of 441.8 mm/period.

The variations in irrigation requirements of pepper as seen in Figure 5.1 above and the other crops in appendix F between the various years indicate that irrigation requirements changes with climatic conditions. There seems to be an apparent increasing trend in the irrigation water requirements of pepper as can be observed from Figure 5.1. The irrigation requirements are calculated using the CROPWAT model which is a function of the crop coefficient, potential evapotranspiration and effective precipitation. The crop coefficient remains constant for different years and therefore changes in irrigation requirements depend on the potential evapotranspiration and the effective precipitation. The potential evapotranspiration is calculated from monthly climatic data (temperature, relative humidity, wind speed and sunshine). In the calculation of the potential evapotranspiration, long term averages of relative humidity, wind speed and sunshine duration were used for the period 1985 to 2006 and therefore the changes in the potential evapotranspiration were as result of changes in temperatures. Considering the irrigation requirements of pepper shown in Figure 5.1, it was found that increase in temperature increases evapotranspiration and therefore irrigation requirements. However, if it rained during the growing season, it tends to reduce the irrigation requirement. For instance, in the 1997- 98 growing season, higher temperature was recorded than the previous season (1996-97) and therefore the irrigation requirement should have been higher than the previous season. However, the irrigation requirement of pepper in that season was smaller than that the previous season because it rained during that period as can be seen in appendix A. Furthermore, in the 2002-2003 growing season, even though there was much higher temperature of about 36.5°C, the irrigation requirements was smaller because an appreciable rainfall of 105.5mm was recorded and can be seen in appendix A. From Figure 5.1, it can be concluded that variations in irrigation requirement of pepper is a function of variability in rainfall pattern, amount of rainfall and temperature changes. Similarly analyses were done for the remaining three crops; rice, tomato and onion as shown in appendix F and it was found that rainfall and temperature changes affected irrigation requirements. This gives an indication that future changes in temperature and rainfall will affect irrigation requirements.

The irrigation requirements of the crops were also computed based on 30-year average climatic conditions 1977 -2006 (baseline climate) shown in appendix B. Figure 5.2 shows comparison of irrigation requirements based on average climatic conditions (1977 – 2006) and averaging of irrigation requirements for the period 1985 to 2006. The long time average irrigation requirements calculated based on average climatic conditions 1977 -2006 (baseline climate) differs from the averaging of 22-year time series of irrigation requirements as shown in Figure 5.2.

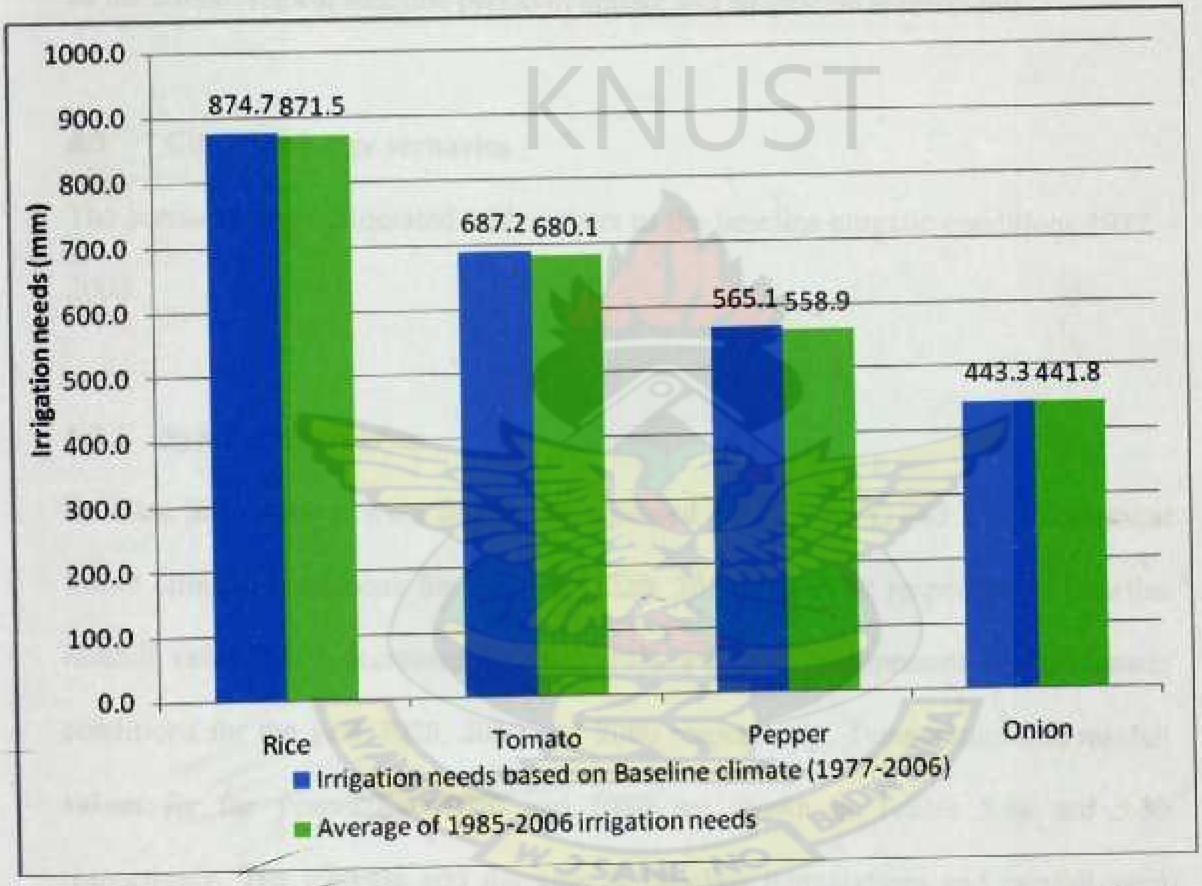

Figure 5.2: Comparison of Irrigation requirements of crops based average climatic conditions 1977 -2006 and the average of 1985 -2006 time series.

Averaging of 22-year time series of irrigation requirements leads to a more realistic estimate of the long-term average requirement than a calculation based on 30-year average climatic conditions. Irrigation requirements based on average climatic conditions may be underestimated because it is not linear with respect to precipitation and potential evapotranspiration. However, in this research the long term average irrigation based on average climatic conditions, 1977 – 2006 is adopted so that the future climatic conditions generated are applied to the baseline climate to determine future irrigation requirements. The present-day long term average climatic conditions, 1977-2006 (baseline climate) give a fair stable climatic condition. IPCC recommends that where possible the most recent 30-year climate 'normal' period should be adopted as the climatological baseline period in impact and adaptation assessments.

5.3 Climate change scenarios

The scenarios were generated with respect to the baseline climatic conditions 1977 – 2006.

5.3.1 Synthetic scenarios

Baseline temperatures were uniformly increased by 1°C, 1.5°C and 2°C to represent future climatic conditions for the year 2020, 2050 and 2080 respectively. Baseline rainfall values were decreased by 10%, 15% and 20% to represent future climatic conditions for the year 2020, 2050 and 2080 respectively. Temperature and rainfall values for the year 2020, 2050 and 2080 are shown in Tables 5.3a and 5.3b respectively. The increase and decrease in baseline temperatures and rainfall were selected based on previous studies done by other researchers such as Opoku-Ankomah and Minia, (2007) in the study area.

Table 5.3a: Maximum and minimum monthly temperatures for the year 2020, 2050 and 2080 based on synthetic scenarios

	Baseline		2020		2050		2080	
Months	Max. Temp. °C	Min. Temp. °C	Max. Temp. °C	Min. Temp. °C	Max. Temp. °C	Min. Temp. °C	Max. Temp. °C	Min. Temp. °C
January	35.4	20.3	36.4	21.3	36.9	21.8	37.4	22.3
February	36.5	22.4	37.5	23.4	38.0	23.9	38.5	24.4
March	39.5	25.5	40.5	26.5	41.0	27.0	41.5	27.5
April	38.9	26.7	39.9	27.7	40.4	28.2	40.9	28.7
May	36.4	25.5	37.4	26.5	37.9	27.0	38.4	27.5
June	33.3	23.8	34.3	24.8	34.8	25.3	35.3	25.8
July	31.4	22.9	32.4	23.9	32.9	24.4	33.4	24.9
August	30.7	22.7	31.7	23.7	32.2	24.2	32.7	24.7
September	30.7	21.9	31.7	22.9	32.2	23.4	32.7	23.9
October	34.6	22.5	35.6	23.5	36.1	24.0	36.6	24.5
November	36.9	20.5	37.9	21.5	38.4	22.0	38.9	22.5
December	35.7	19.4	36.7	20.4	37.2	20.9	37.7	21.4

Table 5.3b: Monthly rainfall/mm for the year 2020, 2050 and 2080 based on synthetic scenarios

	Rainfall/ mm			
Months	**Baseline**	**2020**	**2050**	**2080**
January	0.0	0.0	0.0	0.0
February	1.1	1.0	1.0	0.9
March	13.8	12.4	11.7	11.0
April	48.6	43.7	41.3	38.8
May	100.0	90.0	85.0	80.0
June	137.7	123.9	117.0	110.1
July	181.3	163.2	154.1	145.0
August	268.0	241.2	227.8	214.4
September	159.3	143.4	135.4	127.5
October	48.1	43.3	40.9	38.5
November	2.7	2.5	2.3	2.2
December	2.2	2.0	1.9	1.8

EPA (2000) predicted that maximum and minimum temperature for Navrongo in UER for 2020 will increase by 0.9°C and 1.0°C respectively. Opoku-Ankomah and Minia (2007) based on scenarios indicated that by the year 2050 annual mean temperature could rise by 2°C while annual rainfall amounts decrease by over 12%. Temperature for Northern Ghana for the period 2020-2030 will increase by 0.5 to

1.0°C and 1.5 to 2°C depending on low and high scenario respectively as defined by Halsnaes, (2008). The other climatic parameters such as relative humidity, wind speed and sunshine duration were held constant. Long term average changes of temperature and rainfall show climate change as defined by Doll (2002) in her studies, which says climate change is changes in the long-term averages of precipitation and temperature only. Such climatic conditions are possible in the future based on global warming with the resultant increase in mean temperatures.

5.3.2 GCMs scenario

The outputs of the GCMs, MRI-232A and ECHO-G generated temperature and rainfall figures for Upper East Region, which is located within MAGICC/SCENGEN square degrees (10°N–12°5'N and 2°5'W– 0°) for the year 2020, 2050 and 2080. Monthly temperature and rainfall predictions for Upper East Region for the future (2020, 2050 and 2080) based on the MRI-232A and ECHO-G are shown in Figures 5.3a, 5.3b, 5.3c and 5.3d

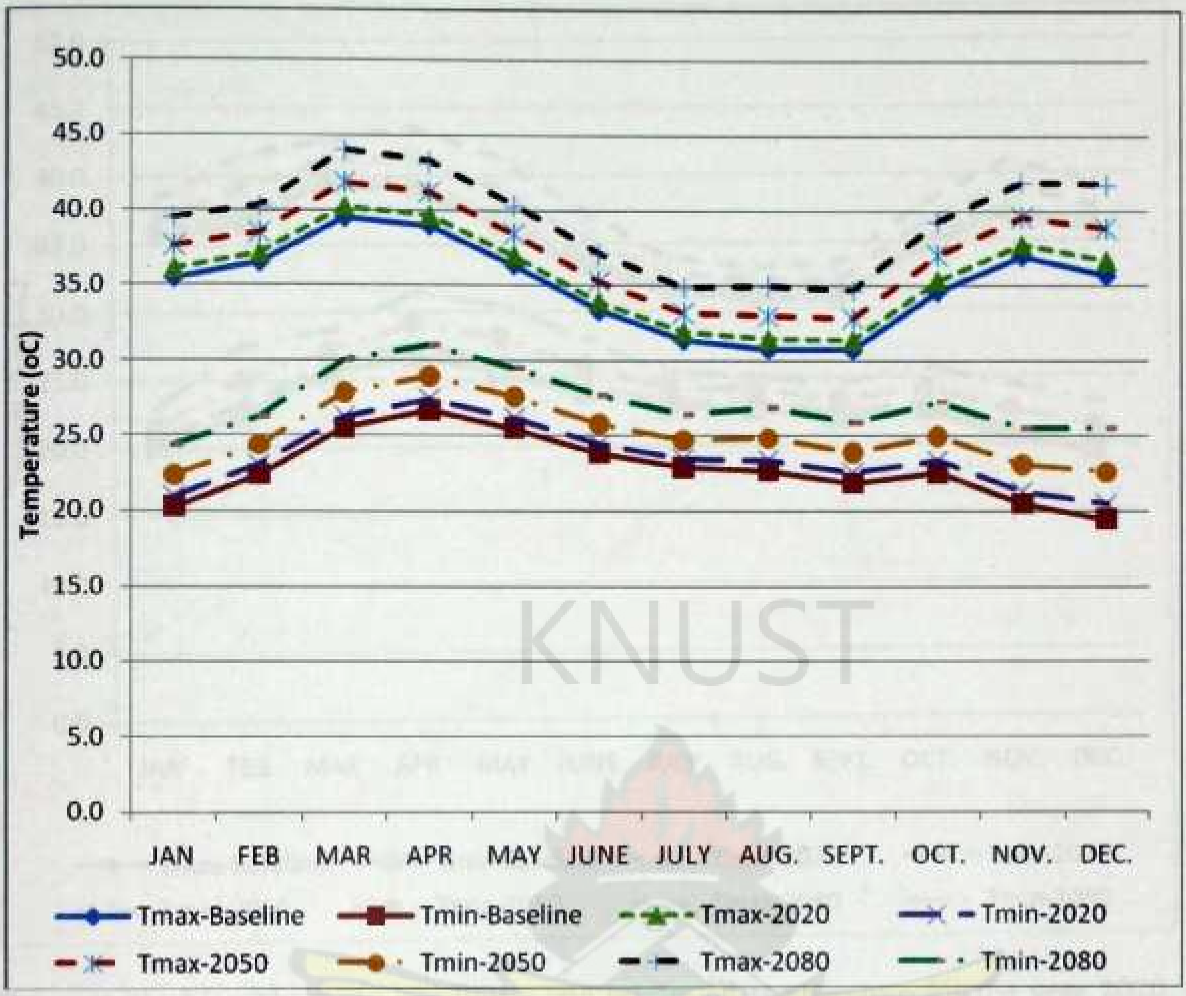

Figure 5.3a: Monthly mean maximum and minimum temperature for the year 2020, 2050 and 2080 based on MRI-232A model

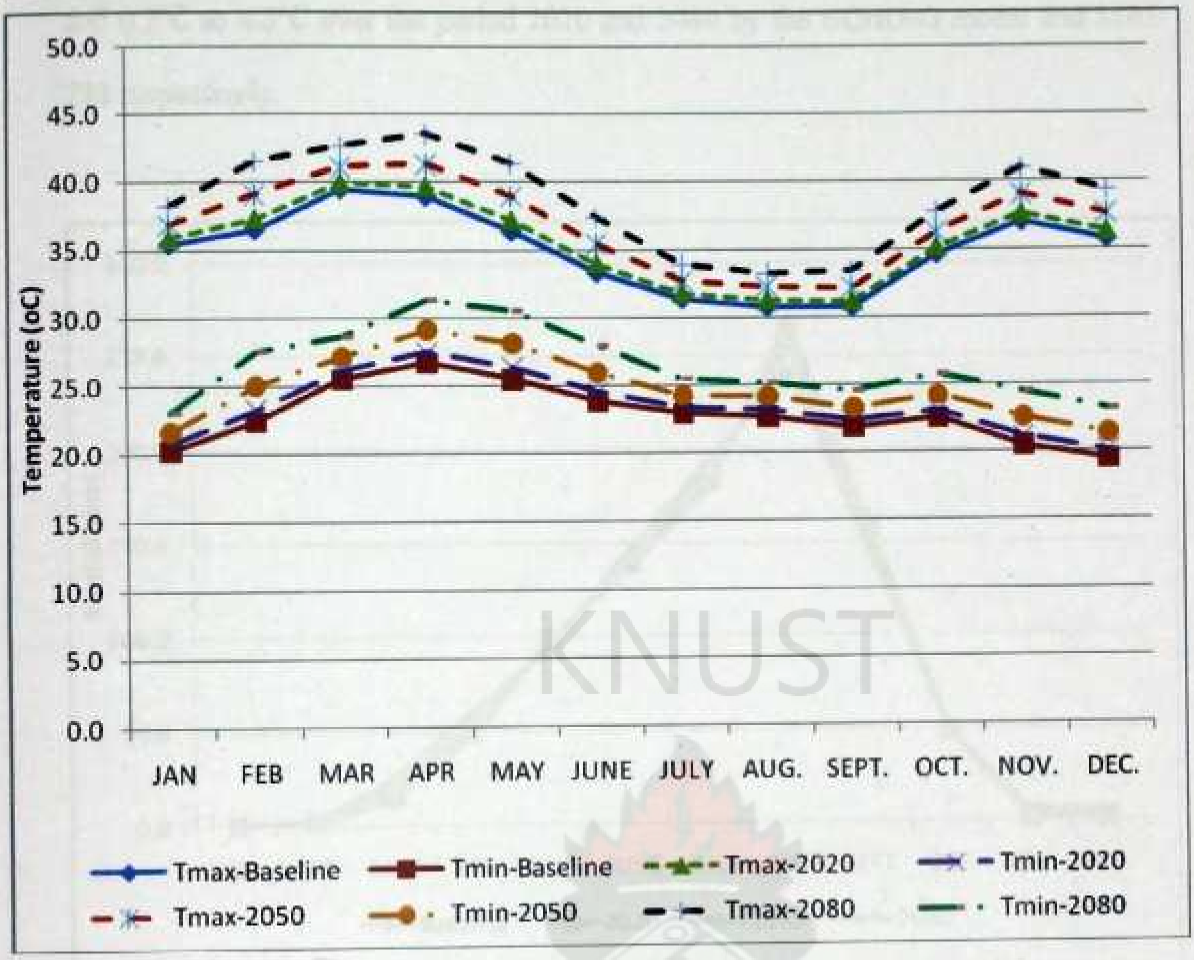

Figure 5.3b: Monthly mean maximum and minimum temperature for the year 2020, 2050 and 2080 based on ECHO-G model.

Projected monthly mean maximum and minimum temperatures of 2020, 2050 and 2080 based on MRI-232A and ECHO-G as shown in Figures 5.3a and 5.3b are higher than the baseline temperatures. Comparison of predicted temperatures by the two models, MRI-232A and ECHO-G, however indicate that temperatures generated by MRI-232A in the months of July to January for years 2020, 2050 and 2080 are slightly higher than ECHO-G by 0.5% to 6%. This agrees with a study conducted in Australia by Green, (2008) on climate change projection methods using the MRI-232A and ECHO-G models, which revealed that MRI-232A model predicted much higher temperature values than the ECHO-G model as shown as in appendix G. Monthly temperature is projected to increase on the average by about 0.6°C to 3.6°C and 0.7°C to 4.3°C over the period 2020 and 2080 by the ECHO-G model and MRI-232 respectively.

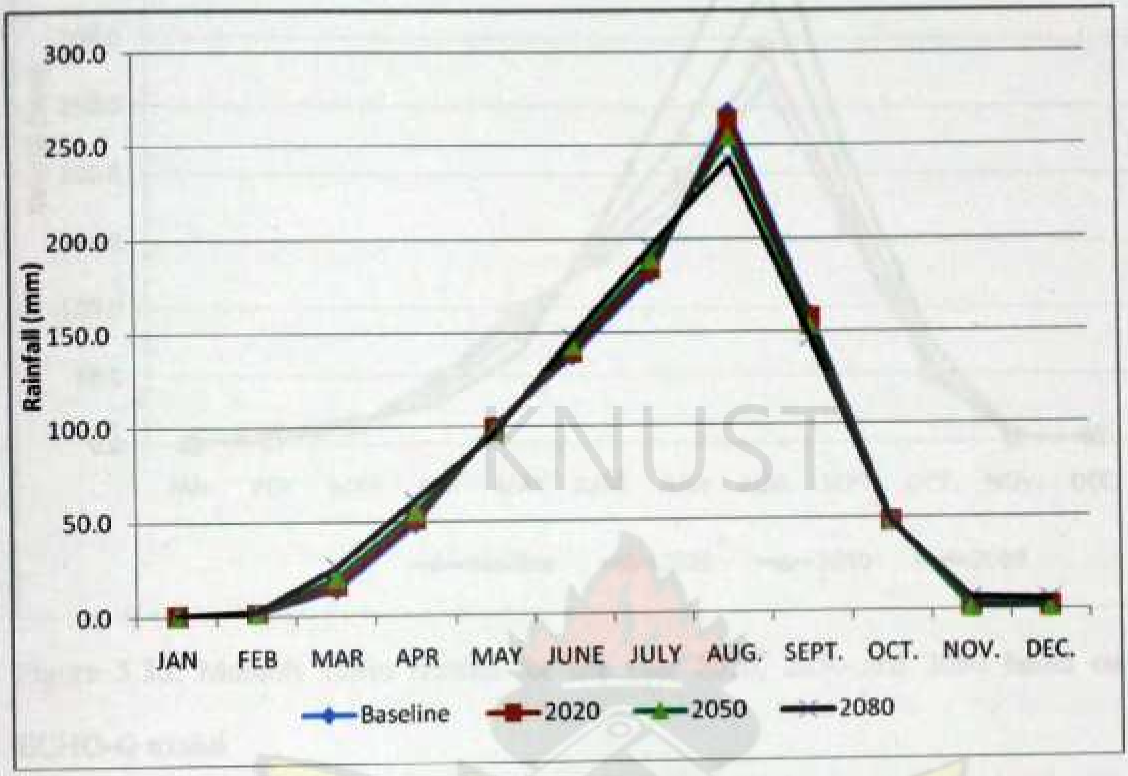

Figure 5.3c: Monthly rainfall for the year 2020, 2050 and 2080 based on MRI-232A model

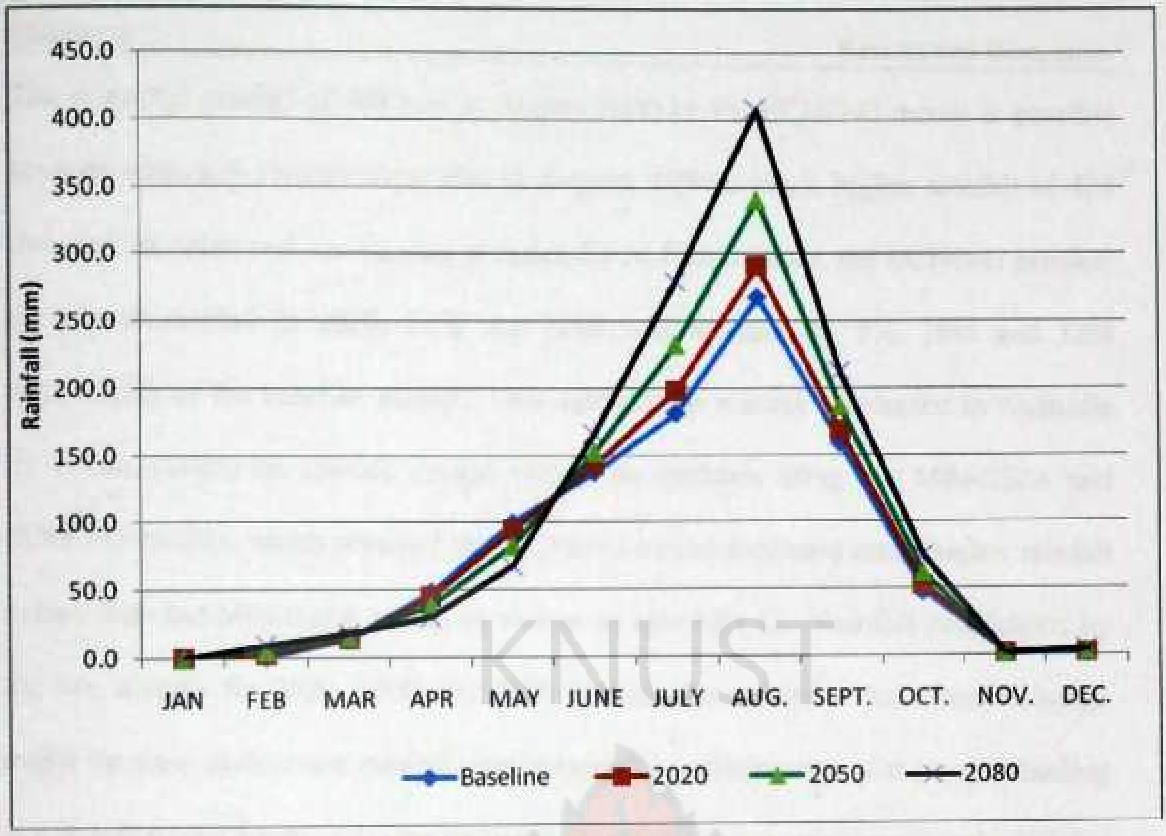

Figure 5.3d: Monthly mean rainfall for the year 2020, 2050 and 2080 based on ECHO-G model

Comparison between the baseline and MRI-232A model shows that rainfall increase from June to July and decreases from August to October for the years 2020, 2050 and 2080. The rainfall prediction by MRI-232A for the years 2020, 2050 and 2080 does not show clear variation from the baseline rainfall and it means that baseline rainfall may occur in the future. The MRI-232A predicts the annual rainfall in 2080 will increase by about 1.18% of the baseline rainfall while annual rainfall in 2020 and 2050 will decrease by 0.02% and 0.05% respectively of the baseline. The ECHO-G model predicts that rains from June to November for 2020, 2050 and 2080 would be higher than the baseline as shown in Figure 5.3d. Comparison of predicted rainfall by the two models, MRI-232A and ECHO-G, indicate that in August when the highest rains are recorded, the ECHO-G prediction is about 130 mm higher than MRI-232A.

The projected rainfall of 408 mm in August 2080 by the ECHO-G model is possible because historical records show that in August, 1994 a much higher rainfall of 428 mm was recorded and can be seen in appendix A. Furthermore, the ECHO-G predicts the annual rainfall in 2020, 2050 and 2080 will increase by 5%, 16% and 32% respectively of the baseline rainfall. This agrees with a study conducted in Australia by Green, (2008) on climate change projection methods using the MRI-232A and ECHO-G models, which revealed that ECHO-G model predicted much higher rainfall values than the MRI-232A model as shown in appendix G. Rainfall predictions by the two models for 2020, 2050 and 2080 buttress the assertion that climate change might increase or decrease rainfall (precipitation) in certain parts of the world leading to either extreme floods or severe droughts. Rainfall is one particular climatic variable which is very difficult to predict. It is reported that climate in semi-arid regions will become more variable in the years ahead and that rainfall amounts in these areas will keep on declining thus creating more hardships for the inhabitants of this region (Obeng, 2005). This assertion that rainfall will keep on declining in the Upper East Region should be critically looked into as it has been shown that rainfall could increase or decrease as predicted by the models. In so far as rainfall is predicted to increase in certain months, only the rains during the growing period of the crops have influence on their irrigation requirements. Historical trends of rainfall in the study area show that there have been years of good rains and years of poor rains. The models also predict that there will be years when the rainfall in certain months will be higher or lower than the baseline.

5.4 Future irrigation needs

The irrigation needs of the four major crops (rice, tomato, pepper and onion) were computed based on future climatic conditions predicted by both the synthetic scenarios and the GCMs scenarios. Table 5.4a show the irrigation needs of the four crops for the baseline, synthetic scenarios and GCMs (MRI-232A and ECHO-G) for the year 2020, 2050 and 2080. The result in Table 5.4a shows that variations in temperature and rainfall in the future have effect on net irrigation water requirements and thus climate change. The irrigation needs of all the four crops for the years 2020, 2050 and 2080 are higher than the baseline. The climate conditions of the 2020, 2050 and 2080 differ from those under baseline climate, and these changes lead to different values of net irrigation water requirements of the four major crops cultivated in the study area. The growing season of the crops as determined from the farmers and the extension officers for the baseline shown in Table 5.2 were also used to compute the irrigation requirements for the future case scenarios of 2020, 2050 and 2080. Table 5.4b shows the percentage changes of net irrigation water requirements relative to the baseline. Clearly, it is seen that changes in temperature and rainfall as a result of climate change will increase irrigation water requirements.

Comparison of percentage changes of irrigation needs of all the crops shows that rice has the least percentage change in all the climate change scenarios but does not necessarily mean that rice will be the least affected by climate change. Based on synthetic scenarios, rice will be the most affected by climate change because its irrigation requirement will increase by 11.8mm/period, 20.8mm/period and 29.8mm/period for the period 2020, 2050 and 2080 respectively as shown in Table 5.4a when compared to the other crops. However, based on the GCM scenario (MRI-

232A), tomato will be the most affected by climate change because the increases of its irrigation requirements are 7.7mm/period, 22.7mm/period and 57.5mm/period for the 2020, 2050 and 2080. The irrigation needs of rice will increase by about 0.9%, 1.99% and 4.73% for the period 2020, 2050 and 2080 respectively based on average of all the three climate change scenarios considered. Based on average results of the synthetic scenarios and GCMs scenarios, the irrigation needs of tomato will increase about 1.21%, 2.87% and 5.60% respectively for the period of 2020, 2050 and 2080 respectively. The MRI-232A model furthers shows that irrigation needs of tomato will increase to about 8.34% in 2080. Onion and Pepper which have the least irrigation needs in the baseline have larger percentage changes in irrigation needs than rice for the years 2020, 2050 and 2080. The irrigation needs of onion will increase by about 1.5%, 3.16% and 6.40% for the years 2020, 2050 and 2080 respectively based on the average of the synthetic scenarios and the GCMs scenarios. The irrigation needs of pepper will increase by about 1.14%, 3.23% and 6.14% on the average of the climate change scenarios for the years 2020, 2050 and 2080. Irrigation needs of pepper for the 2080s based on the MRI-232A will increase to about 9.03%. Even though, the percentage changes in irrigation requirements of pepper and onion are higher than rice and tomato, the actual increases in their irrigation requirements are less than rice and tomato. In general, in these simulations the higher temperature and altered rainfall regimes impacted on net irrigation water requirements by affecting crop evapotranspiration and thus crop water demand.

The net irrigation water requirements of the four crops will increase by about 0.6 – 9% due to climate change depending on the climate change scenarios and time slices

Table 5.4a Impacts of climate change on net irrigation water requirements of crops, (mm/period) in 2020, 2050 and 2080 climate scenarios

Crops	Baseline	2020			2050			2080		
		Synthetic 1	MRI-232A	ECHO-G	Synthetic 2	MRI-232A	ECHO-G	Synthetic 3	MRI-232A	ECHO-G
Rice	880.4	892.2	887.3	886	901.2	896.5	896.2	910.2	937.8	927.3
Tomato	689.4	700.8	697.1	695.4	707.8	712.1	707.8	714.7	746.9	729.5
Pepper	567.3	576.3	573.3	571.6	582.1	588.4	585.1	587.9	618.5	604.4
Onion	443.3	451.6	449.8	448.8	456.0	459.9	457.1	460.2	480.4	471.1

Table 5.4b: Percentage changes (%) in net irrigation water requirements of crops between climate scenarios

Crops	Baseline	2020			2050			2080		
		Synthetic 1	MRI-232A	ECHO-G	Synthetic 2	MRI-232A	ECHO-G	Synthetic 3	MRI-232A	ECHO-G
Rice	0.0	1.34	0.78	0.64	2.36	1.83	1.79	3.38	6.52	5.33
Tomato	0.0	1.65	1.11	0.87	2.66	3.29	2.67	3.67	8.34	5.81
Pepper	0.0	1.60	1.06	0.77	2.61	3.73	3.14	3.63	9.03	6.55
Onion	0.0	1.87	1.46	1.24	2.85	3.74	3.11	3.81	8.36	6.27

5.5 Future irrigation abstraction scenarios

Future abstractions from Tono and Vea reservoirs for the cultivation of the four major crops (rice, tomato, pepper and onion) during the dry season were also estimated based on future climatic conditions generated by the climate change scenarios. The future climatic conditions generated by the climate change scenarios make it possible to compare how abstractions from the reservoirs would be affected by climate change. In the estimation of future water abstraction from the reservoirs, two scenarios were considered. For the first scenario, the maximum land areas used for the cultivation of the four crops over the period 1985 to 2006 were selected as the areas that could be irrigated in the future (2020, 2050 and 2080). In the second scenario, the total irrigable area of Tono and Vea irrigation projects of about 2490 ha and 850 ha respectively were considered to be irrigated in the future. For this scenario, each of the four crops was assumed to be cultivated on the total irrigable area. The irrigation efficiency for the future was assumed to be the same as the baseline period (50%). For the calculation of climate change impacts, irrigated land extents were kept the same for the years 2020, 2050 and 2080 with climatic conditions being the only determining factors. Table 5.5 show details of land areas that could be irrigated in the future based on the first scenario above (i.e. using maximum land areas cultivated between 1985 and 2006).

Table 5.5: Areas under cultivation in the future based on maximum land areas cultivated between 1985 and 2006

	Irrigable areas (hectares)	
Crops	Tono scheme	Vea scheme
Rice	1090	280
Tomato	805	314
Pepper	23	5
Onion	56	10
Total	1974	609

The total areas that would be used for the cultivation of the four crops in future based on the maximum land areas cultivated between 1985 and 2006 fall within the total irrigable areas of Tono and Vea irrigation projects of about 2490 ha and 850 ha respectively. The table below shows details of future irrigation abstractions from Tono and Vea reservoirs for dry season farming when the maximum land areas cultivated between 1985 and 2006 were considered to be cultivated in future.

Table 5.6: Future irrigation abstractions (Mm^3) from Tono and Vea reservoirs when maximum land areas between 1985 and 2006 are cultivated

Climate change scenarios	Irrigation abstraction (Mm^3)					
	Tono reservoir			Vea reservoir		
	2020	2050	2080	2020	2050	2080
Synthetic	31.50	31.82	32.13	9.55	9.64	9.74
MRI-232A	31.33	31.79	33.29	9.49	9.64	10.10
ECHO-G	31.28	31.71	32.77	9.48	9.61	9.93
Average	31.37	31.78	32.73	9.50	9.63	9.92
% of Reservoir Storage Capacity	33.73	34.17	35.19	59.41	60.20	62.01

The maximum water ever abstracted from the Tono and Vea reservoirs for the cultivation of the four major crops are 27.67 Mm^3 and 8.88 Mm^3 respectively as estimated in Table 5.1. Future irrigation abstractions would be higher than the historical abstractions based on the synthetic, MRI-232A and ECHO-G climate change scenarios. Comparison of future irrigation abstractions when maximum land areas cultivated between 1985 and 2006 were considered to the maximum storage capacity of Tono and Vea reservoirs suggest that future abstractions would be about 33 – 35 % and 59 – 62 % respectively of the reservoirs maximum storage capacities. The reservoirs presently are used to supply domestic water and the quantities abstracted for domestic use might increase in the future as result of population growth. It was found out that the present (2008) domestic water abstracted from Tono reservoir is negligible because the villages served have a total population of less than 500. The possible increase in domestic abstraction from Tono reservoir will be negligible. It can be deduced that the impacts of climate change will not be felt (significantly) on Tono irrigation project because the future irrigation abstractions due to climate change is only 33 - 35% of the maximum storage capacity. The situation at Vea irrigation project is a bit gloomy because the present (2008) annual domestic water abstraction of 1,454,000 m^3 is about 9.1% of the maximum storage volume (16 Mm^3). The present domestic water abstraction serves a population of about 49,162. Assuming annual population growth rate of about 2.5% (same as national population growth rate), the domestic abstraction will increase to about 1,907,780 m^3, 4,001,679 m^3 and 8,393,817 m^3 for the years 2020, 2050 and 2080 respectively. The domestic abstraction for these years 2020, 2050 and 2080 is about 11.9%, 25% and 52% respectively of the maximum storage of 16 Mm^3. Comparison of future irrigation abstraction of about 59 to 62% of the maximum storage volume to future domestic water abstraction shows that in 2020, climate change will not have any significant impact on Vea reservoir because both irrigation and domestic abstractions put together will be about 71% of the maximum storage volume. However, in 2050, both irrigation and domestic abstractions will be over 85% of the maximum storage volume. The remaining percentage may not be sufficient for livestock watering and for the fish ponds. Interactions with the staff revealed that in allocating water, priority is given to domestic uses, livestock watering before irrigation of crops. Interaction with the staff of the project also revealed that in drought years (i.e. years of insufficiency of rain for extended period resulting in a considerable hydrologic imbalance and, consequently water shortages, crop damage, stream flow reduction and depletion of ground water and soil moisture) the stored water in the reservoir is not adequate for domestic water supply, animal watering and irrigation. In such years, for instance in 1995, the irrigable areas were reduced. Future irrigation abstractions shown in Table 5.6 above when maximum land areas between 1985 and 2000 are considered, shows that climate change will increase future irrigation abstraction by 3%. Even though, climate change will have a minimal impact on Vea reservoir, coupled with an increase in domestic abstraction, the stored water in the reservoir may not be adequate for both irrigation (when maximum land areas between 1985 and 2006 are cultivated in the future) and domestic use for 2050 and beyond.

In the second scenario, the total irrigable areas were considered to be cultivated in the future and Tables 5.7 and 5.8 present the future abstraction of the four crops based on the average of the climate scenarios (synthetic and MRI-232A and ECHO-G).

Table 5.7a: Future irrigation abstraction from Tono reservoir when the total irrigable area is cultivated

Crops	Irrigation abstraction (Mm^3)		
	2020	2050	2080
Rice	44.43 (47.78)	44.88 (48.26)	46.70 (50.22)
Tomato	34.90 (37.53)	35.46 (38.13)	37.20 (40.00)
Pepper	28.70 (30.86)	29.30 (31.51)	30.80 (33.12)
Onion	22.49 (24.18)	22.90 (24.63)	23.92 (25.72)

Future irrigation abstraction from Tono reservoir when, for instance, the total irrigable area is cultivated with rice will be about 44.43 Mm^3, 44.88 Mm^3 and 46.70 Mm^3 for the years 2020, 2050 and 2080 respectively. This will translate into 47.78%, 48.26% and 50.22% (the figures in the bracket in table 5.7a above) of the reservoir maximum storage capacity for the same period (2020, 2050 and 2080). It can be deduced therefore that climate change will not have an impact on Tono reservoir because future increases in irrigation abstractions as result of climate change is about 47.78% to 50.22% of the storage capacity when rice which is water demanding crop is cultivated. The cultivation of the remaining crops on the total irrigable area will also not have any significant impact on Tono reservoir provided the reservoir store enough water during the rainy season. The Tono reservoir could be utilised to its maximum benefit by cultivating the total irrigable area and considering other water demanding crops such as water melon which has ready market.

Table 5.7b: Future irrigation abstractions (Mm^3) from Vea reservoir when the total irrigable area is cultivated

Crops	Irrigation abstraction (Mm^3)		
	2020	2050	2080
Rice	15.17 (94.80)	15.32 (95.75)	15.94 (99.64)
Tomato	11.91 (74.46)	12.03 (75.20)	12.70 (79.36)
Pepper	9.80 (61.23)	10.00 (62.52)	10.51 (65.72)
Onion	7.68 (47.98)	7.82 (48.86)	8.17 (51.04)

Table 5.7b provides details of future irrigation abstraction from Vea reservoir when the total irrigable area is cultivated with rice, tomato, pepper and onion and the percentages of the abstraction to the reservoir maximum capacity (the figures in brackets). It can be deduced from Table 5.7b that the Vea reservoir cannot supply enough water for the cultivation of rice because abstractions for cultivation of rice without considering domestic abstraction is about 94.80%, 95.75% and 99.64% of the maximum storage capacity for the periods 2020, 2050 and 2080 respectively. However, the reservoir can support the cultivation of tomato, pepper and onion when the total area is cultivated in 2020. In 2050, the reservoir could supply enough water for the cultivation of pepper and onion. Domestic abstraction from Vea reservoir in

2080 is about 52% of the maximum storage capacity and therefore, the reservoir cannot supply water for the cultivation of the crops on the total irrigable area which will make use of 99.64%, 79.36%, 65.72% and 51.04% of the maximum storage capacity for the cultivation of rice, tomato, pepper and onion respectively. Tono and Vea irrigation projects are being managed by the Irrigation Company of Upper Regions (ICOUR) and therefore could consider cultivating less water demanding crops at Vea and shift more water demanding crops to Tono where there is abundance of water.

5.6 Climate change adaptation measures

Adaptation to climate change is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). There are two main types of adaptations namely autonomous adaptation and planned adaptation.

Autonomous adaptation is adaptation that does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems or by changes in the socio-economic conditions specific to anthropogenic systems, without any intervention.

Planned adaptation measures are conscious policy options or response strategies, often multi-sectoral in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptations.

The results obtained show clear evidence that climate change will affect agriculture as it increases irrigation water demand and therefore necessitating appropriate measures to minimize the impacts. Article 4.1b of The United Nations Framework Convention on Climate Change (UNFCCC) provides that all Parties must formulate and implement national or regional programmes containing measures to facilitate adequate adaptation to climate change. Ghana, being a signatory to UNFCCC should have the appropriate policies and programmes to address climate change. In view of this, stakeholders such as EPA, MoFA, GIDA, ICOUR, WVR basin officer and extension officers were interviewed to identify and suggest potential measures to deal with climate change in Upper East region of Ghana.

At the moment, there is no well defined policy on climate change adaptation strategies. It was realized that farmers over the years have devised means of adjusting to droughts and sometimes flood conditions due to variations in climatic conditions. Through field interviews, it came out that farmers resorted to mulching and the cultivation of short duration leafy vegetables as a means of withstanding drought years. In extreme situations farmers cultivate on river beds or dig ditches on these river beds where water is abstracted for irrigation and other domestic purposes as a means of adapting to hash climatic conditions.

Mindful of the fact that people can only adapt to climate change if they know the activities that cause it, it is imperative that adaptation measures include activities such as the provision of information on climate change and potential impacts that may improve general awareness or prompt consideration of adaptation. Based on this, a number of adaptation measures are suggested, and covered the areas of agro-biodiversity, soil and land management, water management, change in timing of farm operations, agro-forestry, government agricultural subsidy and support.

Agro-biodiversity

The development of new crop varieties including types, cultivars and hybrids, has the potential to provide crop choices better suited to temperature, moisture and other conditions associated with climate change. The country's research institutions such as Crop Research Institute are involved in the development of plant varieties that are more tolerant to such climatic conditions as heat or drought. Farmers should be advised to select crop varieties that are tolerant to adverse climatic condition. FAO promotes use of indigenous and locally-adapted plants and animals as well as the selection and multiplication of crop varieties and autochthonous races adapted or resistant to adverse conditions. In Tono irrigation projects, farmers are advised on the selection of crop varieties.

Soil and land management

Climate change adaptation for agricultural cropping systems in Upper East region requires a higher resilience against both excess of water due to high intensity rainfall and lack of water due to extended drought periods. Both problems occur in the region and they might increase in the future because of climate change. A key element to respond to both problems is the application of organic matter. Organic matter improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil during extended drought. However, farmers prefer to use inorganic fertilizer to organic manure because it readily releases the nutrients. Farmers should be encouraged to apply organic matter fortified with inorganic fertilizer to reduce the impact of climate change.

Cover crops such as alfalfa should be planted on bare soils. Maintenance of permanent soil cover can also increase soil organic matter and reduce impacts from flooding, erosion, drought, heavy rain and winds. Surface mulch cover protects soil from excess temperatures and evaporation losses and can reduce crop water requirements by 30 percent. Farmers should be encouraged to practice mulching.

Water management

Good water management practices and technologies could spread and buffer production risks associated with climate change. A greater percentage of water abstracted for irrigation does not get to crops because of losses in the system. During field visits, it was observed that the furrows were poorly constructed and as such a lot of water is wasted. Some farmers construct unnecessarily big furrows with the intention of abstracting much water to their farms. Irrigation practices in the region should be improved by educating farmers on how to construct furrows and ways of determining if they have irrigated to field capacity. The irrigation systems should be maintained in order to reduce losses. Efficient irrigation systems such as drip and micro-spray techniques should be introduced in drought-prone areas to make efficient use of limited water available for irrigation. In Tono irrigation project, drip irrigation is being piloted. Water harvesting methods such as runoff or rainwater harvesting can be introduced to store enough water during wet season for use during dry periods. Presently, the farmers get to irrigate their crops every two or three days. Some farmers think that they would not get the water in the next two or three days and therefore tend to over irrigate their crops. This existing irrigation scheduling should be altered to one that fosters an increase in moisture retention in the face of decreasing rainfall and increasing evaporation (EPA, 2000). This will prevent farmers from over irrigating leading to the incidence of salinization.

Changing the timing of operations

Changing the timing of operations involves production decisions, such as planting, spraying and harvesting, to take advantage of the changing duration of growing seasons and associated changes in temperature and moisture. This type of adaptation includes the scheduling of crops, irrigation, harvesting, mulches, planting, seeding and tillage.

Changing the timing of these farm practices has the potential to maximize farm productivity during the growing season and to avoid heat stresses and moisture deficiencies.

Agro-forestry

While agriculture stands to be greatly affected by projected climate change, it also is, and has been historically, a major source of greenhouse gases to the atmosphere, thus itself contributing to climate change. At present, agriculture and associated land use changes emit about a quarter of the carbon dioxide (through deforestation and soil organic carbon depletion, machine and fertilizer use), half of the methane (via livestock and rice cultivation), and three-fourths of the nitrous oxide (through fertilizer applications and manure management) annually released into the atmosphere by human activities (Rosenzweig and Tubiello, 2007)

Planting of trees and modifying current management of agricultural systems by farmers could therefore greatly help to mitigate global anthropogenic emissions. Trees absorb atmospheric carbon dioxide (carbon sequestration) and therefore farmers should be encouraged to plant more trees. The White Volta basin through a project called PAGEV (Project for Improving Water Governance in the Volta Basin) helped farmers to plant trees along the banks of White Volta River and this should be supported and replicated throughout the Basin and its associated river systems in order to help improve soil moisture conditions as well as sequester carbon dioxide released through agricultural activities.

Government programmes and insurance

It is necessary that government through it ministries and agencies promote the adoption of adaptation measures through dissemination of information on climate change, possible impacts and vulnerabilities, potential adaptation options, among others.

A visit to the Environmental Protection Agency in Bolgatanga revealed that the agency through durbars and foras educates the public on the effects of bush fires and vegetation removal as well as the need to protect the environment as a means of minimizing the possibility of climate change. This however needs to be further strengthened and supported by other governmental and non-governmental agencies so that awareness can reach every section of the potential stress zones.

Government can provide agricultural subsidies and support to farmers to decrease the risk of climate-related income loss as a support to the economic risks associated with climate change. Government can help farmers to adapt to climate change through the development of information systems capable of forecasting weather and climate conditions associated with climate change. Weather predictions over days or weeks have relevance to the timing of operations such as planting, spraying or harvesting.

These measures if implemented and subsequently adapted by farmers would help them deal with the threats of climate change and its associated problems.

5.7 Limitations of the study

The assumptions and limitations surrounding this study are enumerated below to give further clarification to the results.

5.7.1 GCMs model limitations

Simulation models investigate complex interactions and feedbacks of many variables. As a consequence there are several limitations and uncertainties and apply to the results presented. The GCMs climate scenarios employ grids of 2.5^0 latitude by 2.5^0 longitudes. Due to the low spatial resolution of GCMs, many smaller-scale elements of climate are not properly represented. Precipitation, in particular, is poorly represented both spatially and temporally in GCMs results. Future climate for the Upper East region were modelled based on only one emission scenario, AIFI. Other emission scenarios were not considered.

5.7.2 CROPWAT model limitations

The net irrigation requirements were estimated neglecting the impact of increased atmospheric CO_2 concentrations on crop physiology. GCMs generally do not consider the effects of increased CO_2 concentrations on plant physiology, possibly leads to an underestimation of regional warming and an overestimation of humidity (and cloudiness) in particular over tropical continents (IPCC, 2001).

The irrigation efficiency was assumed to be same although changing through time. In fact, it is plausible that all other things being equal, irrigation efficiency would decrease under climate change, as warmer climates and increased evaporative demands could lead to larger water losses during transportation to the field

5.7.3 Overall limitations of the approach

In this study, it was assumed that future weather variations are only due to climate change. Other decisive factors such as the inter-annual and the multi-decadal variability were not taken into account. These other drivers that may influence future weather trends, exacerbating and ameliorating the impacts of climate change, should be considered for more exhaustive analysis.

Future plant adaptations, such as an increase in water use efficiency through a decrease in bulk stomatal conductance as a result of increased atmospheric concentration of CO_2 were neglected, constituting another limitation.

It was not possible to predict future changes in planting dates when modelling future irrigation requirements.

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Historical water abstractions for irrigation from Tono and Vea reservoirs which ranged from 9.66Mm^3 to 27.67Mm^3 and 1.82Mm^3 to 8.88Mm^3 respectively for the cultivation of the four crops are far less than their maximum storage capacity of the reservoirs.

Results of the study showed that temperatures in Upper East Region will increase by about 0.6°C to 4.3°C for the years 2020, 2050 and 2080 based on synthetic and GCMs scenarios thus increasing evapotranspiration which will cause an increase in irrigation water requirements. The irrigation requirements of the four crops will increase by about 0.6 – 9% due to climate change depending on the climate change scenarios and time slices. This will result in an increase in water abstraction from the reservoirs, therefore stored water in the reservoirs should be utilized efficiently and the irrigation practice improved to minimize loses.

Climate change will not have significant impacts on Tono reservoir and therefore the total irrigable area should be utilized and also other water demanding crops which have ready market cultivated because there is enough water to support their cultivation.

Climate change will have minimal impact on Vea reservoir but coupled with an increase in domestic water abstraction, the water stored in the reservoir will not be adequate for both irrigation and domestic use for the year 2050 and beyond when maximum land areas between 1985 and 2006 are cultivated. Furthermore, the stored water will be enough for the cultivation of rice on the total irrigable area in 2020 and beyond and therefore ICOUR could shift the cultivation of rice and other water demanding crops to Tono irrigation project.

6.2 Recommendations

1. The ICOUR should measure and keep records on the quantity of water abstracted from the Tono and Vea reservoirs for irrigation because these records will serve as a baseline data for planning.

2. The climate change adaptation measures identified and reviewed should be incorporated into the national climate change adaptation policy and programmes and government institutions such as MoFA, EPA, FORIG, CRI, GIDA, etc, which have a stake in climate change supported to implement these measures.

3. Farmers should be educated on climate change adaptation measures through agro-forestry, soil and water management such as conservation agriculture and the application of organic manure.

4. Crop varieties tolerant to adverse climatic conditions should be cultivated because of future increases in temperature.

5. Farmers should be educated on good water management practices.

6. Further studies on climate change in Upper East Region using GCMs should employ a high spatial resolution such as 0.5 latitude by 0.5 longitudes and other emission scenarios apart from AIF1. Climate data from GCMs should be downscaled to remove uncertainties.

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APENDICES

Appendix A: Historical climatic conditions

Monthly rainfall (mm) for Navrongo in the Upper East Region of Ghana

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1960	0	0	14	81.3	92.5	110.7	113	211.1	384.3	33	0	0	1039.9
1961	0	0	0.3	20.3	49.8	157.2	152.9	199.1	234.7	3.1	0	0	817.4
1962	0	0	0.3	51.6	49	178.6	120.7	328.7	158.2	82.8	41.7	0	1011.6
1963	0	70.6	0	99.1	101.9	82.2	288	354.6	133.1	87.4	26.7	0	1243.6
1964	0	0	12.9	11.7	105.7	106.4	168.9	144.3	322.8	36.1	8.9	5.1	922.8
1965	25.7	0	0	66.8	69.3	91.4	260.6	229.9	185.4	32.3	0	0	961.4
1966	0	10.2	10.4	90.9	32	146.3	211.6	296.4	120.1	67.8	0	0	985.7
1967	0	19.6	15.5	37.9	87.6	67.6	88.4	319.3	221.5	12.9	2.3	4.3	876.9
1968	0	0	104.7	100.8	67.3	129.5	303	175.8	121.2	49	10.4	0	1061.7
1969	0	0	0	73.9	66.3	114.3	158.2	315.7	256.5	91.7	2.5	0	1079.1
1970	0	0.8	0.5	58.7	71.1	95.5	185.4	319.3	168.4	31	0	0	930.7
1971	0	0	32.8	42.9	96.5	188.5	165.6	339.3	221	57.9	0	26.9	1171.4
1972	0	0	3.1	125	73.9	142.8	218.2	189	121.2	40.9	0	0	914.1
1973	0	0	3.6	82	207.8	142.8	330.2	325.9	126.5	53.6	0	0	1272.4
1974	0	0	62.2	59.7	82.5	145.3	167.1	269.2	141.5	49	0	0	976.5
1975	0	8.9	0.3	20.6	97	82.8	259.1	268.2	149.4	10.4	0	0	896.7
1976	4.6	0	4.8	59.7	131.8	75.2	202.3	178.5	137	207.7	0	0	1001.6
1977	0	0	38.7	13.4	57.1	41.9	204.3	176	90.1	49	0	0	670.5
1978	0	0	36.9	89.3	231.2	90.2	182.4	344.4	131.7	111.5	0	0	1217.6
1979	0	0	0	114.8	168.3	139.4	261.8	211.7	164.2	56.2	4.6	0	1121
1980	0	0	0.3	74.5	95.9	64.7	176.9	307.3	150.8	69.2	0	0.3	939.9
1981	0	0	2	42.7	62.7	198.1	166.5	232.7	84.4	3.9	0	0	793
1982	0	0	79.6	36.5	16.1	81.5	130.7	243.2	236.2	51.5	1	0	876.3
1983	0	0	0	20.5	98.2	139.7	119.9	261.1	78.6	1	0	0	719
1984	0	0	8.7	97.5	188.2	84.5	98	222	116.2	36.7	0.5	0	852.3
1985	0	0	0	2.6	64.4	164.6	231	306	181.9	14	0	0	964.5
1986	0	0	9.4	37.8	113.1	179.2	248.8	142.4	447.7	41	5.8	0	1225.2
1987	0	0	85.5	9.3	31.8	274.3	176.6	413	95.3	46.1	0	0	1131.9
1988	0	0	26.6	130.2	31.9	141.6	123.2	246.9	187.4	0.7	26	0	914.5
1989	0	0	11.2	32.3	41.3	162.1	184.1	354	297.8	47.2	0	31.8	1161.8
1990	0	0	0	19.7	136.1	48.9	233	249.7	126.1	9.9	13.7	33.6	870.7
1991	0	0	34	43.1	148	64.7	164.7	357.4	83.5	81.1	0	0	976.5
1992	0	0	0	58.8	153.4	152.7	243.7	211.5	154.1	58.6	0	0	1032.8
1993	0	0	0	46.5	75.2	157.1	172.5	170.4	173.5	12.5	1.6	0	809.3
1994	0	0	32.3	12.7	115.8	62.4	164.3	428.2	100.8	84.7	0	0	1001.2
1995	0	0	5.7	41.6	44.6	141.5	94	231.1	55.7	72.5	0	0	686.7
1996	0	0	1.1	47.4	194.6	207.2	108.2	300.5	206.6	38.4	0	0	1104
1997	0	0	7.5	34.8	155.5	204	91.3	194.7	178.9	73.3	0	0	940
1998	0	19.7	0	20.8	134.8	77	127.5	281.9	146	47.9	0	0	855.6
1999	0	4.1	1.5	29.6	117.9	108.1	312.6	455.5	258.1	77.9	0	0	1365.3
2000	1	0	0	2.8	53.7	228.7	237.9	282.2	158.2	22.6	0	0	987.1
2001	0	0	0	30.3	125.1	131.1	176.9	336.2	155.9	4.2	0	0	959.7
2002	0	0	0	65.1	105.3	94	192.9	211.2	122.2	85.3	20.2	0	896.2
2003	0	1.8	0.9	22.3	95.8	207.2	182.8	284.4	238.6	100.1	6.1	0	1140
2004	0	0	28	176.6	74.3	139.8	259.9	210.4	118.5	34.7	2.2	0	1044.4
2005	0	4.5	0	20.7	13.7	226.1	179	189.3	88.3	28.7	0	0	750.3
2006	0	3.8	4	82.4	55.6	117.8	193.6	183.4	153.1	83.2	0	0	876.9

Monthly mean maximum temperature (oC) for Navrongo in the UER of Ghana

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1976	34.8	38.6	39.0	33.5	34.7	31.7	31.8	30.3	31.9	32.0	34.7	35.5
1977	36.0	3.2	38.1	38.8	36.2	33.5	31.5	30.2	31.3	34.1	36.9	34.8
1978	36.2	38.9	38.1	34.4	34.4	33.2	30.2	31.2	31.8	34.3	36.3	36.4
1979	37.0	38.1	39.5	39.7	34.9	31.5	30.6	30.8	31.3	34.1	36.2	34.3
1980	36.9	38.0	39.9	39.4	36.1	33.6	31.9	30.6	32.3	34.2	36.2	33.9
1981	34.7	38.3	39.3	38.9	35.7	34.1	30.8	30.7	3.1	36.3	37.1	36.9
1982	34.7	36.9	37.6	37.5	35.2	33.2	32.4	30.4	32.2	34.0	35.6	34.8
1983	32.1	38.2	39.6	40.6	36.1	32.5	32.0	31.3	32.2	36.6	37.3	35.7
1984	34.8	36.9	39.3	37.8	34.8	32.8	32.3	32.1	31.5	34.6	37.1	34.1
1985	36.3	36.4	39.4	38.9	37.4	33.5	30.8	30.2	30.7	35.2	37.4	33.6
1986	34.8	38.6	39.0	39.5	36.7	33.4	30.5	30.7	31.0	34.0	35.5	34.2
1987	36.5	39.2	38.5	40.2	39.0	33.1	31.8	31.3	32.1	34.3	37.6	35.5
1988	34.8	38.3	40.1	38.2	37.6	32.8	30.4	30.1	31.2	35.7	36.9	33.8
1989	33.8	35.9	38.3	39.7	38.8	33.7	31.1	30.2	31.6	33.9	37.3	35.1
1990	34.7	36.9	39.6	38.7	36.4	33.7	31.2	31.5	31.9	36.1	38.1	36.2
1991	36.1	36.4	39.4	37.9	33.0	32.9	31.2	30.4	32.6	33.5	36.6	34.8
1992	33.4	37.5	39.6	38.2	34.3	32.2	30.4	30.0	31.9	34.7	35.5	36.2
1993	33.9	37.8	39.2	39.2	38.4	35.4	30.9	31.0	31.2	34.8	37.7	35.6
1994	33.9	37.8	39.8	39.6	36.1	32.6	31.8	30.0	31.2	32.7	35.6	34.5
1995	34.0	36.8	40.1	39.1	37.1	34.3	31.7	30.0	32.2	34.4	37.4	36.7
1996	37.8	39.1	40.0	39.1	36.7	32.0	31.5	30.8	31.0	33.3	36.4	36.8
1997	37.0	33.9	38.4	37.8	35.6	31.8	31.6	31.7	32.6	34.5	37.2	36.3
1998	35.7	38.9	39.9	40.0	36.7	33.4	32.0	30.6	30.7	34.1	37.5	36.1
1999	36.4	36.7	40.7	39.2	37.1	34.1	31.4	30.2	30.9	33.6	37.4	35.6
2000	36.7	35.6	39.5	40.3	37.1	33.2	31.2	31.0	32.0	34.6	37.9	35.7
2001	36.1	36.9	40.4	39.8	36.7	33.4	31.9	30.8	31.8	36.6	38.2	37.9
2002	34.8	37.8	40.9	39.4	37.3	33.9	32.6	30.7	32.2	34	37	36.1
2003	36.1	39.2	40	39.4	37.6	32.3	31.3	31	31.9	34.9	37.3	36.3
2004	36.4	38	38.5	37	34.2	35.4	30.9	30.9	31.6	36.1	37.1	38.1
2005	34.5	39.7	41.1	40.3	37.6	33	31.1	30.8	32.2	35	38.1	37.2
2006	37.1	38.7	40.7	39.8	36	34.4	31.5	30.8	31	33.3	36.4	36.8

Monthly mean minimum temperature (°C) for Navrongo in the UER of Ghana

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1976	18.6	23.4	25.3	27.1	24.5	22.4	22.6	21.9	22.2	22.0	20.9	17.9
1977	20.6	17.7	24.3	27.1	25.5	23.9	23.0	22.3	22.3	21.8	19.5	18.8
1978	20.0	22.7	25.2	24.5	24.2		22.3	22.4	22.1	22.6	20.6	19.5
1979	20.6	21.4	26.3	27.0	24.8	23.2	22.4	22.7	22.3	22.8	21.0	19.8
1980	21.1	23.5	25.0	26.5	25.7	24.1	23.5	22.6	22.7	23.0	21.1	18.3
1981	19.3	22.8	25.6	26.7	25.2	24.0	22.9	22.6	2.2	22.4	20.2	18.6
1982	19.0	23.0	24.9	26.3	24.8	23.5	22.9	22.4	22.7	22.5	19.6	19.1
1983	19.5	23.8	26.1	27.7	25.4	23.5	22.9	22.9	22.5	21.7	19.9	20.2
1984	20.3	22.0	25.8	26.6	24.6	23.5	23.2	22.7	22.1	22.5	21.4	19.1
1985	21.4	22.5	27.3	27.1	26.3	24.1	22.1	22.6	22.4	21.9	20.3	18.8
1986	18.9	23.4	25.3	27.1	25.9	23.7	22.4	22.4	22.0	22.3	19.4	18.3
1987	20.4	22.5	24.6	26.9	27.3	24.1	23.2	22.7	22.9	23.0	20.1	19.8
1988	20.6	22.5	26.8	26.9	26.2	23.6	22.8	22.7	22.6	22.2	20.3	19.3
1989	18.9	21.5	23.7	26.7	26.1	23.2	22.9	22.5	22.1	21.7	19.8	19.6
1990	20.8	21.7	24.5	26.5	25.2	23.9	22.8	22.4	22.1	22.7	22.5	21.1
1991	21.4	22.7	26.0	26.2	24.4	24.3	23.1	22.9	23.2	22.2	20.0	19.6
1992	19.8	22.8	26.3	26.3	24.7	23.2	22.5	22.5	22.1	22.5	20.8	19.2
1993	19.1	23.1	25.5	26.9	26.0	24.7	22.7	22.8	22.3	22.8	22.9	20.5
1994	20.6	22.7	25.7	27.2	25.3	23.7	23.1	22.9	23.1	22.7	19.2	19.5
1995	18.6	21.1	26.2	27.0	25.9	24.5	23.2	22.5	23.0	22.7	20.5	20.1
1996	19.9	23.6	26.1	26.6	25.7	23.1	22.8	22.6	22.5	22.1	17.6	18.1
1997	20.2	20.7	25.6	25.8	25.1	23.6	23.1	23.0	23.3	23.3	21.1	19.3
1998	20.1	23.4	25.4	28.1	26.5	24.5	23.6	23.1	22.9	23.1	20.5	19.9
1999	21.4	21.8	25.9	26.1	25.3	23.9	23.0	22.7	22.3	22.4	20.5	18.7
2000	21.8	21.0	24.4	27.2	25.5	23.5	22.5	22.4	21.9	22.3	19.6	18.4
2001	18.6	21.3	24.4	26	25.7	23.4	23	22.4	22.4	22.5	20.6	20.1
2002	20.9	22.1	26.5	27.4	26.1	24.2	23.7	22.9	22.5	22.4	20.3	19.6
2003	20.8	23.6	24.9	26.6	26.2	23.6	23.2	23	22.7	23.6	21.3	19.1
2004	20.7	22.6	24.2	25.6	24.2	24.5	22.7	22.8	22.7	23	21.7	20.7
2005	20.4	25.7	27.5	28.3	26.1	24.1	22.9	22.8	23.1	22.4	20.9	20.7
2006	21.9	23.6	26	26.9	25.2	24.5	23.1	23	23.3	23.3	21.1	19.3

Appendix B: Baseline climate for Navrongo (1977 – 2006)

	Rainfall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity, (%)	Wind speed (km/d)	Duration of sunshine (hr)	ETo (mm/d)
JAN	0.0	35.4	20.3	25	104	9.1	4.94
FEB	1.1	36.5	22.4	27	112	8.9	5.55
MAR	13.8	39.5	25.5	37	112	8.5	6.09
APR	48.6	38.9	26.7	50	130	7.7	6.13
MAY	100.0	36.4	25.5	62	138	8.5	5.81
JUNE	137.7	33.3	23.8	74	121	8.1	4.92
JULY	181.3	31.4	22.9	79	104	6.5	4.2
AUG.	268.0	30.7	22.7	81	95	5.2	3.83
SEPT.	159.3	30.7	21.9	81	78	6.4	4.03
OCT.	48.1	34.6	22.5	73	78	9.1	4.85
NOV.	2.7	36.9	20.5	50	69	9.3	4.58
DEC.	2.2	35.7	19.4	36	78	9.1	4.35

Appendix C: Land areas under cultivation

Tono Irrigation Scheme

Year	Cultivated Areas (ha)				Total
	Rice	Tomato	Pepper	Onion	
1985 - 86	550	0	0	0	550
1986 - 87	791	0	0	0	791
1997 - 88	1090	37	0	0	1127
1988 - 89	1165	0	0	0	1165
1989 - 90	736	42	0	0	778
1990 - 91	603	134	0	0	737
1991 - 92	572	174	0	0	746
1992 - 93	636	266	0	0	902
1993 - 94	475	334	0	0	809
1994 - 95	655	505	0	0	1160
1995 - 96	801	389	0	0	1190
1996 - 97	903	565	0	0	1468
1997 - 98	345	388	0	0	733
1998 - 99	865	580	6.2	6.3	1457.5
1999 - 00	594	805	6	32	1437
2000 - 01	965	713	23	56	1757
2001 - 02	777	410	9	22	1218
2002 - 03	669	589	9	5	1272
2003 - 04	1030	31	7	6	1074
2004 - 05	1059	130	8	35	1232
2005- 06	381	166	12	39	598

Vea Irrigation scheme

Year	Cultivated Areas (ha) Rice	Tomato	Pepper	Onion	Total
1985 - 86	162	136	0	0	298
1986 - 87	213	230	0	0	443
1997 - 88	217	278	0	0	495
1988 - 89	0	191	0	0	191
1989 - 90	280	314	0	0	594
1990 - 91	205	92	0	0	297
1991 - 92	80	166	0	0	246
1992 - 93	60	123	0	0	183
1993 - 94	278	0	0	0	278
1994 - 95	147	0	0	0	147
1995 - 96	254	122	0	0	376
1996 - 97	76	257	0	0	333
1997 - 98	113	171	0	0	284
1998 - 99	123	225	0	0	348
1999 - 00	29	262	4.2	0	295.2
2000 - 01	126	166	1	7	300
2001 - 02	165	198	2	5	370
2002 - 03	167	205	5	0	377
2003 - 04	70	54	2	2	128
2004 - 05	66	45	0	0	111
2005- 06	78	64	0	10	152

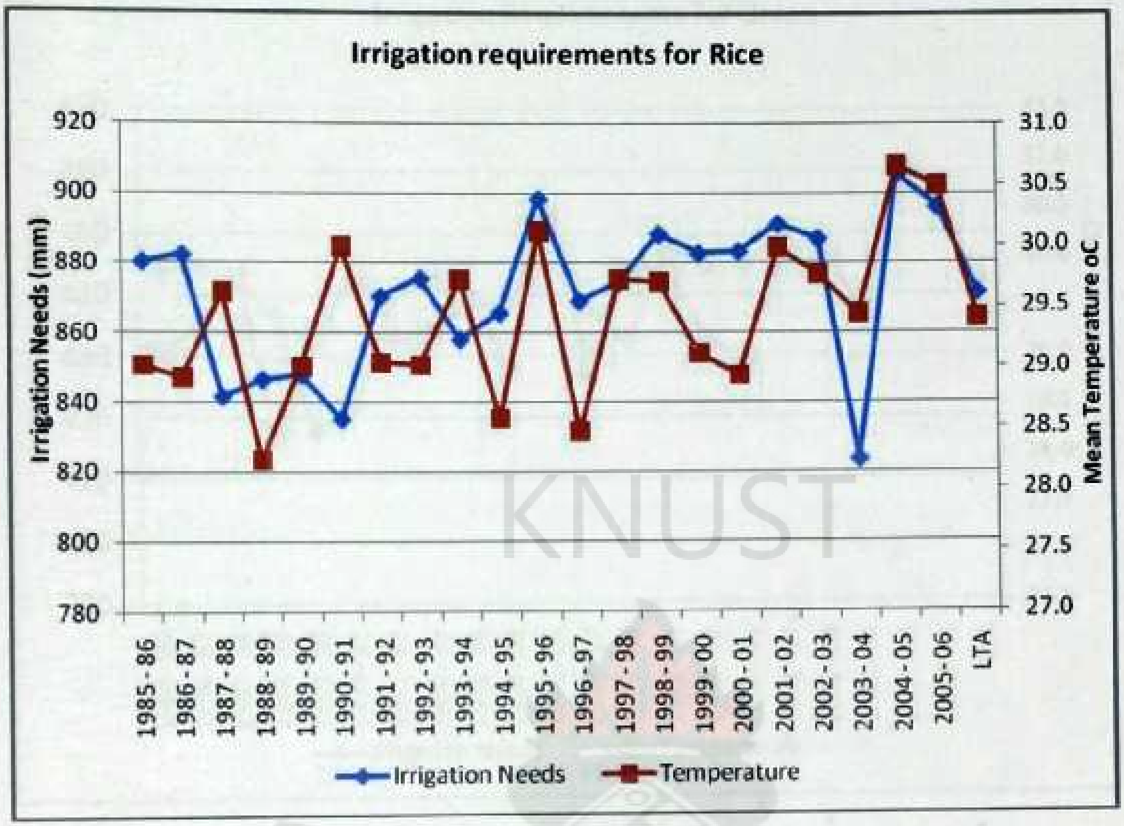
Appendix D: Validation Statistics used for ranking models

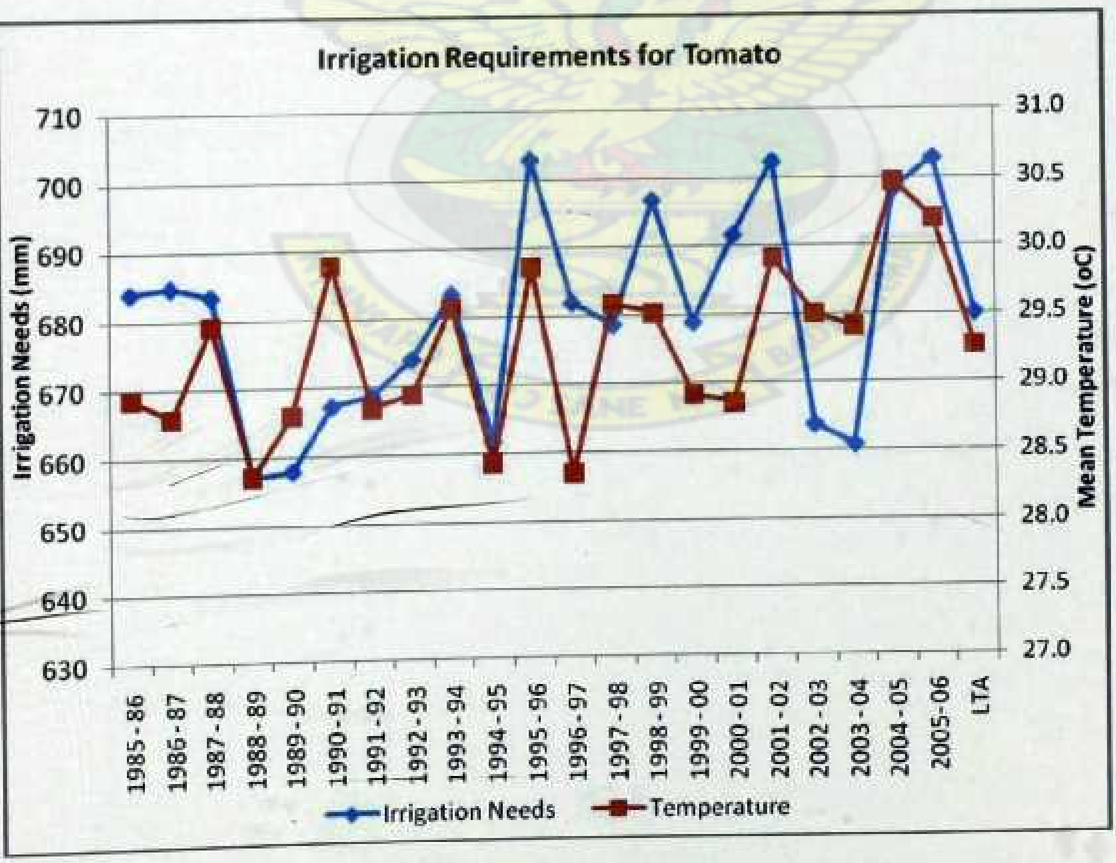
RANK (Score)	FLUX ADJ.	MODEL	Pattern Correlation	RMSE mm/day	Bias mm/day	RMSE Cor (mm/day)
1 (+ 8)	Yes	CCCMAS 3.1 (T47)	0.888/0.836	0.949/0.547	-0.010/+0.679	0.949/0.541
1 (+ 8)	Yes	MRI-2.3.2	0.886/0.909	0.967/0.438	-0.084/+0.033	0.963/0.437
1 (+ 8)	Yes	ECHO-G	0.910/0.840	0.864/0.609	+0.128/+0.290	0.854/0.585
4 (+ 3)		HadCM3	0.858/0.910	1.256/0.711	+0.230/+0.590	1.235/0.397
4 (+ 3)		MIROC 3.2 med	0.833/0.687	1.162/0.802	+0.035/+0.275	1.162/0.752
6 (+ 2)		GFDL 2.0	0.868/0.773	1.099/0.938	+0.091/+0.693	1.095/0.632
6 (+ 2)		GFDL.2.1	0.857/0.789	1.149/0.784	+0.215/+0.497	1.128/0.606
8 (+ 1		CCSM3	0.797/0.777	1.327/0.627	+0.160/+0.679	1.317/0.622
8 (+ 1)		IPSL4	0.808/0.752	1.269/0.783	-0.090/+0.384	1.266/0.682
10 (- 1)		ECHAM5	0.808/0.887	1.351/0.742	+0.247/+0.567	1.328/0.476
10 (- 1)		HadGEM 1	0.797/0.851	1.614/0.681	+0.385/+0.312	1.568/0.605
10 (- 1)		CSIRO 3.0	0.841/0.588	1.209/0.875	-0.161/+0.288	1.198/0.826
10 (- 1)		GISS.ER	0.774/0.795	1.430/0.723	+0.297/+0.406	1.399/0.598
14 (-3)		BCCR	0.793/0.684	1.311/0.741	+0.307/+0.108	1.275/0.733
15 (- 4)		FGOALS-glo	0.816/0.414	1.226/1.096	+0.307/+0.512	1.187/0.969
15 (- 4)		MIROC 3.2 hi	0.800/0.650	1.340/1.110	+0.281/+0.740	1.31/0.827
15 (- 4)		GISS-H	0.733/0.726	1.512/0.766	+0.340/+0.338	1.473/0.688
18 (-5)		INM3.0	0.700/0.456	1.606/0.982	+0.116/+0.381	1.590/0.905
19 (- 6)		CNR M3	0.772/0.761	1.438/0.843	+0.540/+0.532	1.333/0.654
20 (- 7)		PCM	0.665/0.474	1.715/0.935	+0.343/+0.328	1.680/0.875
Mean		5 best models	0.938/0.885	0.713/0.531	+0.060/+0.254	0.710/0.467
Mean		9 best models	0.924/0.860	0.787/0.602	+0.073/+0.325	0.783/0.507
Mean		All models	0.910/0.843	0.870/0.655	+0.184/+0.352	0.850/0.539

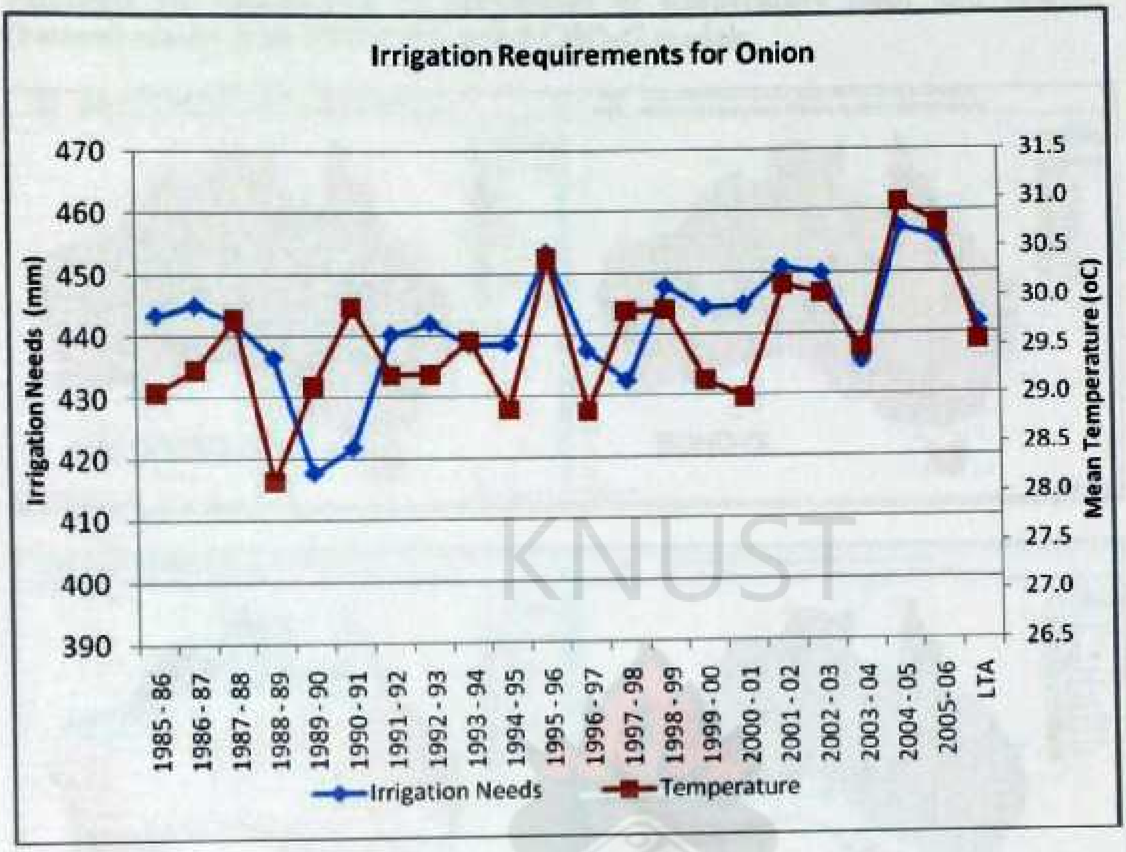
Appendix E: Selection of models, based on projected rainfall and temperature for 2000 – 2005

Model	2000	2001	2002	2003	2004	2005
CSIRO Rain	$y = 0.739x + 20.70$ $R^2 = 0.877$	$y = 0.794x + 17.99$ $R^2 = 0.938$	$y = 1.125x - 2.599$ $R^2 = 0.927$	$y = 0.775x + 7.695$ $R^2 = 0.900$	$y = 0.816x + 10.29$ $R^2 = 0.742$	$y = 0.844x + 28.50$ $R^2 = 0.694$
CSIRO Temp	$y = 0.814x + 4.817$ $R^2 = 0.857$	$y = 0.910x + 1.829$ $R^2 = 0.901$	$y = 0.823x + 4.253$ $R^2 = 0.943$	$y = 0.873x + 2.775$ $R^2 = 0.948$	$y = 1.104x - 3.683$ $R^2 = 0.766$	$y = 0.696x + 7.760$ $R^2 = 0.945$
HADCM3 Rain	$y = 0.765x + 20.72$ $R^2 = 0.877$	$y = 0.824x + 17.91$ $R^2 = 0.937$	$y = 1.166x - 3.080$ $R^2 = 0.916$	$y = 0.813x + 6.855$ $R^2 = 0.906$	$y = 0.851x + 10.22$ $R^2 = 0.732$	$y = 0.888x + 28.89$ $R^2 = 0.694$
HADCM3 Temp.	$y = 0.812x + 4.825$ $R^2 = 0.857$	$y = 0.912x + 1.737$ $R^2 = 0.906$	$y = 0.820x + 4.289$ $R^2 = 0.938$	$y = 0.873x + 2.746$ $R^2 = 0.952$	$y = 1.103x - 3.735$ $R^2 = 0.767$	$y = 1.103x - 3.735$ $R^2 = 0.767$
CCCMS Rain	$y = 0.752x + 20.51$ $R^2 = 0.877$	$y = 0.809x + 17.68$ $R^2 = 0.939$	$y = 1.143x - 2.879$ $R^2 = 0.917$	$y = 0.795x + 6.970$ $R^2 = 0.904$	$y = 0.834x + 9.847$ $R^2 = 0.739$	$y = 0.868x + 28.23$ $R^2 = 0.698$
CCCMS Temp	$y = 0.815x + 4.721$ $R^2 = 0.857$	$y = 0.913x + 1.706$ $R^2 = 0.897$	$y = 0.826x + 4.107$ $R^2 = 0.940$	$y = 0.882x + 2.448$ $R^2 = 0.958$	$y = 1.098x - 3.590$ $R^2 = 0.748$	$y = 0.700x + 7.570$ $R^2 = 0.945$
MRI -232A Rain	$y = 0.751x + 20.39$ $R^2 = 0.883$	$y = 0.804x + 17.81$ $R^2 = 0.938$	$y = 1.138x - 2.833$ $R^2 = 0.921$	$y = 0.789x + 7.186$ $R^2 = 0.903$	$= 0.833x + 9.666$ $R^2 = 0.747$	$y = 0.869x + 27.81$ $R^2 = 0.710$
MRI -232A Temp	$y = 0.811x + 4.843$ $R^2 = 0.859$	$y = 0.912x + 1.746$ $R^2 = 0.908$	$y = 0.819x + 4.320$ $R^2 = 0.94$	$y = 0.873x + 2.733$ $R^2 = 0.954$	$y = 1.094x - 3.455$ $R^2 = 0.758$	$y = 0.694x + 7.765$ $R^2 = 0.948$
ECH0—G Rain	$y = 0.770x + 20.02$ $R^2 = 0.884$	$y = 0.828x + 17.37$ $R^2 = 0.939$	$y = 1.171x - 3.769$ $R^2 = 0.919$	$y = 0.815x + 6.373$ $R^2 = 0.903$	$y = 0.857x + 9.393$ $R^2 = 0.737$	$y = 0.902x + 27.73$ $R^2 = 0.709$
ECHO—G Temp	$y = 0.82x + 4.578$ $R^2 = 0.856$	$y = 0.920x + 1.461$ $R^2 = 0.900$	$y = 0.830x + 3.949$ $R^2 = 0.939$	$y = 0.889x + 2.227$ $R^2 = 0.96$	$y = 1.107x - 3.871$ $R^2 = 0.750$	$y = 0.707x + 7.329$ $R^2 = 0.950$

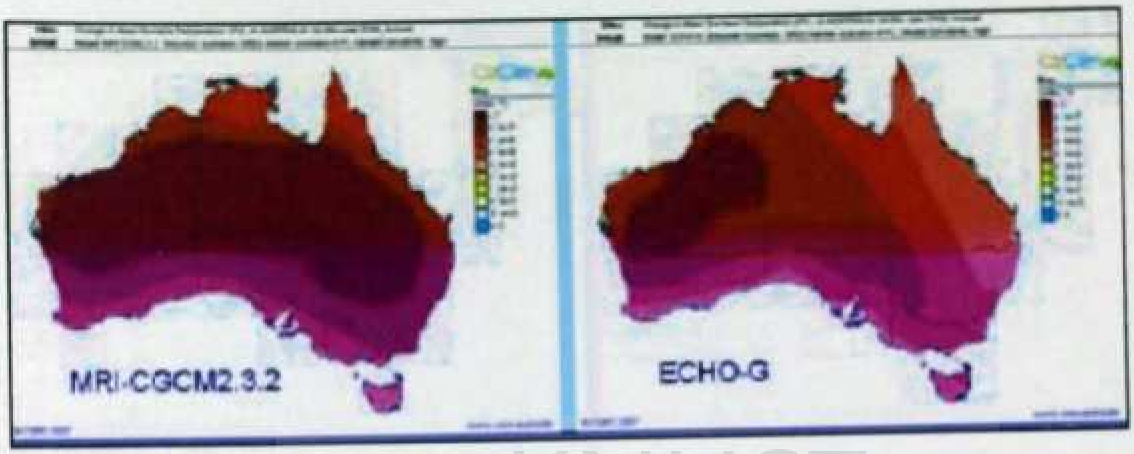
Appendix F: Irrigation requirements of rice, tomato and onion

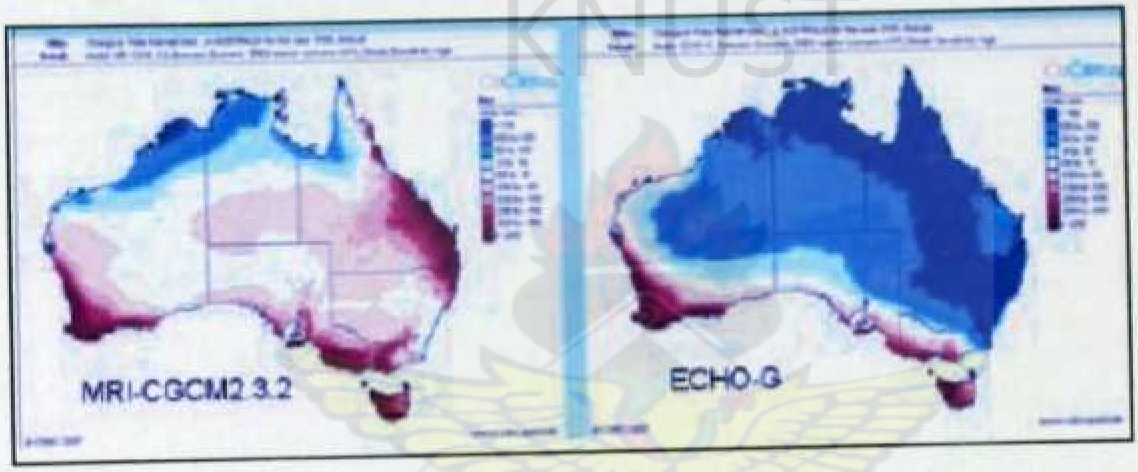





Irrigation Requirements for Onion
Irrigation Needs (mm)
Mean Temperature (oC)
470
460
450
440
430
420
410
400
390
31.5
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
1985-86
1986-87
1987-88
1988-89
1989-90
1990-91
1991-92
1992-93
1993-94
1994-95
1995-96
1996-97
1997-98
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
LTA
Irrigation Needs
Temperature

Appendix G: Comparison of projections of temperature (top) and rainfall (bottom) results from MRI-232A and ECHO-G models





Source: www.sharingknowledge.net.au (Accessed on 15/12/2008)