ASSESSING THE IMPACTS OF CLIMATE CHANGE ON THE AVAILABILITY OF STORED WATER FOR IRRIGATION PURPOSES IN THE SEMI-ARID AREAS OF GHANA

A Case Study of Tono and Vea Irrigation Projects

By

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DECLARATION

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 nor 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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Dedication

To My Dad, Mum and sweet Sisters

I love you, ALL!

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Abstract

This study investigates the potential impacts of climate change on the availability of stored water for irrigation in the semi-arid region of Ghana. The study was based on two mediumsized reservoirs – Tono and Vea – used for irrigation purposes and managed by the Irrigation Company of Upper East Regions, ICOUR. Historical water abstraction from the 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/CLIMWAT model. Future climatic conditions for the years 2020, 2040, 2060 and 2080 were determined based on synthetic and empirical downscaling of AR4-CNCM3 GCM scenarios. The historical water abstraction via evaporation losses was computed for both reservoirs and subsequently their future evaporation losses was also estimated by the use of Thornthwaite"s evapotranspiration formula. Finally, future irrigation needs were computed based on future climatic conditions with plausible climate change adaptation strategies suggested. Results of the study suggest that the net irrigation water requirements of the four crops will increase by about 1.4% – 9.8% due to an increase in mean temperature between 1°C - 3°C with a corresponding increase in rainfall of about 10%-35.5% depending on the type of climate change scenario and time slices. Climate change will relatively not have much significant impact on Tono irrigation project because future estimated total water abstraction (ETWA) when the total irrigable area at Tono is cultivated with rice will be about 71% to 77% of the maximum storage capacity between 2020 and 2080. Therefore the total irrigable area of 2490 ha could be utilized for the cultivation of rice and usage by other sectors since there is abundance of water. Climate change will however, have a major toll on Vea reservoir as the ETWA when the historical maximum land areas are cultivated exceeds the total water use allocated for irrigation and evaporation losses (TWAIE) ; and also the dam will be in a state of distress when all the irrigable lands are used solely for rice cultivation as an additional 3.95Mm^3-6 Mm^3 of water will be required to augment production denying other sectors usage.

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
CR1	Crop Research Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
EPA	Environmental Protection Agency
ESD	Empirical Statistical Downscaling
ETWA	Estimated Total Water Abstracted
FAO	Food and Agricultural Organization
GCMs	General Circulation Models
GMeT	Ghana Meteorological Agency
GIDA	Ghana Irrigation Development Authority
GIR	Gross Irrigation Requirement
GSS	Ghana Statistical Service
IPCC	Intergovernmental Panel on Climate change
ITCZ	Inter-Tropical Convergence Zone
LTA	Long Term Average
MDGs	Millennium Development Goals
MOFA	Ministry of Food and Agriculture
NIR	Net Irrigation Requirement
RCM	Regional Circulation Models
SD	Statistical Downscaling
SADA	Sahara Accelerated Development Authority
SRES	Special Report on Emission Scenarios
TAR	Third Assessment Report
TWAIE	Total Water Allocated for Irrigation and Evaporation losses
UER	Upper East Region
UTC	Coordinated Universal Time

WVB(R)	White Volta Basin (River)

CHAPTER ONE

1. INTRODUCTION

1.1 Background

"Water is an essential life sustaining element. It pervades our lives and is deeply embedded in our cultural backgrounds" (UN World Water Development Report, 2006).Water is required by all living creatures for survival. It is also required for economic growth and development. Water supplies from rivers, lakes and rainfall are characterized by their unequal natural geographical distribution and accessibility. Water is one of several current and future critical issues facing Africa (IPCC, 2007a). The achievement of the Millennium Development Goals (MDGs) depends largely on improved water supply and sanitation in the developing countries.

Climate change has the potential to foist additional pressures on water availability and accessibility as issues of drought, flood, and climatic variability have dominated headline news in recent times. This has caused governments in countries such as Ghana to take more stringent action on water resources management. The management of water resources is the concern of all stakeholders involved. (Hermans *et al*, 2006). According to Hagan (2007) most of the rivers in the world have been dammed to serve as water storage facilities for hydropower generation, drinking water supply and irrigation purposes. Reservoirs are indispensable storage facilities in arid and semi-arid regions of the world where there is irregular rainfall (Wiafe, 1997). Extreme drought and floods characterize these areas resulting in insecure livelihood.

In the rural areas of Ghana where surface water is scarce, reservoirs are used for daily activities to improve the livelihood of the people (Hagan, 2007). The Upper East Regions of Ghana and other

Northern Regions of Ghana where there is irregular rainfall patterns, small dams have been constructed on small rivers and streams to ensure all year round cultivation and also water supply for livestock and domestic purposes as well (Faulkner, 2008). Small dam development in the northern regions of Ghana have been considered as one of the noteworthy strategies to combat poverty by improving the standard of living of the people through improved smallholder irrigation techniques and livestock production. They are seen as an important tool in achieving some of the goals of vision 2020 of Ghana and also the United Nations MDGs on poverty reduction (Asante, 2010).

1.2 Problem Statement

The indigenes in the semi-arid regions of Ghana especially in the Upper East Region of the country are mostly farmers, who depend largely on stored waters in small and medium-sized dams for the irrigation of their farms, rearing of livestock and other domestic activities (Asante, 2010). Traditionally, because the major source of water in these regions is predominantly from rainfall, the sustainability of agriculture in this semi-arid region is primarily determined by water supply being adequate to meet demand. However, with the increase in population, advancement in technology, climate change and high social living standards leading to increase in domestic water usage among the people there is an additional demand for water (Nielson *et al*, 2001). It is therefore imperative to look into the effect of climate change on stored water for irrigation in these areas.

According to Nielsen et al. (2001) responses to climate change and variability have impact on the crop-water-supply-demand relationship. Assessing the potential impact of climate change on stored water for irrigation and agricultural activities in the semi-arid region of Ghana will enhance livelihood and food security in the country. According to (Asante, 2010) stored water systems in this region apart from being used for irrigation are competed for among various users – for domestic water supply, livestock watering and construction purposes, among others. The sustainability of irrigated agriculture stands threatened if the consequences of climate variability and climate change are not considered in our current developmental agenda and frameworks.

1.3 Justification

Despite the susceptible nature of the Upper East Region (UER) to climate change due to its unimodal rainfall pattern coupled with long periods of droughts and dry-spells, relatively few studies have been carried out 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 phenomenal issue globally and it is therefore imperative for studies undertaken on it, in the UER, where there is a connection between agriculture and the livelihood of the indigenes.

Over the years, irrigation water has enabled farmers to increase yields by reducing their independence on rainfall thus, boosting the average crop production while decreasing the interannaul 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 event 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 the irrigation water requirements, especially in water stress areas such as Upper East Region of Ghana.

1.4 Objectives of Study

The main objective of this research is to assess the potential effects of climate change on stored water for irrigation purposes in the semi-arid regions of Ghana.

In order to accomplish the main objective, the following specific objectives were set;

- To establish an irrigation water and evaporation abstraction baseline for the Tono and Vea Irrigation Projects.
- To create a set of future climate conditions using climate models and scenarios for the Upper East Region
- To assess the impacts of climate change on irrigation water needs for species of crops grown in the region.
- To identify potential adaptation measures required to deal with climate change in the region.

1.5 Organization of Thesis

The thesis is organized in five chapters under the broad headings as Introduction; Literature Review; Methodology; Results and Discussion and; Conclusion and Recommendation.

Chapter 1 gives a background of the thesis, the problem statement, justification of the study and sets out the main and specific objectives to allow readers get a better understanding of the topic. Chapter 2, follows with review of literature about the study area and climate change, climate change scenarios and means of generating them emphasizing on statistical (empirical) downscaling approach of GCMs. It further discusses the impact of climate change in water resources, irrigation and plants responses to water stress; adaptations to climate change and review of studies carried out in the area of study. The materials and methods employed for the study are outlined Chapter 3. In Chapter 4, the results and discussion of the study are presented.

Finally, the conclusions of the findings and recommendations on the study are made in Chapter

CHAPTER TWO

2 LITERATURE REVIEW

This chapter reviews literature on the study area, its climate, geology, economic activities and water resources. The impacts of climate change on water resources and irrigation in the area is also looked at. It further reviews the various forms of climate scenarios generation and their relevance to this study.

2.1 Introduction

Several studies have been taken on the rivers and water bodies in the semi-arid region of Ghana and in particular the UER (Liebe, 2002; Mdemu; 2002; Faulkner, 2006; Anayah, 2009; Asante, 2009 and Nakuja *et al*, 2011). However, it is the works of Mdemu (2002) and Asante (2009) that had much relation to the area of study for this research. Mdemu, looks at the water productivity in medium and small reservoirs in the UER, and in this case the Tono and Dorongo reservoirs. Using a variety of scientific models he concluded that the water productivity of the reservoirs under study were low and asserted potential for improvement existed.

This research is a sequel to the work of Asante (2009), in which he used synthetic scenarios and GCMs to assess the impacts of climate change on the Tono and Vea reservoirs for irrigation. Significant among his numerous conclusions was that the impact of climate change would not have significant impact on the Tono as it will on the Vea reservoir. He however, did not estimate the impact of evaporation losses on the dams in assessing their viability to sustain agriculture in the future under extreme conditions; and also using GCMs for such a relatively small watershed area makes his finding quite imprecise as the spatial resolution is bigger than that used in regional climate change impact assessment such as his area of study. This study seeks to incorporate the impact of evaporation losses on the reservoirs and also use relatively low spatial models through empirical downscaling of GCMs.

There is a brief literature review on the Tono and Vea irrigation schemes under the subsequent headings of climate, soils and geological formation, drainage, relief, socio-economic activities, economic analysis of small reservoirs in UER etc.

2.1.1 Climate

The region is within the Inter-Tropical Convergence Zone (ITCZ) where the movement of the two air masses – the Harmattan or North –East (NE) Trade Winds and the South-West Monsoon winds, determine the climate (Jens Liebe, 2002). Rainfall in the region is uni-modal, hence it is erratic and spatially distributed starting from April/May and ending in September/October with a dry period of 6 – 7 months. Annual rainfall ranges between 700 and 1100mm (Barry et al., 2005). Temperatures in the region are consistently high, with the highest temperatures being recorded in

March or April (40-42°C) and coolest month being August (26°C). Mean annual temperatures ranges between 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.

2.1.2 Soils and Geological Formation

The geological formations covering the UER are divided into three main groups; the Granitic, the Voltaian and the Birimian rocks. A large part of the area is underlain by metamorphic and igneous complex with gnesis and granodiorite predominating; where hills rise above the soil surface. 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, plinthsols and fluvisols developed from granites, birimian rocks and alluvia of mixed origin (Quansah, 2005). The soils have predominantly light textured surface horizons, shallow and low soil fertility, weak with low organic matter content, and predominantly coarse textured. Erosion is a serious problem on these soils. Soils in the valley bottoms are heavy textured. Valley soils 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 flooding.

2.1.3 Relief

The relief of the UER is related to the geology, where a range of Birimian greenstone hills rising up to 457m above sea level dominate north of Zebilla and Bawku along the border with Burkina

Faso and in the southwest along the White Volta River (WVR) (Adu, 1969). The relief of the area is generally flat, gently undulating with slopes ranging from 1-5% except in a few uplands where slopes are about 10% (Adwubi, 2007). The UER has the highest elevation of 455m in the northern part and the granitic areas being lowest ranging from 122m-260m above sea level in the southern part of the region (Leibe, 2002).

2.1.4 Socio-Economic Activities

The Ghana Statistical Survey (GSS) report for 2012 indicates Agriculture, hunting and forestry are the main economic activities in the region. About eighty percent of the economically active population engages in agriculture (GSS, 2012). The main produces are millet, guinea-corn, maize, groundnut, beans, sorghum and dry season tomatoes and onions. Livestock and poultry production are also common. 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 cotton ginnery at Pusu-Namongo (near Bolgatanga) and the Northern Star tomato at

Pwalugu. Other existing industries are the Meat processing Factory at Zuarungu and the Rice Mills at Bolgatanga

2.1.5 Drainage

The area is mainly drained by the White Volta River (WVR) and its major tributaries, the Red Volta, the Sissili 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 the 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 south of Bolgatanga and large parts of Navrongo are drained by the Atankwidi subcatchment, whilst the Tono sub-catchment drains areas northwest and west of Navrongo. All tributaries south of WVR in the Gambaga escarpment drain southward away from the WVR (Liebe, 2002). Most of the sub catchments 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, aquaculture and other uses during the dry season.

2.1.6 Economic Analysis of Small Reservoirs in UER

Due to the uni-modal rainfall pattern in the Upper East Regions, most farmers depend on reservoirs for smallholder irrigation and livestock production. The farmers do not have to pay for the use of these small reservoirs and do not have to spend some of their profit on the maintenance of the reservoirs. The little profit generated from the sale of their produce goes a long way to improve the standard of living of the people. A lot of benefits are derived from the construction of small reservoirs as, they can be a good avenue for the eradication of poverty in the communities if they are properly managed and maintained. IFAD (2006) estimates a net return of USD109 and USD53 for plots of 0.05 ha of tomato and onion, respectively. This revenue is very substantial if one considers the extent of poverty in the region.

2.1.7 Tono and Vea Irrigation Projects

The Tono Irrigation Scheme is located at Navrongo in the Kasena-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 (ICOUR). 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 to provide 37 Mm^3 for irrigation. The reservoir is filled by collecting runoff from a catchment area of about $650km^2$. The scheme has road networks and two main canals serving the right and left banks with a total length of about 120km and 42km respectively (see Figure. 2.1). 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 Ayamga, 1992).

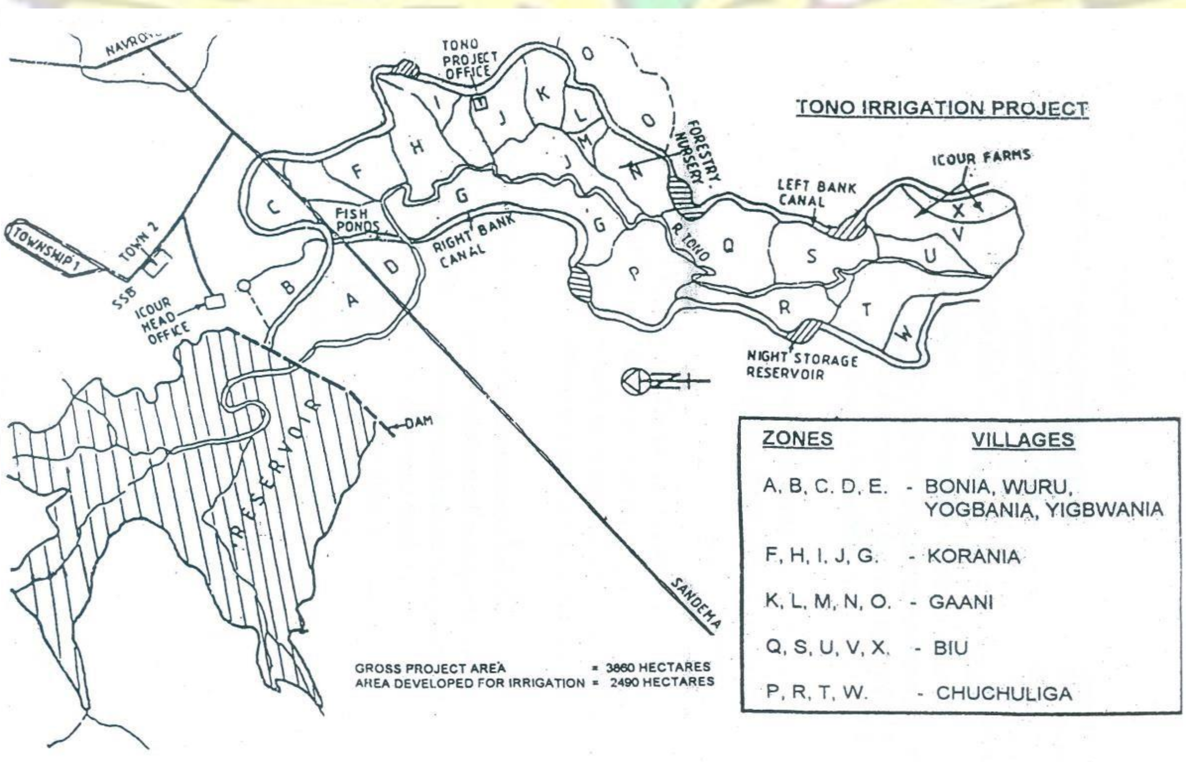


Figure 2. 1: Schematic View of the Tono Irrigation Project (Source: ICOUR UER, 2012)

The Vea irrigation project is located 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 (see Figure 2.2). The project has a reservoir with a maximum surface area of 405 hectares and maximum storage of $17Mm^3$. The maximum storage of the reservoir consists of live storage of $16Mm^3$ and dead storage of I Mm^3. The reservoir has a total crest length of 1,585 meters. The reservoir is built along the course of River Yaragatanga and it is also filled by collecting runoff from a catchment area of $136km^2$. The project has a network of roads and canals with a total length of the main road and main canal of about 18km and 21km respectively. The project is divided into upland and lowland respectively. 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 cover about 3.2 hectares.

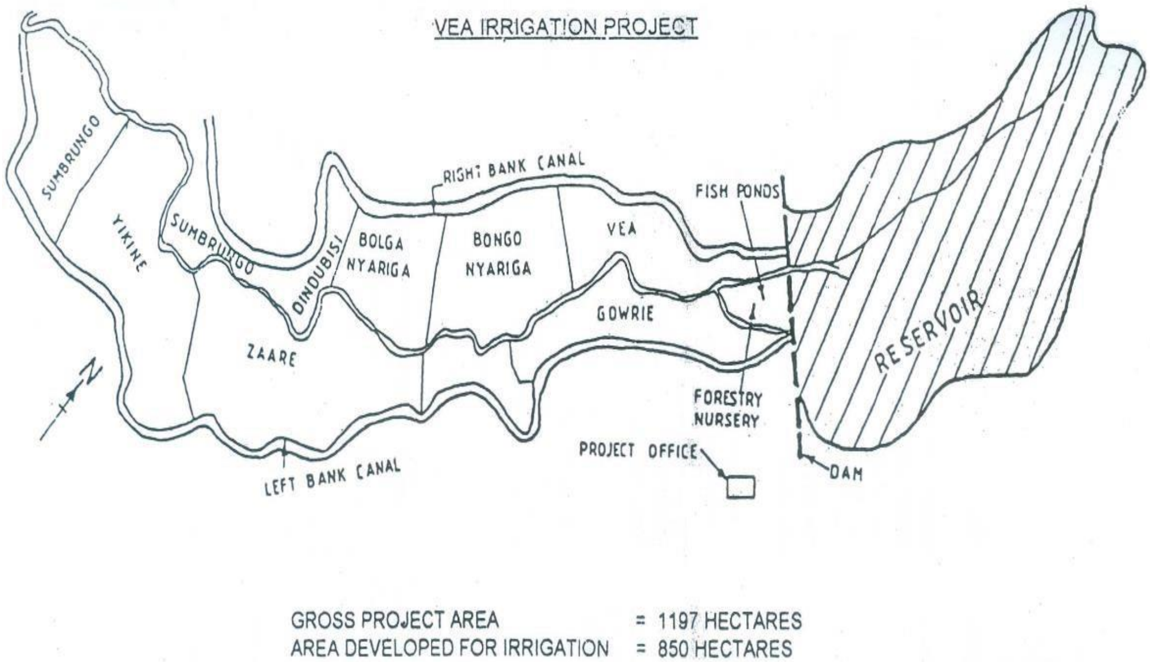


Figure 2. 2: Schematic View of the Vea Irrigation Project (Source: ICOUR UER, 2012)

2.2 Climate Change Scenarios for Impact and Adaptation Assessment

2.2.1 Climate Change and Climate Variability

Climate is "average" weather (current atmospheric condition) for a given place or a region. It defines typical weather conditions for a given area based on long-term averages.

Climate variability refers to the climatic parameter of a region varying from its long-term mean. These changes result from atmospheric and oceanic circulation, caused mostly by differential heating of the sun on earth. The atmosphere and ocean circulate in three dimensions and each acts on the other. The atmosphere moves faster than the ocean, but the ocean stores a large amount of heat and releases it slowly over long periods. Thus, the ocean acts as a memory in this circulation. These atmosphere-ocean circulations cause climate to vary in season-to-season or year-to-year time periods. Climate variability can cause abrupt disruptions, such as floods, droughts, or tropical storms. (USAID, 2007)

Doll (2002) defined climate change as changes in the long-term averages of precipitation and temperature only. Climate change can also be referred to be 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 pervasive cumulative ecological effects such as the extinction of life forms and sea level rise (Simon, 2008). Climate change could occur due to natural variability or anthropogenic conditions. In other words, climate change may be due to some internal processes and/or external forces. The natural variability 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 a result of human activity that began with the industrial revolution is the other external factor which has caused changes in the atmosphere.

2.2.2 Climate Scenarios

The impact of climate change will be felt at the regional or local scale, however high uncertainties exists in predictions of climate change at these scales although it is known that increased greenhouse concentrations will increase global temperature (Giorgi et al., 2001). 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 (IPCCTGICA, 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 appropriate policy responses. Climate scenario unlike weather forecasts 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 behavior 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.

2.2.3 Criteria for Selecting Climate Scenarios

In 2007, the IPCC suggested another criterion to the four already existing criteria as elaborated in Smith and Hulme (1998). These are criteria that climate scenarios should meet if they are to be useful for impact assessment by researchers and policy makers. They are:

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

- *Representative*. They should be representative of the potential range of future regional climate change.
- *Accessibility*. They should be straight forward to obtain, interpret and apply for impact assessment

2.2.4 Types of Climate Scenarios

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

2.2.4.1 Synthetic Scenarios

The 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. It has to its advantage, as being very simple to apply by impact analysts, transparent and easily interpreted by policy makers and non-specialists, also their ability of capturing a wide range of possible changes in climate, offering a useful tool for evaluating the sensitivity of an exposure unit to changing climate. In addition, different studies can readily apply the same synthetic scenarios to explore relative sensitivities of exposure units. Their major disadvantage is their arbitrary nature. Some scenarios may also be inconsistent with the uncertainty range of global changes.

2.2.4.2 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.

Temporal analogues make use of climatic information from the past as an analogue of possible future climate. There are two types: palaeoclimatic analogues based on information from the geological record and analogues selected from the historical instrumental record, usually within the past century. This can provide a potentially rich data set of observed, and therefore physically plausible, climate.

Spatial analogue on the other hand, are regions which today have a climate analogous to the study in the future (Bergthorsson et al, 1988). The approach is highly restricted, however, by the lack of correspondence between the other important features (both climatic and non-climatic) of the two regions.

2.2.4.3 General Circulation Model (GCM)

General Circulation Models or Global Climate Models (GCMs) are state-of-the art numerical coupled models that represent several subsystems of the earth"s climate (atmosphere, oceans, sea, ice, land surface processes) that are thought to be capable of simulating the large-scale state of the climate. They are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations at planetary scales, GCMs are able to reliably simulate the most important mean features of the global climate, for instance, the Inter-Tropical Convergence Zone (ITCZ), the three-dimensional atmospheric circulation cells, and the jet streams (Zorita and Von Storch, 1999). These GCMs used for climate simulations typically have horizontal spatial resolutions of hundreds of kilometers. However, only GCMs often in conjunction with nested Regional Climate Models (RCMs) or other downscaling methods have the potential to provide geographically and physically consistent estimates of regional climate which are required in impact analysis (IPCC, 1994). The results obtained from GCMs are considerably useful in evaluating potential climate changes at a global scale. However, due to the GCMs coarse spatial resolution, local land surfaces characteristics are ignored during the simulation procedure.

Trenberth, (1992) declared that, the ability of climate models to simulate smaller scale extreme events, such as tropical storms, small scale extra-tropical storms and associated areas of intense weather has so far been limited by the low resolution of the GCMs. However, to properly evaluate regional and local effects of climate variations, such as watershed, there is the need for higher level of detail because many effects are sensitive to the nuances of the local climate.

West Africa lacks such complex scientific tools and hence rely mostly on the coarse resolution GCMs for weather forecasting and climate projections despite its numerous less predictable smaller scale (micro scale and mesoscale) tropical systems. This contributes to the mostly unreliable weather forecasts. In addition, restricted computational facilities and lack of human resources as well as problems of insufficient climate data (sparse availability of climate data) in West Africa is another contributing factor (Boko M.*et al*., 2007). There is therefore the need to downscale these coarse resolution GCMs for climate impact studies such as the agriculture, health and energy sectors.

2.3 Downscaling and Purpose of Downscaling

One of the major problems in applying GCM projections to regional impact assessments is the coarse spatial scale of the gridded estimates in relation to many of the exposure units being studied.

Several methods have been adopted for developing regional GCM-based scenarios at the sub-grid scale, a procedure variously known as “regionalization” or “downscaling”. (IPCCTGICA,2007). According to Benestad *et al*.(2008) downscaling is defined as the process of making the link between the state of some large scale variables and the state of some variables representing a much smaller space (referred to as the “small scale variables”). Specifically, its purpose is using GCMs to make an inference about the local climate at a given location. For instance, the global mean value of temperature is usually not directly relevant for practical use (Benestad *et al*., 2008). GCMs have resolutions of hundreds of kilometers, whilst regional climate models (RCMs) may be as fine as tens of kilometers. However, climate impact assessment applications often require point-specific climate projections in order to capture fine-scale climate variations, particularly in regions with complex topography, coastal or island locations, and in areas of highly heterogeneous land cover (Wilby *et al*., 2004). Therefore a gap exists between what climate models can predict about future climate change and the information relevant for environmental studies. It is therefore common to downscale the results from the GCMs either through a nested high-resolution regional climate model (RCM) also known as physical downscaling or through empirical/statistical downscaling (IPCC, 2004). Statistical downscaling is much less computationally demanding than physical downscaling using numerical models, offering an opportunity to produce ensembles of high resolution climate scenarios.

2.3.1 The Empirical Statistical Downscaling Models

Statistical downscaling involves adapting coarse-resolution (typically 250 km) global climate change scenarios provided by the GCMs to regional or local scale. These methods link the large scale outputs of GCMs (typically large scale fields such as 300 or 500mb geo-potential height` with simultaneous local historical observations (typically surface variables such as precipitation or temperature) in the region of Interest (Gutierrez *et al*., 2011).

Wilby *et al*. (2004), also define statistical downscaling as developing quantitative relationships between large-scale atmospheric variables (predictors) and local surface variables (predictands). Statistical downscaling therefore refers to a process of inferring information about the smallscale, given the large-scale conditions by means of a statistical model in some publications. This is referred to as empirical downscaling. The essence of empirical statistical downscaling henceforth ESD is to identify synchronized or "matching" time behavior on large- and small scales, hence practical ESD focuses on the time dimension. ESD assumes an implicit and fundamental link between the two scales (Benestad et al., 2008).

The most common form has the predictand as a function of the predictors, but other types of relationships between predictors and the statistical distribution parameters of the predictand or the frequencies of the extreme of the predictand may also be used. Statistical downscaling methods (SDMs) combine the information of retrospective GCM analysis/forecasts databases (Reanalysis datasets) with simultaneous historical observations of the variables of interest (Observed datasets, either station networks or grids of interpolated observations) to infer appropriate statistical transfer models. Therefore, besides the GCM datasets, two basic ingredients of the statistical downscaling methodology are the Reanalysis and Observations datasets, which are required to define and calibrate the SDMs (see figure. 2.3). ESD is therefore used to fill the gap between these GCM/RCM and point specific climate change impact models.

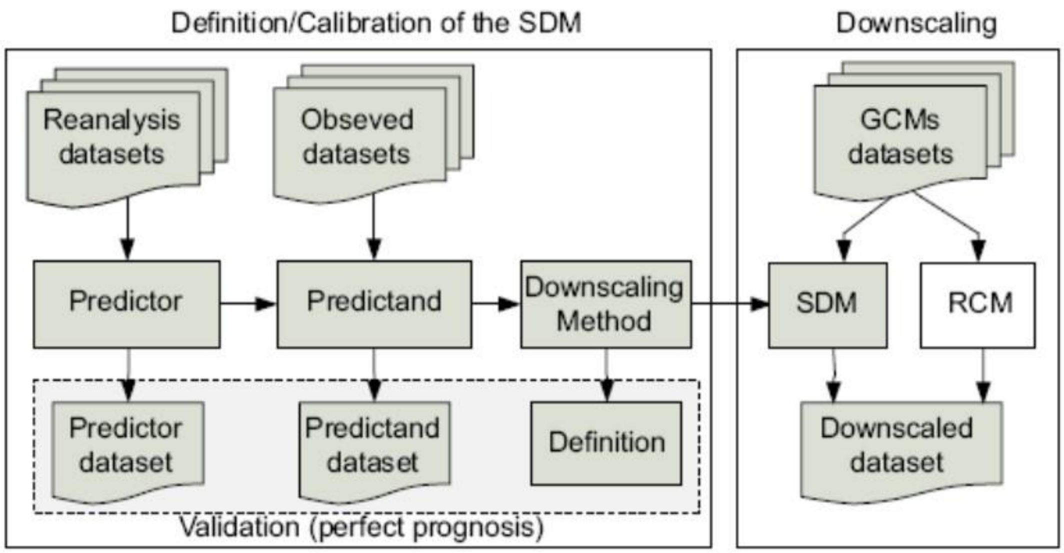


Figure 2. 3*: Scheme of the downscaling process. Source (Gutierrez et al., 2011).*

Statistical downscaling is an elaborate multidisciplinary discipline; that involves a cascade of different scientific applications to access and process large amounts of heterogeneous data. Hence, a statistical downscaling web portal developed by the Santander Meteorology group with technical assistance of the EU-funded ENSEMBLES (Gutierrez *et al*., 2011) project is used in this work. The portal is internet-based with GRID technologies allowing the transparent use of distributed resources, both for data and computation – thus connecting data providers and endusers in a transparent, web-based environment. The downscaling portal provides user-friendly homogeneous access to a subset of ENSEMBLES GCMs (both seasonal predictions and climate change projections) and RCM outputs, allowing local interpolation or downscaling to the region/location of interest and the removal of biases.

The skill of the downscaling method depends on the variable, season and region of interest, with the latter variation dominating. Hence, for each particular application and case study, an ensemble of statistical downscaling methods needs to be tested and validated to achieve the maximum skill in predicting and a proper representation of uncertainties. Thus, validation is a key issue in the ENSEMBLES downscaling portal, and; it is automatically performed when a downscaling method is defined.

2.3.2 Review of Methods of Empirical Statistical Downscaling

The table below summarizes the main SD techniques under broad headings weather classification, regression models and weather generators. This categorization is similar to that used by IPCC TAR (Giorgi*et al*., 2001)

Table 2. 1 :A summary of the strengths and Weaknesses of the main SD Methods (Source Wilby et al., 2004*)*

Method	**Strengths**	**Weaknesses**
Weather Classification **(**e.g. analogue method, hybrid approaches, fuzzy classification, self-organizing maps, Monte Carlo Methods).	• Yields physically interpretable linkages to surface climate • Versatile (e.g., can be applied to surface climate, air quality, flooding, erosion, etc.) • Compositing for analysis of extreme events	• Requires additional task of weather classification. Circulation –based schemes can be insensitive to future climate forcing • May not capture intratype variations in surface climate
Weather Generators **(**e.g Markov chains, stochastic models, spell length methods, storm arrival times, mixture modeling)	• Production of large ensembles for uncertainty analysis or long simulations for extremes. • Spatial Interpolation of model parameters using landscape • Can generate sub-daily	• Arbitrary adjustment of parameters for future climate • Unanticipated effects to secondary variables of changing precipitation parameters
	information	

Regression Models (e.g. linear regression, neural networks, canonical correlation analysis, kriging).	• Relatively straightforward to apply • Employs full range of available predictor variables • „Off-the-shelf" solutions and software	• Poor representation of observed variance • May assume linearity and/or normality of data Poor representation of extreme events

2.3.3 Conditions for Statistical (Empirical) Downscaling

The four necessary conditions which must be fulfilled in SD include; Strong relationship, Model representation, Description of change and model Stationarity. If any of these conditions are not fulfilled, then the ESD may be flawed and pointless.

The basis of ESD is the assumption that there is a close link between the large-scale predictor and the small-scale predictand, thus a strong relationship. It is only when they co vary to a large degree and have similar time structure that it is possible to use a predictor to calculate the predictand.

ESD takes the predictor as given, and it is therefore important that the predictor is simulated well by the models. In other words, if the parameter taken as the predictor is unrealistic, then the ESD results will be wrong too.The question of the degree to which the predictor is representable also depends on time scale. Sometimes the monthly mean gridded values may give a reasonable description, whereas daily values may be more problematic.

It is important that the predictor parameter responds to given perturbations in a similar fashion as the Predictand, or the ESD results will not capture the changes. This can also be seen from the simple mathematical expression describing an ideal situation: $y = F(X)$. If this equation truly is representative, the equality implies that y and $F(X)$ respond in the same way.

The fourth important aspect to ESD is the issue of stationarity. By this, the statistical relationship between the predictor and the predictand does not change over time.

2.4 Impacts of Climate Change on Soils and Water Resources

The IPCC Fourth Assessment Report (AR4) posits that in Africa, very few regional to subregional climate change scenarios using RCMs or empirical downscaling have been constructed due to restricted computational facilities and lack of human resources (Hudson and Jones, 2002, Swart et al., 2002) as well as problems of insufficient climate data (Jenkins et al., 2002). 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 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. 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. In contrast, more people in eastern and western Africa will be likely to experience reduction rather than an increase in water stress (Arnell, 2006a)

Water resources in Ghana are essential for socio-economic development. Impacts of climate change on the water resource can put the country at risk. The 2010 national census by the GSS claim that about 41.6% of the economically active population in the country are engaged in agriculture whereas in the semi-arid regions of the country over 70% of its populace engage in agriculture, forestry and fishing activities.

The 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. Extreme rainfall intensities may result in serious soil erosion and overall land degradation. Also 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 ground water table is high (Asante , 2009). On the contrary, prolonged drought conditions will adversely affect the entire hydrological regimes of the study area, which might result in a threat of desertification.

2.4.1 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 renewal water resources – about 2630 Gm^3 /year out of 3815 Gm^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 water irrigation requirements using the temperature and precipitation scenarios for the base period, 2020 and 2050 period as inputs. The net 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 48,128m^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 change in the water demand due to climate change was found to be about four (4) times (EPA, 2000).

Results by Fischer *et al*. (2006) indicate that the 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. Doll and Siebert (2001) worked on global modeling of irrigation requirements. They developed a global irrigation model by integrating simplified agro-ecological and hydrological approaches, Doll (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 Doll (2002) showed 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 South-East Asia and the Indian subcontinent.

2.4.2 Impact of Evaporation on Water Resources

For small reservoirs to function properly, both water use and storage should be efficient. The storage efficiency is affected by two main processes namely percolation losses and evaporation losses (Liebe *et al*, www.smallreservoir.org). The percolated water feeds into the groundwater and therefore could also be seen as a loss of transfer into other storage medium. In contrast, water loss by evaporation is usually considered as an unproductive loss of water since; the water evaporated cannot be put to any usage as the water vapor is transported away with the wind. Water bodies in arid surroundings can be subject to high evaporation losses due to the oasis effect. These high rates are due to energy advection, or extra energy input from dry surroundings. (Liebe and Van de Giesen,2007). Evaporation losses from small reservoirs affect their water storage efficiency. Many planners and decision makers feel that small reservoirs are unsuitable for rural water supply because they assume that evaporation losses are extremely high. From experiments and studies conducted by researchers such as Liebe and Van de Giesen on water bodies in the Upper East Region, it was detected that using the technique of a floating evaporation pan instead of a Land-based evaporation method, the actual evaporation was below the potential evaporation rate. This according to them is significantly due to the extra energy a pan receives through its sides and bottom. Evaporation losses are therefore lower than often assumed.

2.5 Adaptation to Climate Change

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 moderate harm or exploits beneficial opportunities (IPCC, 2001). There are two main types of adaptations namely autonomous adaptation and planned adaptation. The autonomous adaptation is usually initiated by ecological or socio-economic conditions specific to changes in anthropogenic systems and not any conscious response to stimuli. Planned adaptation measures are conscious policy options or response strategies, often multi-sectorial in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptation.

Whether adaptation is in anticipation (taken before the occurrence of initial impacts) or in reaction (developed and implemented in response to initial impacts), it enables the reduction of vulnerability to climate change of the system or sector concerned. Adaptation is not coping as is shown in the table below.

Table 2. 2 : Difference between Coping and Adaptation

Coping	**Adaptation**
Short-term and immediate. Not continuous	Oriented towards long-term. A continuous process
Motivated by crises, reactive	Results are sustained. Focuses on livelihoods security
Oriented towards survival	Targeted planning. Uses resources efficiently
Promoted by a lack of alternatives	Focuses on finding alternatives

Mitigation on the other hand refers to measures to reduce the emissions of greenhouse gases such as carbon dioxide, methane, nitrous oxide, etc. However, Ghana like majority of countries in the West African Sub-region are not industrialized so rather do adapt to impact of climate change instead of mitigation.

Ghana a signatory to the United Nations Framework Convention on Climate Change (UNFCC) in compliance to Article 4.1b of the UNFCC that entreats parties to formulate and implement national or regional programs containing measures to facilitate adequate adaptation to climate change. Ghana has developed the National Climate Change Strategy to put in place mechanisms that will ensure resilience and reduce vulnerability in the wake of this climate change canker.

CHAPTER THREE

3 METHODOLOGY

This chapter describes in brief the study area and the reasons for selecting the reservoirs. Also, the materials and methods employed for the study are enumerated below.

3.1 Study Area

The Upper East Region (UER) is located at the North–Eastern part of Ghana between latitudes 10°30'' and 11°15'' North and longitudes 0° and 1°30'' West. It is situated in the center of the Volta Basin; bordered by Burkina Faso to the north and Togo to the eastern part. The regional capital is Bolgatanga with other important towns such as Bawku, Navrongo and Paga. The major ethnic groups are the Bimoba, Bissa, Buli, Frafra, Kantosa, Kasem and Kusasi and has a land area of 8842 km^2 which is approximately 3.4%the total land mass of Ghana and is predominantly rural (87%). The region has a population of 1,046,545 which is made up of 506,405 males and 540,140 females (GSS Report, 2012). According to the Statistical Department of Ghana report in 2012 the Upper East Region has a poverty incidence of 88% making it the region that has the highest number of poor people in the country.

3.1.1 Site selection

The Tono and Vea Irrigation schemes of Irrigation Company of Upper East Regions (ICOUR) were selected for the study, out of the over one hundred and sixty (160) reservoirs used in irrigation in the Upper East Region (Van de Giesen *et al.*, 2002).

These sites were selected based on the following criteria;

- Perennial Reservoirs (i.e. reservoirs that do not dry up during the dry season)
- Availability of data

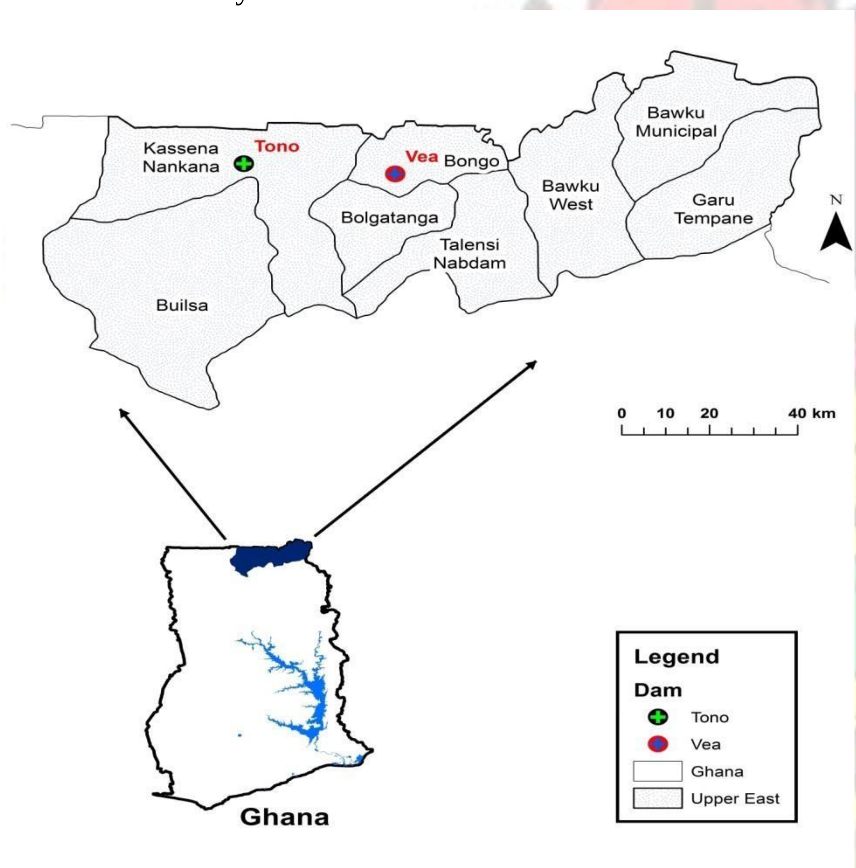


Figure3. 1 The Study Area

3.2 Data Collection

Data was collected from both primary and secondary sources. The primary data, the different types of crops under irrigation were identified. There were also stakeholder consultations and interviews with other irrigation partners such as Heads and coordinators of Environmental Protection Agency (EPA), White Volta Basin (WVB) of the Water Resources Commission and Ministry of Food and Agriculture (MOFA) and the farmers.

Secondary data were historical meteorological data such as rainfall, temperature, relative humidity, wind speed and sunshine hours for the study area. These were collected from the Ghana Meteorological Agency‟s Head office in Accra and used as the baseline data for climate analysis. Areas of land cultivated each year were obtained from official records of Irrigation Company of Upper Region (ICOUR). Also, relevant literature such as peer reviewed journals, text books was obtained through internet and library search.

The CROPWAT 8.0 and CLIMWAT 2.0 software were downloaded from the internet (**http://www.fao.org/nr/water/infores_databases_cropwat.html**) for the purposes of validation and computation of the crop water requirements of the individual crops.

The simulation of the future climate was achieved by using a statistical downscaling web portal developed by the Santander Meteorology group with technical assistance of the EU-funded ENSEMBLES project (Cofiño *et al.*, 2008).

3.3 Validation of Models

Validation of the various models for the study was conducted. This was done through statistical analysis and other scientific procedures to establish the relevance of the models to the study.

CROPWAT 8.0 model was used for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. For the calculation of crop water requirements, CROPWAT needs data on reference evapotranspiration (ETo) hence, the validation of the crop model was by evaluating the calculation of the potential evapotranspiration (ET_o) from full set climatic data (minimum temperature, maximum temperature, wind speed, relative humidity and sunshine hours of daily records) of the observatory baseline period of 1971-2000 into the CROPWAT 8.0 with that of data input from CLIMWAT 2.0 into the crop model for the semi-arid conditions of Navrongo. The estimated data was statistically analyzed to determine the root-mean-square –error (RMSE), slope and Mean Bias Error (MBE).

The downscaling portal validation was done in Perfect Prognosis conditions. The common historical period for predictors (re-analysis) and predictands (local observations) is split into training (the first 75%) and test (the last 25%) subsets. In the training phase the downscaling method was calibrated using the training data (e.g. the regression coefficients are fitted to the data), whereas in the test phase the method is validated on the test data (the test data is not used in the calibration phase and, thus, the results can be extrapolated to new datasets) (Guti´errez *et al.*, 2011).

The validation is performed automatically by the portal both on a daily and on a 10-day aggregated basis. In both cases, basic statistics (mean and standard deviation) and the interquartile range (IQR) of the observations and the downscaled predictions are calculated. The RMSE and MBE were also computed for the predictors and predictands.

3.4 Assessing Current Irrigation Demand and Evaporation Losses

Historical water abstractions from the Tono and Vea reservoirs was determined from the crops cultivated, areas of land cultivated and the efficiency of the irrigation as there were no available records of the abstractions from ICOUR. The irrigation needs of crops namely 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 that are irrigated with water from the reservoirs during the dry season.

The CROPWAT Model by the Food and Agriculture Organization was used to estimate Net Crop Irrigation Requirement (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 is based on Equation 3.01 given as

$$NIR = k_c \times ET_o - P_{eff} \tag{3.01}$$

Where, *NIR* is the net Irrigation Requirement (mm/d), the k_c Crop coefficient (dimensionless), the ET_o Potential evapotranspiration (mm/day); and P_{eff} the Effective precipitation (mm/month). Crop coefficient, k_c 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.

$$ET_o = \frac{\Delta\frac{(R_n - G)}{\lambda_w} + \rho_a C_p \frac{(e_s - e_a)}{\lambda_w}}{\Delta + \gamma_a\left(1 + \frac{r_e}{r_a}\right)} \tag{3.02}$$

Where ET_o is potential evapotranspiration [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 density at constant pressure [kgm^{-3}], C_p is the specific heat of the air [$MJkg^{-1}°C^{-1}$], Δ represents the slope of the saturation vapor 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 the input data below to compute NIR;

1. Climatic Data – Mean Monthly Maximum and Minimum temperatures (°C); Monthly rainfall (mm), relative humidity (%), monthly sunshine duration (hours) and monthly averaged wind speed (m/s)

2. Crop Data – the crop type and planting date. These data were ascertained from an interview with the agronomist on the project, the extension officers from MOFA and the farmers.

Table 3. 1: Growing periods of crops and their soil types as used in the CROPWAT model.

CROP	PLANTING DATE	HARVEST DATE	SOIL TYPE
Rice	November 5	April 4	Black Clay Soil
Tomato	October 20	March 13	Red Sandy Loam
Pepper	October 20	February 27	Red Sandy Loam
Onion	December 5	March 10	Red Sandy Loam

3. Other parameters such as the crop growth stage (days), depletion factors, crop coefficients, maximum rooting depth, yield response function and crop height are automatically displayed, as it is incorporated in the CROPWAT model based on the FAO Manuel 56 (Allen *et al.*, 1998). The model has a database of these parameters which are long time averages for different crops. The NIR was computed using the present long-term average (LTA) climatic conditions, 1971-2000 (baseline climatic data).

The Gross Irrigation Requirements (GIR) is then estimated from the NIR via an irrigation efficiency parameter (irr_{eff}), an indirect proxy of irrigation water loss. An irrigation efficiency of 0.5 was used in this study to represent the efficiencies that the schemes operated from 1985 to 2010.

$$GIR = \frac{NIR}{irr_{eff}} \quad (3.03)$$

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

For the computation of the evaporation losses for the reservoirs, a nine-consecutive year (i.e. 2001-2009) evaporation data from GMet was used to determine the mean (baseline) evaporation for the study. This was the only data available for the study area on evaporation. In estimating the evaporation losses for the dry-season, the evaporation for the seven-month dry season was multiplied by the respective maximum surface areas of the reservoirs.

3.5 Climate Change Scenarios Generation

Two well defined climate scenarios methods were used to create a set of future climatic conditions. These are Synthetic Scenarios method and Empirical Downscaling method.

3.5.1 Synthetic Scenarios Method

In this approach, synthetic scenarios were developed by uniformly increasing or decreasing the historical data sets. Temperature 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 for the 2020, 2050 and 2080 time slices.

3.5.2 Downscaling Method

In this project we used the ENSEMBLES statistical downscaling web portal (version 2) which was developed by the Santander meteorological group based in Spain (Gutierrez *et al*, 2011) .

The infrastructure of the portal is shown below in Figure 3.1.

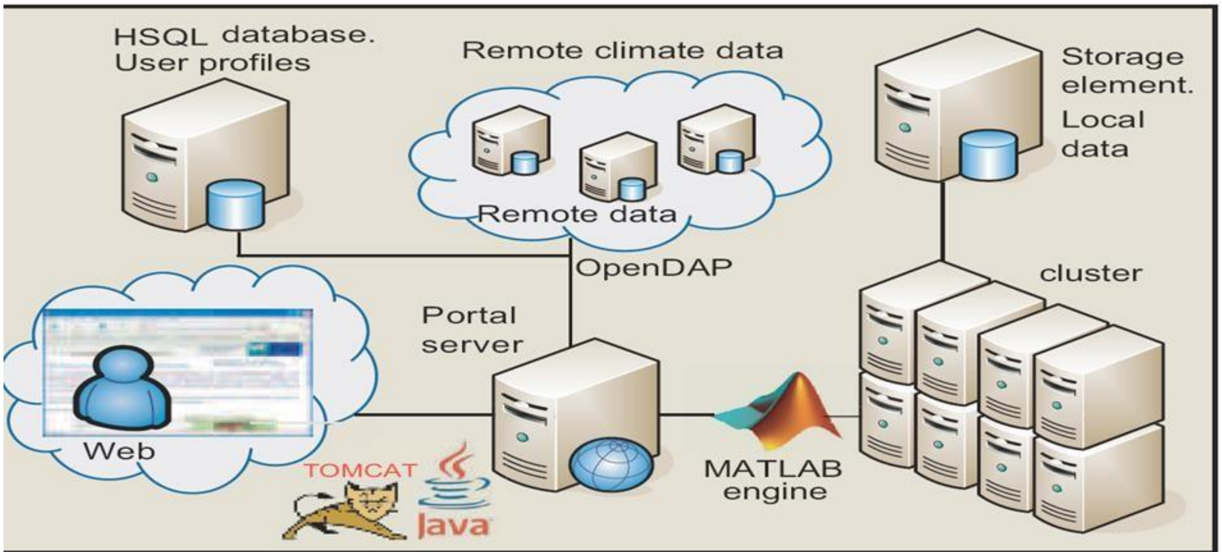


Figure 3. 2. : Schematic representation of the portal showing the Web and GRID components this portal can be accessed on the web at http://www.meteo.unican.es. (Cofiño *et al.*, 2008)

In this work the default analogue statistical downscaling method which falls into a weather typing method category is used. The common historical dataset was then used to calibrate and validate the downscaling method. Below is the procedure taken in downscaling portal. The portal has been organized in different windows (tabs) to gradually access the information necessary to define a downscaling task namely Predictor, Predictand, Downscaling Method and Downscale. The Predictor and Predictand windows correspond to the calibration/ validation of a particular downscaling method, whereas Downscale window runs the actual downscaling process, applying the calibrated method to different General Circulation Models (GCMs) and scenarios.

Each downscaling experiment contains all the information needed for the downscaling process: a unique set of predictors, a number of predictands and a number of downscaling methods. In defining an experiment the following three sequential steps were followed:

The predictors are first selected. Predictors are parameters that affect the local climate variable at that area. The ECMWF, ERA-Interim dataset that is from January I969 onwards (D.P. Dee *et al.*, 2011) was used over a spatial window covering latitude 9.97°N to latitude 12.04°N by longitude -2.46°W to longitude 0.7°E with grid point resolution of 0.75° by 0.75°. Commonly-used predictor variables at a continuous (00) and daily basis were used as shown in Table 3.2.

Table 3. 2: Description of the variables, height levels and times (UTC) of the common set of parameters used. Time values daily refer to daily mean values, whereas times 00 refer to instantaneous values.

List of the Predictor Variables Used

Code	**Name**	**Levels (mb)**	**Time**	**Units**
Z	Geopotential	850	00 UTC	m^2s^{-2}
Q	Specific humidity	850	00 UTC	$Kgkg^{-1}$
T	Temperature	1000	00 UTC	K
V	V velocity	850	00 UTC	ms^{-1}
U	U velocity	850	00 UTC	ms^{-1}
MSL	Mean Sea Level Pressure	surface	DailyUTC	Pa

These variables are used to predict precipitation and temperature over the semi-arid areas of Ghana. The geopotential at 850mb is very significant over the tropics because of the higher temperatures in the tropics compared to 500mb geopotential being significant at the poles and sub tropics. Most of the lifting condensation level occurs at 850mb level. This is the level of significant wet bulb potential temperature. Specific humidity at this 850mb level determines cloud formation and hence the horizontal winds (U and V) determine the direction of the cloud systems. The horizontal winds V and U at the 850mb level carries moist air from the ocean and the dominant easterly clouds from the eastern high lands of Africa respectively. The sea level pressure or surface pressure also determines the moisture uptake into the atmosphere. (Gutierrez *et al*, 2011)

The available GCMs were the AR4-BCM2, -CNCM3 and -ECHAM5. However, the AR4-

CNCM3 was used because it had complete data for all the expected time slices

In selecting the predictand, the „predictand" window is activated. Here the synoptic stations of concern are chosen which consist of historical precipitation and temperature records for the reanalysis period (1969-2000). The Navrongo station was selected due to it being foremost a region under study and also using GMeT as input data for the portal.

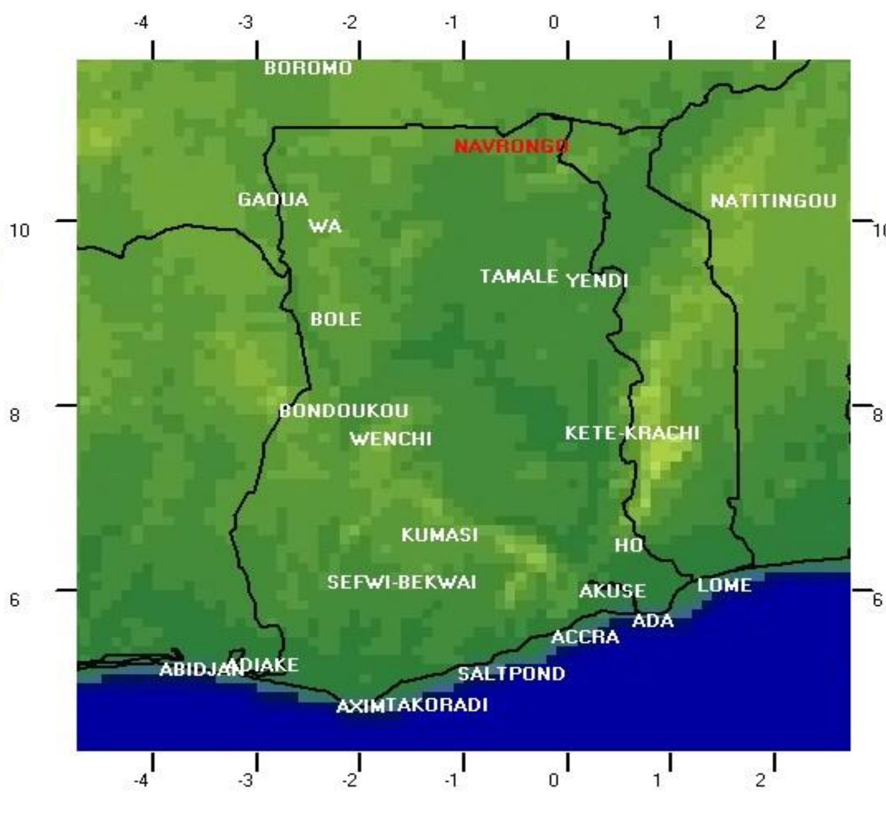


Figure 3. 3: Selecting the predictand domain.

The third step, thus the downscaling method then proceeds after the predictor and „predictor fields" have been successfully done with. The analogue statistical downscaling method is then selected and the downscaling performed thereafter. Automatic validation by the portal for the predictand is also carried out. The common historical dataset will then be used to calibrate and validate (see section 3.3) the downscaling method.

The final downscaling process is carried out by estimating and matching the measured result with the (IPCC 200/7) „climate change future scenarios „A1B‟ available for 2001-2100. The daily data from the available GCMs which have been validated at a daily basis for the different upper-level fields was included as predictors in the portal for this time period.

The real downscaling process is a prerequisite of the validation analyses. If the experiment proves sensitive (very accurate and reliable), then the results can be used to downscale for that location (station) with the available GCM scenarios to obtain the SD climate model for estimate at point specific.

3.6 Future Irrigation Water Demand and Evaporation Losses

Future irrigation demand was estimated based on the future climatic conditions generated. The same procedure and formulae used for the current irrigation demand was applied.

For estimation of the future evaporation losses, the Thornthwaite‟s formula for evapotranspiration was used. This empirical formula was chosen because it is dependent on mean temperatures which can be easily attained in this study for future projections.

The formula is generally, a correlation between temperature and sunshine and it is given as,

$$ET_x = 16\left(\frac{10T}{I}\right)^a \text{mm/month} \qquad (3.04)$$

Where, ET_x= Evapotranspiration [mm], T= mean temperature [°C], I= Yearly Heat Index and a, a constant can be estimated as follows:

$$I = \sum_{j=}^{12}\left(\frac{T_j}{5}\right)^{1.514} \qquad (3.05)$$

where, T_j is the mean temperature of the j^{th} month and

$$a = (675 \times 10^{-9})J^3 - (771 \times 10^{-7})J^2 + (179 \times 10^{-4})J + 0.492 \quad (3.06)$$

The formula was further simplified by Serra and these equations were obtained

$$I = 0.09t_n^{\frac{3}{2}} \quad (3.07)$$

$$a = 0.016J + 0.5 \quad (3.08)$$

Notably, ET_x is the theoretical evapotranspiration based on 30 days and 12 hours of sunshine per day. The actual potential evapotranspiration (ET_o) for a particular month with mean temperature T°C is given by;

$$ET_o = ET_x \left(\frac{DT}{360}\right) \quad (3.09)$$

Where, D=Number of days in the month and T= average number of hours between sunrise and sunset in the month.

The computation of the future evaporation losses for both reservoirs was undertaken in the same manner as with the computation of current evaporation losses in section 3.4

3.7 Climate Change Adaptation Strategies

The major stakeholders in the irrigation and agricultural sector in the UER such as the project Manager of ICOUR, Regional Director of EPA, Regional Director MOFA and the Basin Officer of the White Volta Basin were interviewed to know the potential climate adaptation measures that can be implemented to cope with climate change.

There was also a review of literature on other adaptations strategies from other countries to assess which of these could be implemented in the region.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

This chapter discusses the results and findings as established by this study. Firstly, the outcomes in validating the various models for this study are thoroughly addressed here. Also, the estimation of the historical and future water abstraction via irrigation of the four major crops and evaporation losses on the reservoirs during the dry-season is discussed here. This chapter further looks at the results from the projections of the future climatic conditions using the synthetic scenarios and empirical downscaling approach and their impacts on crop production in some extreme scenarios. Finally, some adaptation mechanisms that can be employed by the major stakeholders to manage the impacts of climate change are enumerated for consideration and the chapter concludes on an assessment of the limitations of the study.

4.1 Validation of Models

Validation of the various models (crop and climate) used for the study was conducted. This was done to determine the closeness of the model data to that of the observed data hence, their relevance as a tool for the study.

4.1.1 CROPWAT & CLIMWAT Models

CLIMWAT is a climatic database used in combination with the computer program CROPWAT and allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. The CROPWAT 8.0 and CLIMWAT 2.0 were used for this study.

In validating the crop model, the accuracy of the potential evapotranspiration, ETo (see eqn.3.02 and 3.06) in computing net water requirements, was estimated using the CROPWAT 8.0.

Climatic data from the CLIMWAT and GMet (field observed data) for the baseline period (19712000) of Navrongo was imputed into the CROPWAT model. The computed ETo from these sources were later compared.

The results revealed that the $ET_{o\text{-}crop}$ estimated from CLIMWAT i.e. climatological stations data through CROPWAT have good agreement with that of $ET_{o\text{-}ref}$ estimated from full set of climatic data. There is a good positive fit thus, a positive correlation between the predicted data from CLIMWAT and the actual data from GMet. The slope and coefficient of determination (R^2) were closer to 1 (i.e. 1.051 and 0.993 respectively) whilst, the root mean square error (RMSE) and mean bias error (MBE) values were around 0.260 mm/day and near to zero (-0.25), respectively. The statistical results show the accurateness of the crop model in estimating the ET_o hence, the net crop irrigation requirements.

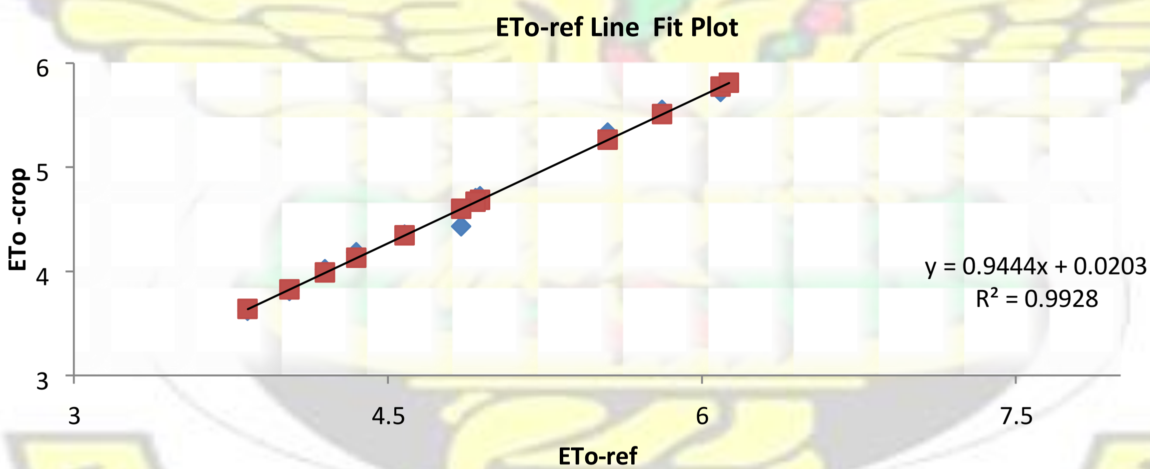


Figure 4. 1: A graph showing the 'Goodness of fit' plot for the ET_o of the reference data (19712000) and that of the CLIMWAT 2.0 using the CROPWAT 8.0 crop model.

4.1.2 Statistical Downscaling Model

The validation which is done on a perfect prognosis is performed automatically by the portal both on a daily and on a 10-day aggregated basis. In both cases, basic statistics (mean and standard deviation) and the inter-quartile range (IQR) of the observations and the downscaled predictions are calculated. The portal also includes several statistical metrics that best describe the portal"s sensitivity of a defined experiment. A summary of the results presented in (Appendix A)

Table 4. 1:Summary of validation results

CLIMATE VARIABLE	RMSE	MAE	R^2
Maximum Temperature	0.821°C	0.028°C	0.960
Rainfall	24.15mm	-4.865mm	0.924

Table 4.1summarizes the root mean square error (RMSE), mean absolute error (MAE) and the coefficient of determination (R^2) analysis that was computed on the 30-years (i.e. 1980-2010) climatic conditions (i.e. maximum temperature and rainfall) measured by GMet (field observed) and the downscaling model (predicted).The results demonstrates the models ability in simulating the future climate conditions for the semi-arid region of Navrongo.

The downscaling portal did not have GMet minimum temperature data for the area hence it not being validated.

4.2 Historical Water Abstraction Baseline and Evaporation Losses

The storage capacities of the Tono and Vea Dams are approximately $93Mm^3$ and $16Mm^3$, respectively. The reservoirs were initially built with the ultimate intention of boosting agriculture through irrigation. This is evidenced from the IDA report that stated that, out of the $93Mm^3$ storage capacity of the Tono Dam, $37Mm^3$ representing about 40% was allocated for irrigation purposes (IDA, 1978). However, currently Vea supplies domestic water to the Bolgatanga Township distributing about 1,895,142 m^3 of water in 2010 whereas plans are advanced for the Tono Dam (that does not have records of domestic water abstraction) that currently supply water to ICOUR

Township 1 and 2, to start supplying water to the Navrongo township (from an interview with Mr. Thomas Sumboh, Deputy ICOUR Project Manager in November 2012).

The largest historical abstractions from the reservoirs are mainly for irrigation during the dry season while, little or no supplementary irrigation is practiced in the wet season. The computation of the water abstractions for the irrigation schemes, considered the four major crops (rice, tomato, pepper and onion) which are grown in the dry season. The computed crop irrigation requirement (CIR) from CROPWAT (see Equation 3.02), the cultivated land areas per crops and the irrigation efficiency was used to calculate the water abstracted for irrigation.

An irrigation efficiency of 50% was used in the computation despite the 65% (IDA, 1978), which the irrigation schemes were designed with. This efficiency is representative of the efficiencies of the schemes since inception, as a result of the deterioration and poor maintenance culture that the schemes have endured over the years.

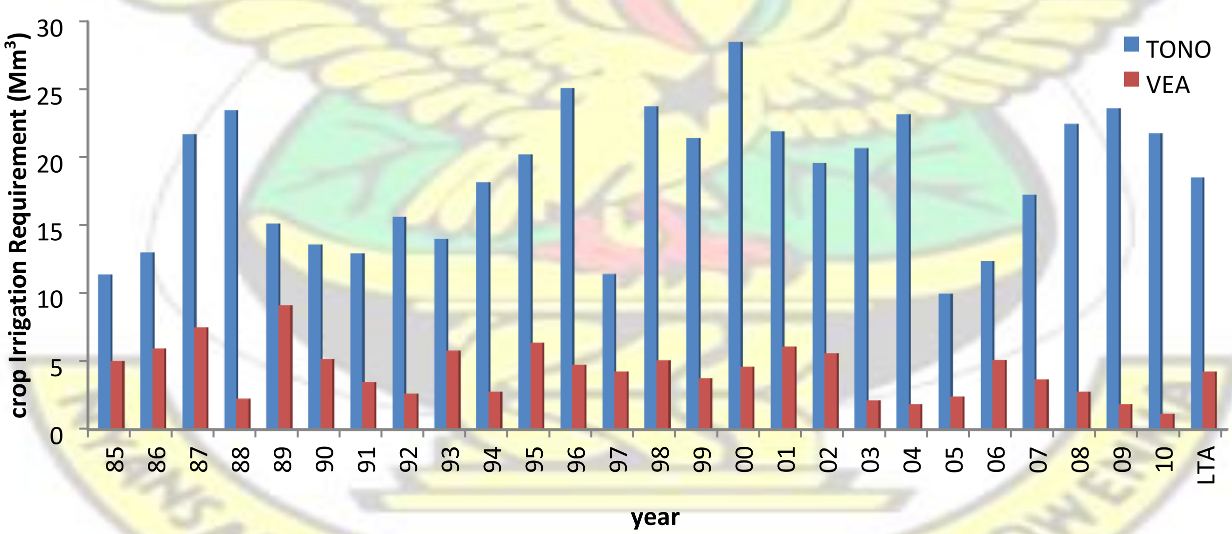


Figure 4. 2: Water abstracted for irrigation in the dry season from Tono and Vea Reservoirs (1985 – 2010)

From Figure 4.2, the maximum and minimum abstractions for the cultivation of four crops was 9.994 Mm^3 and 28.510 Mm^3 for the crop season of 2005-2006 and 2000-2001 respectively for the Tono reservoir whereas, on the Vea Reservoir a minimum of 1.162Mm^3 for the 2010-2011 crop seasons and a maximum of 9.133 Mm^3 for the 1989-1990 crop seasons were recorded (see Appendix B). The Tono Scheme recorded a long-term average (LTA) irrigation water abstraction of 18.562Mm^3 whilst that of the Vea was 4.276Mm^3. The quantity of water abstracted for irrigation, is dependent on the prevailing climatic conditions and the area of land under cultivation. With temperature being a factor of evapotranspiration, seasons with high temperatures will have high water withdrawals for irrigation, since more water will be required by the crops for growth.

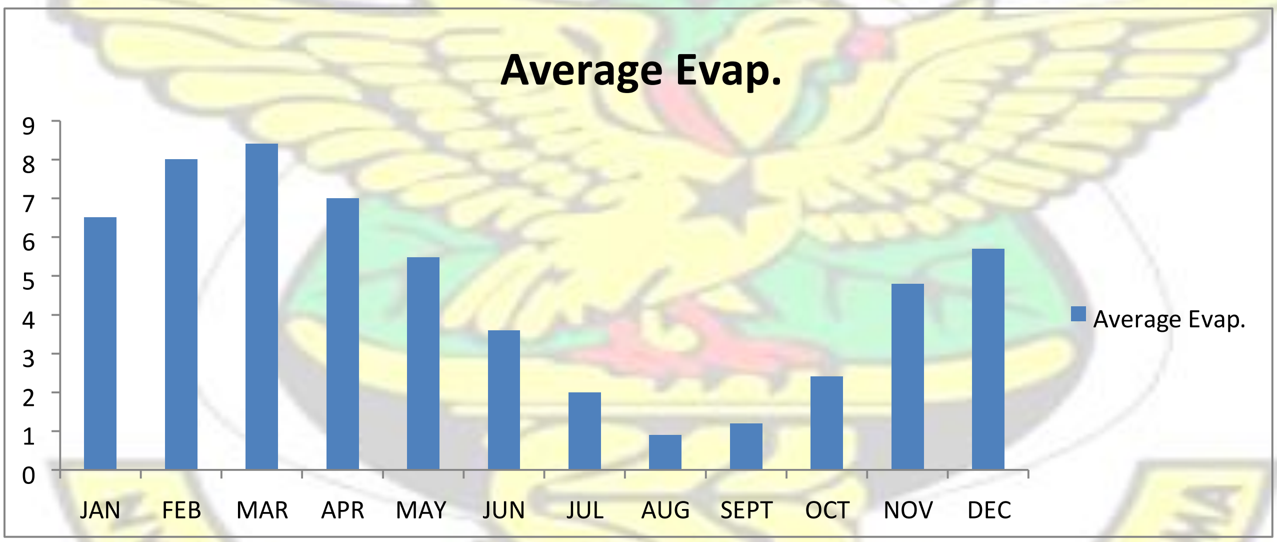


Figure 4. 3: Mean daily evaporation for Navrongo (2001 – 2009)

Figure 4.3, illustrates the mean water withdrawal from the reservoirs through evaporation losses in Navrongo for nine consecutive years (i.e. 2001-2009). The region being semi-arid has a 7month dry season, starting from the month of November to May (see Appendix D) with the month of March having the highest mean evaporation value of 8.4mm/day whereas, August experiences the lowest mean evaporation of 1.2 mm/day.

In determining the quantum of water loss through evaporation, for the dry season in the Navrongo area, an estimated total water loss of about 1,067.5 mm/dry season (i.e. for 7-month period) representing the potential evaporation for the months of November to May, was multiplied to the surface areas of the Tono and Vea reservoirs. The Tono reservoir with a maximum surface area of about 1860 ha loses about 20,460,000 m^3 (i.e.20.5 Mm^3) whilst the

Vea reservoir with its maximum reservoir surface area of about 405 ha also loses about

4,455,000 m^3 (4.5 Mm^3) of water during the dry season.

In determining the estimated total water abstracted (ETWA) for the baseline period, the water abstracted from the reservoirs for irrigation and that through evaporation losses were added hence, ETWA was 39.062 Mm^3 and 8.776 Mm^3 for the dry season of the baseline period for the Tono and Vea reservoirs respectively.

From Figure 4.2 and the analysis above, it can be realized that, the availability of water for irrigation was not an issue historically as the total irrigable lands of 2490 ha and 850 ha for the Tono and Vea schemes respectively were not fully cultivated hence, sufficiency of water for irrigation. Furthermore, of the 93Mm^3 capacity of the Tono reservoir, only about 42.04% of its volume of water was abstracted in the dry season via the irrigation of crops and losses due to evaporation. Likewise, about 54.8% of the total volume of water in the Vea reservoir was abstracted for this period. These dry season abstractions were all less than the 63% representing the total volume of water allocated for irrigation and evaporation (TWAIE) purposes per the design of both schemes (IDA,1978).

There is however, a possibility of increment in irrigation water use in the future as a result of climate change, extension of land under cultivation and increase in domestic water supply as a result of population growth and change in lifestyles due to affluence. These future incidents might lead to the reservoirs not yielding much to supply the required water for irrigation in the instance of cultivating the total irrigable lands.

4.3 Estimated Irrigation Needs

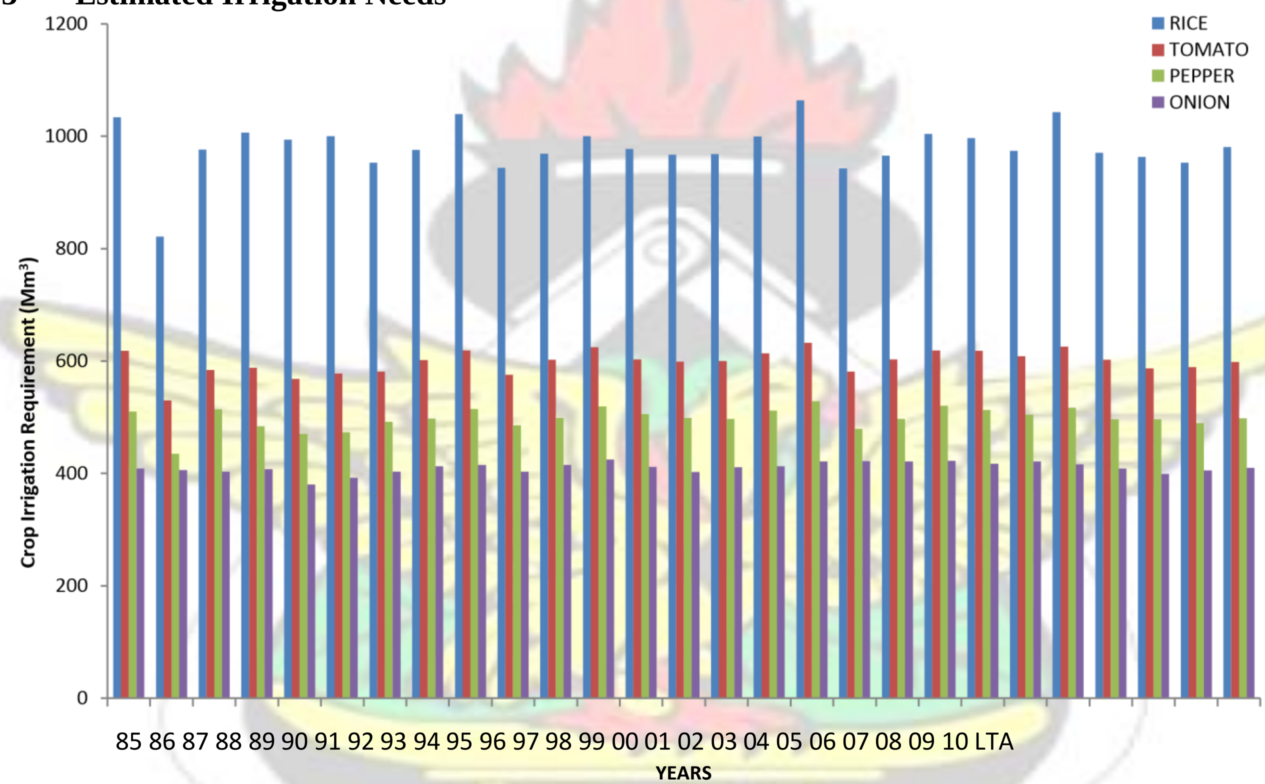


Figure 4. 4: Crop irrigation requirements of the four major crops grown in the dry season (1985-10)

The irrigation requirement of rice ranges from 821.2mm/period to 1063 mm/period with LTA of 980.9. The irrigation requirement of tomato ranges between 530.1 – 632.6 mm/period with LTA of 598mm/period and that of pepper ranges from 434.9mm/period to 528.3mm/period with LTA of 498 mm/period. The irrigation requirement of onion ranges from 380.1mm/period to 424.4mm/period with LTA of 410.1 mm/period (see Appendix C).

The theoretical computation of the irrigation requirements of the four major crops in Appendix C as demonstrated in Figure 4.4 is to serve as the irrigation baseline. The irrigation requirements were computed based on the climatic conditions that prevailed over those periods, the soil types used for the cultivation of the crops and the planting dates of these crops (see Table 3.1) which were determined by interviewing the agronomist on the schemes, the extension officers and the farmers. Other parameters such as the crop growth stage (days), depletion factors, crop coefficients, maximum rooting depth, yield response function and crop height are automatically displayed, as it is incorporated in the CROPWAT model based on the FAO Manuel 56 (Allen *et al.*, 1998). The model has a database of these parameters which are long time averages for different crops.

From Figure 4.4, it can be deduced that the irrigation requirement of the crops differs per year. This is because in the computation of the potential evapotranspiration ET_o, which is one of the functions of the crop irrigation requirement (see Equation 3.02), is dependent on monthly climatic data - temperature, relative humidity, wind speed and sunshine duration. For the computation of ET_o in this study, the maximum temperature was changed annually, with the rest of the climatic data being Long-Term-Averages (LTA) representing the baseline climate of 1971 – 2000 hence, unchanged. Thus, the changes in the evapotranspiration are as a result of the changes in temperature. The effective precipitation also changed annually unlike the other function of the irrigation requirement; thus the crop coefficient k_c, which is constant for different years therefore, the changes in the irrigation requirements, depends on the effective precipitation and potential evapotranspiration.

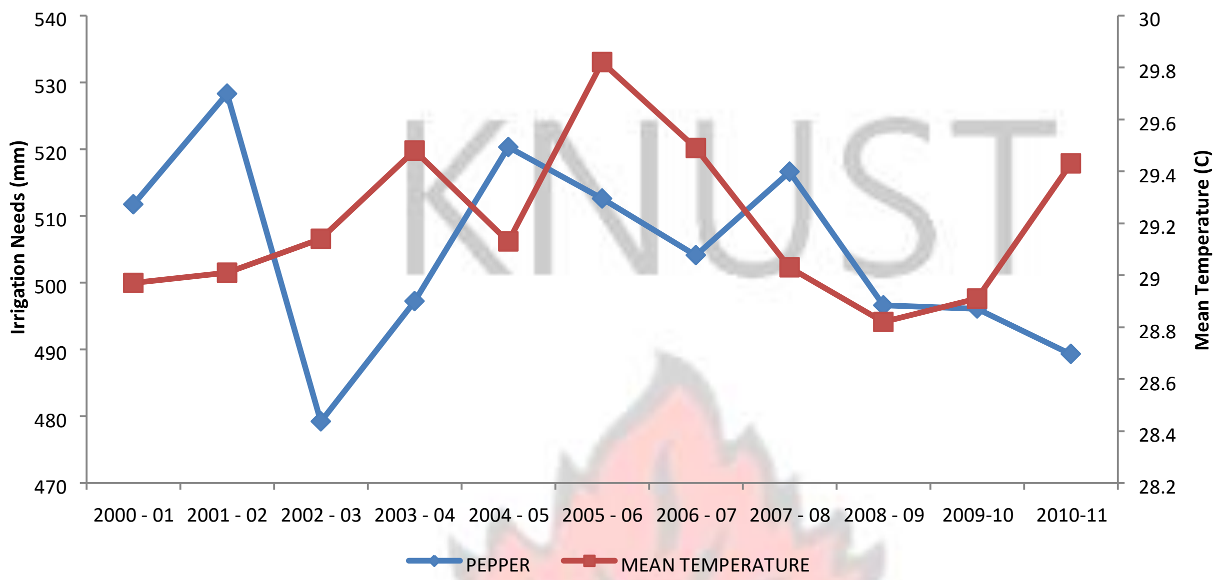


Figure 4. 5: Irrigation requirements of pepper

Considering the irrigation requirement of pepper over the past decade, i.e. 2001 -2010 (Figure 4.5). It will be realized, that generally increase in temperature increases evapotranspiration and therefore irrigation requirement. However, it was observed that a substantial rainfall during the growing season of the crops tends to reduce their irrigation requirement. For instance in the 2005 -2006 growing season higher temperature were recorded than the previous season 2004-2005 and therefore the irrigation requirement should have been higher than the previous. However, the irrigation requirement of pepper in that season was smaller than that of the previous year because it rained as much as 1044 mm/year during 2004-2005 plant seasons as compared to the 750.1 mm/year in 2005-2006 as can be seen in Appendix D. Furthermore, a similar incidence can be realized in the 2010-2011 growing season when though temperature was high the irrigation requirement was low for that year as compared to that of the preceding year. Similar analyses were made for the remaining three crops viz rice, tomato and onion (see Appendix H). The comparative studies re-emphasized that rainfall and temperature changes affected irrigation requirements hence, an indication that future changes in temperature and rainfall will affect irrigation requirements.

4.4 Climate Change Scenarios

The Scenarios were generated with respect to the baseline climatic conditions 1971-2000.

4.4.1 Synthetic Scenarios Method

As postulated by Doll (2002); climate change is changes in the long term averages of precipitation and temperature only, hence, the baseline temperatures for Navrongo were uniformly increased by 1°C, 1.5 °C and 2°C to represent future climate 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. Temperatures and rainfall values for the year 2020, 2040, 2060 and 2080 are shown in Figure 4.6 (Appendix F). The increase and decrease in baseline temperatures and rainfall were selected based on previous studies done by other researchers and organizations in the study area, such as the Environmental Protection Agency (EPA) of Ghana‟s publication on climate change in 2000 which predicted that the 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) as cited in Asante (2009) 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 or high scenario respectively as defined by Halsanes, (2008).

4.4.2 Statistical (Empirical) Downscaled Model Method

The output of the AR4-CNCM3 GCM in the statistical downscaling portal was used in this study. The AR4-CNCM3 model was selected and downscaled because it had complete data for simulation of the future climate for the various time slices for the Navrongo region. The SRES AIB (Nakicenovic *et al*., 2000) emission scenario as used by the IPCC in its Fourth Assessment Report (AR4) was used for the downscaling process. The portal was unable to simulate for minimum temperatures due to high scores of missing daily minimum temperature values in the GMet field observed data, used as a predictand in the study hence, the baseline minimum Temperature were used for the respective future analysis . Figure 4.7, shows graphical representation of the future simulated climates for the 2020, 2040, 2060 and 2080 times slices.

From Figure 4.6, the simulated future climatic conditions (i.e. rainfall, minimum and maximum temperature) uniformly increase as in temperature-wise and also decrease as in rainfall-wise across all the time slices, due to the uniform application of values to the baseline climate conditions as discussed above (section 4.4.1)

The projection of the future maximum temperatures generally followed-closely the trend-pattern of the baseline temperature (Figure 4.7), although there are a few variations with some monthly projections which are expected with reference to historical trends (Appendix F). Example is the increase in the trend of February values across all the time slices as compared to that of the baseline; and a few exceptions such as the 2060 temperature values for September and the JuneJuly-August temperature values in the 2080 time slice.

From Figure 4.7, mean maximum temperatures, of the downscaled GCM (i.e. AR4-CNCM3) for the years 2020, 2040, 2060 and 2080 are compared graphically with the baseline temperature. It is realized that, there is a gradual annual averaged temperature increment of 1.3°C-3.0°C for the years 2020 to 2080. In 2020, the downscaled GCM model projects an annual average temperature increment of 1.3°C with an average increase in temperature for the 7-month dry season of about 0.97°C from the baseline, for the semi-arid region. Also, 2040 , 2060 and 2080 with simulated average annual temperature increase of 1.5°C, 1.45°C and 3.0°C, have a gradual temperature increment for their dry seasons – 1.01°C for 2040, 1.16° for 2060 and 2.73°C for

2080. The model thus hypothesizes that; there would be less change in temperature between the 20 year period between 2040 and 2060 as compared to that of 2060 and 2080. The projected maximum temperature corresponds to studies by Asante (2009), which projected monthly temperature for three time slices (i.e. 2020, 2050 and 2080) to increase on the average by about 0.6°C to 4.3°C, using two GCMs viz MRI-232A and ECHO-G. His projections although, seems to be on the higher side which might be due to the type of models and spatial resolutions used among other reasons which will be discussed further in this report.

The estimation of future evaporation loss for the region was determined by inserting the future mean generated temperature by both synthetic and empirical downscaled approaches into the Thornwaith‟s evapotranspiration formula (see equation 3.04). It was however, realized that there was no change in the future evaporation estimated by the evapotranspiration fomula as compared to that of its baseline value (i.e. 1067.5 mm/ seven-month dry season)

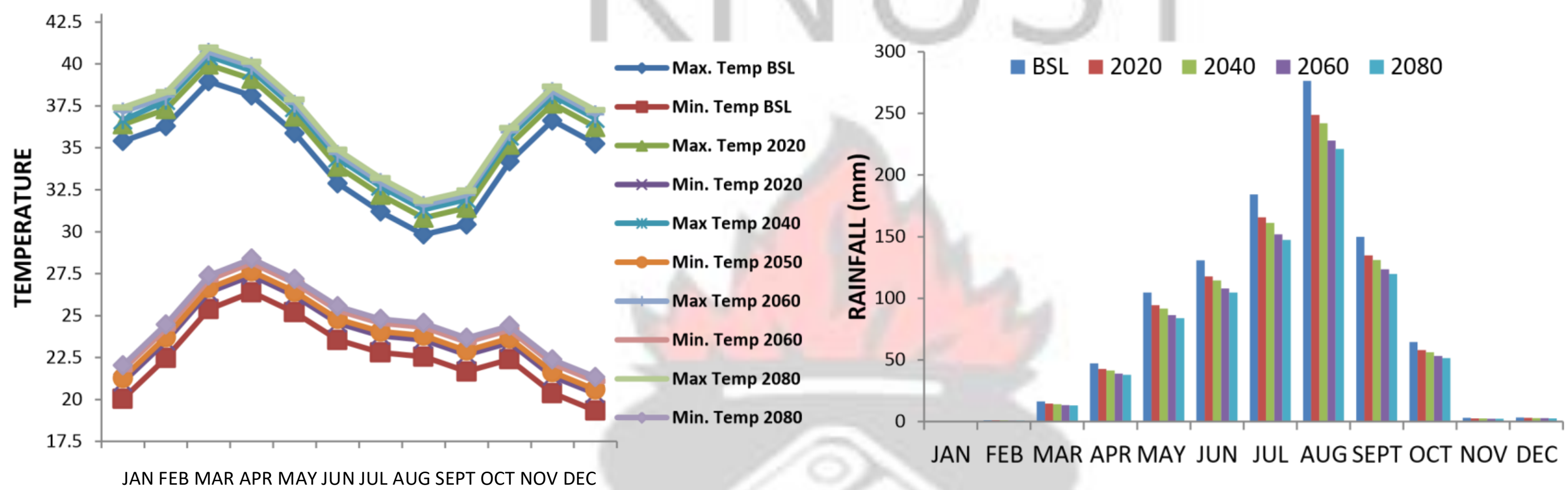


Figure 4. 6 : Monthly Mean Max.and Min. Temperature and Rainfall for the year 2020, 2040, 2060 and 2080 based on Synthetic Scenarios

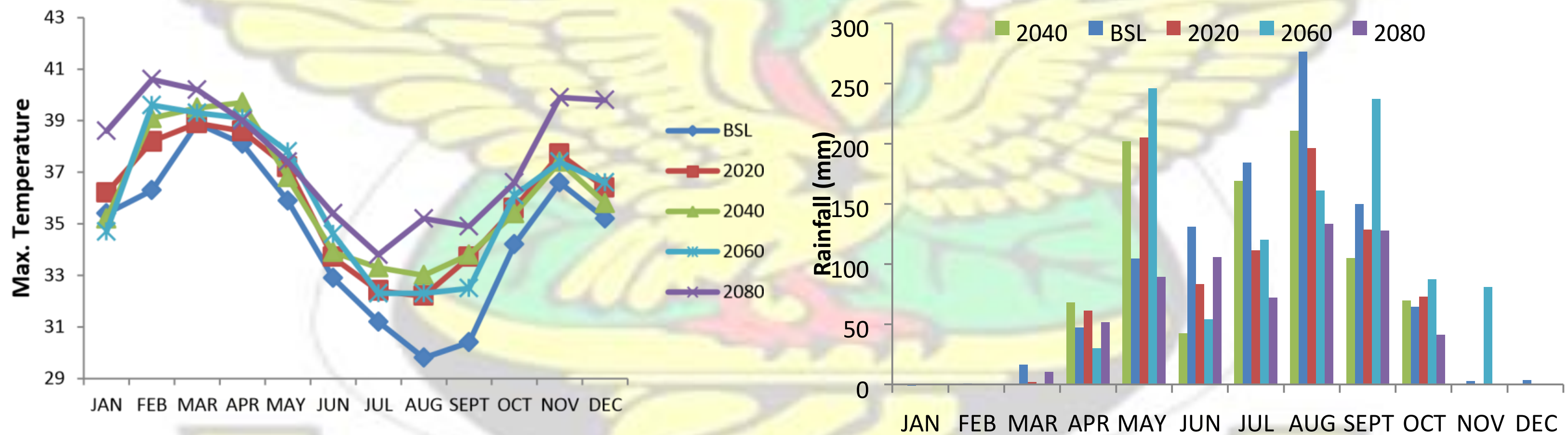


Figure 4. 7: Monthly Mean Max. Temperature and Rainfall for the year 2020, 2040, 2060 and 2080 based on AR4- CNCM3 Model

The IPCC, AR4 (Fourth Assessment Report) on Africa asserts that precipitation projections are generally less consistent with large inter-modal ranges for seasonal mean rainfall responses. These inconsistencies are partly due to the inability of the GCMs to reproduce the mechanisms responsible for precipitation including for example the hydrological cycle (Lebel *et al*., 2000) or to account for the orography (Hudson and Jones, 2002). They are also explained partly by the model limitations in simulating different tele-connections and feedback mechanisms which are responsible for rainfall variability in West Africa sub region. With these exposés, it is not surprising the nature of results obtained from the projections of the downscaled GCM model for precipitation for the time slices. They are inconsistent, pattern-wise with the baseline. Some of the projections deviate from the historical uni-modal rainfall pattern of the area. The downscaled GCMs model for the 2020 and 2080 comparatively do follow the pattern-trend of the baseline although there are significant variations as seen in Figure 4.7. These uncertainties make it difficult to provide any precise estimation of runoffs, especially of arid and semi-arid conditions where slight changes in precipitation can result in dramatic changes (Fekete *et al*, 2002).

There is a noticeable decrease in the amount of rainfall through the simulation of the future climate by the empirically downscaled GCM. The 2020, 2040 and 2080 projections recorded a decrease of 12.3%, 11.6% and 35.5% respectively, in the amount of precipitation in relation to that of the baseline. However, the 2060 projection indicated an increase in precipitation of 18.1% from the baseline rainfall. This is certainly due to the high variable rainfall pattern that the region experiences.

There was a significant decrease in the amount of rainfall in the dry season for the 2080 projections of about 23.93mm. Conversely, the amount of rainfall in the dry season for the 2020, 2040 and 2080 increased by 92.47mm, 94.47mm and 180.97mm respectively to that of the dry season in the baseline climate. Projections on rainfall made by Asante (2009) on Navrongo claim, rainfall would decrease by 5%, 16% and 32% for the 2020, 2050 and 2080 time slices respectively; using the ECHO-G GCM and this corroborates with this study findings although there are some variations.

The projections for the three years 2020, 2040 and 2080 runs in tandem with the assertion made by Obeng (2005) and (Asante, 2009) that rainfall in the semi-arid regions will keep on declining. This assertion that rainfall will keep on declining in the Upper East Regions should however, be looked into as it has been shown that inter-seasonal rainfall could either decrease or increase as predicted by the model for the 2060 projections. Historical trends of rainfall in the study area also show that, there is high variability in the rainfall pattern with years of good rains and vice versa. The model predicts that there will be years when the rainfall in certain months will be higher or lower than that of the baseline.

In so far as rainfall is predicted to increase or decrease in certain months, only the rains during the growing period of the crops (in this case the dry season see Table 3.4) have influence on their irrigation requirement.

4.5 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 the synthetic scenarios and the empirical downscaled GCM scenarios. Table 4.2 shows the irrigation needs of the four crops for the synthetic scenarios and the empirical downscaled GCMs model (i.e. AR4- CNCM3) for the year 2020, 2040, 2060 and 2080. The climate conditions of the future time slices differ from those of the baseline and these changes lead to different net irrigation water requirements of the four major crops irrigated in the study area. The result in Table 4.2 shows that variations in temperature and rainfall in the future have effect on crops net irrigation requirements thus, impacts of climate change. Table 4.3 shows the percentage changes of net irrigation water requirements relative to the baseline.

A perfunctory comparison of percentage changes of irrigation needs of the entire crop shows that rice would have the least percentage change in almost all the climate change scenarios but this does not necessarily mean that, rice will be the least affected by climate change. Based on the future projections by both the synthetic scenarios and the empirical downscaled GCM model, rice would be most affected by climate change . Its irrigation requirement as projected by the synthetic scenarios will increase by 14.4mm/period, 25.8mm/period, 32.4mm/period and 57.4mm/period for the period 2020, 2040, 2060 and 2080 respectively; when compared to other crops as shown in Table 4.3.Based on the empirically downscaled GCM model (i.e. AR4CNCM3 model) scenario also ,its irrigation requirement will increase by 16mm/period, 47.6mm/period and 58.8mm/period for the 2020, 2040 and 2080 period. There seem to be an anomaly in the irrigation requirement for majority of the crops under the 2060 empiricaldownscaled-future-climate-condition-projections. Whilst, all the CIR from its estimates (i.e GCM CNCM3) increases for all the other time slices it decreases for the year 2060 only thus, less water would be required for irrigation (see Table 4,3). This might be due to the significant variations in climate for this particular year (See Section 4.4.2). Even though, the percentage changes in irrigation requirements of pepper and onion are higher than those of rice and tomato, the actual increases in their irrigation requirements and their irrigation needs in the baseline are less than rice and tomato.

It can be deduced generally in theses simulations that, the higher temperature and altered rainfall regimes impacted on the net irrigation requirement (NIR) by affecting crop evapotranspiration and thus crop water demand. The significant changes in the NIR, as projected by the empirical downscaled scenarios might have a potential impact on yield, physiological and nutritional qualities of the crops. Depending on the climate change scenarios and time slices, the net irrigation water requirements of the four crops will be increased by about 1.49 to 9.67 %.

Table 4. 2: Impacts of climate change on net irrigation water requirements of crops, (mm/period) in future climate scenarios

		2020		2040		2060		2080	
CROPS	Baseline	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Rice	969.6	984	985.6	995.4	988	1002.6	908.7	993.8	1028.4
Tomato	589.3	603.7	613.4	609.1	611.1	614.2	575.5	618.1	646.3
Pepper	493.5	505.3	509.2	509.6	505.1	513.9	429.2	517.2	541.1
Onion	404.4	412.5	421.4	421	412.8	438.5	408.3	421	439.9

Table 4. 3: Percentage changes (%) in net irrigation water requirements of crops between climate scenarios

		2020		2040		2060		2080	
CROPS	Baseline	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Rice	0.00 0.00	1.49	1.65	2.66	1.90	3.40	-6.28	2.50	6.06
Tomato	0.00	2.44	4.09	3.36	3.70	4.23	-2.34	4.89	9.67
Pepper	404.4	2.39	3.18	3.26	2.35	4.13	-13.09	4.80	9.64
Onion		2.00	4.20	4.10	2.08	8.43	0.96	4.10	8.78

4.6 Future Water Abstraction Scenarios

The future climate conditions generated by the climate change scenarios (see section 4.4) were used to estimate the future abstraction from the Tono and Vea reservoirs for the cultivation of the four major crops (rice, tomato, pepper and onion) during the dry season together with the estimated evaporation losses for the region. The future climate conditions generated by the climate change scenarios make it possible to compare how abstractions from the reservoirs would be affected by climate change.

Estimation of future abstraction from the reservoir for irrigation purposes were done considering two extreme scenarios. The first scenario, considered the maximum historical land areas as used for the cultivation of the four crops (i.e. over the period 1985 to 2010) see Appendix E, as plausible areas that could be irrigated in the future. The second scenario, also considered the total irrigable area allocated for farming in both irrigation schemes for the cultivation of rice only, for the years 2020, 2040, 2060 and 2080. The irrigation efficiency for these scenarios was assumed to be the same as the baseline period (50%) and the calculation of climate change impacts, irrigated land extents were kept the same for the years 2020, 2050 and 2080.

4.6.1 Future Cultivation Based on Maximum Land Areas for Crops between 1985 2010

Table 4. 4: Areas under cultivation in the future based, on maximum land areas (ha) cultivated for 1985 – 2010 for Tono and Vea Irrigation schemes.

CROP	TONO	VEA
Rice	1227.74	280
Tomato	805	314
Pepper	85.63	5
Onion	56	10
Total	**2174.37**	**609**

Table 4.4 shows details of land areas that could be irrigated in the future based on maximum land areas cultivated between the years of 1985 and 2010. The total areas that would be used for the cultivation of the four crops in the future, based on this scenario, fall within the total irrigable areas of Tono and Vea irrigation schemes (i.e. 2490 ha and 850 ha respectively).

A description report on the Tono Irrigation Development by the IDA (1978), postulates a 4.44Mm^3, 21Mm^{3}and 37Mm^{3}of water allocated for the purposes of domestic water supply for Navrongo, evaporation losses and irrigation purposes respectively. This represents 5%, 23% and 40% of the 93Mm^3 storage capacity of water in the Tono reservoir. Conversely, there is no available information on the water use allocations for the design of the Vea Dam, as ascertained from ICOUR and IDA. For the purpose of this study, 40% and 23% of the 16Mm^3 of the Vea Dam was assumed as the total water allocated for irrigation and losses through evaporation (TWAIE) respectively.

Figure 4.9 shows the future irrigation abstractions from Tono and Vea reservoirs for dry season farming when the maximum land areas are cultivated. From the abstraction historical data in Appendix B (Figure 4.2), the ETWA from the Tono and Vea reservoirs for the cultivation of the four major crops are 39.062 Mm^3 and 8.776 Mm^3 respectively. In Figure 4.9, future estimated irrigation abstraction would be higher than the historical abstractions based on the synthetic and empirically downscaled AR4-CNCM3 climate change scenarios.

A comparison of future irrigation abstractions when maximum land areas are cultivated to the maximum storage capacity of Tono and Vea suggests that, the future abstractions in the dry season would be between 57.22 – 61.81% and 83.31 – 90.43% of the storage capacities for both schemes respectively (see appendix I).

The future ETWA in Tono, from Figure 4.9 indicates water withdrawal through irrigation and evaporation would be lower than the 63% allocated TWAIE activities for all the future time slices in the case of the synthetic scenarios.

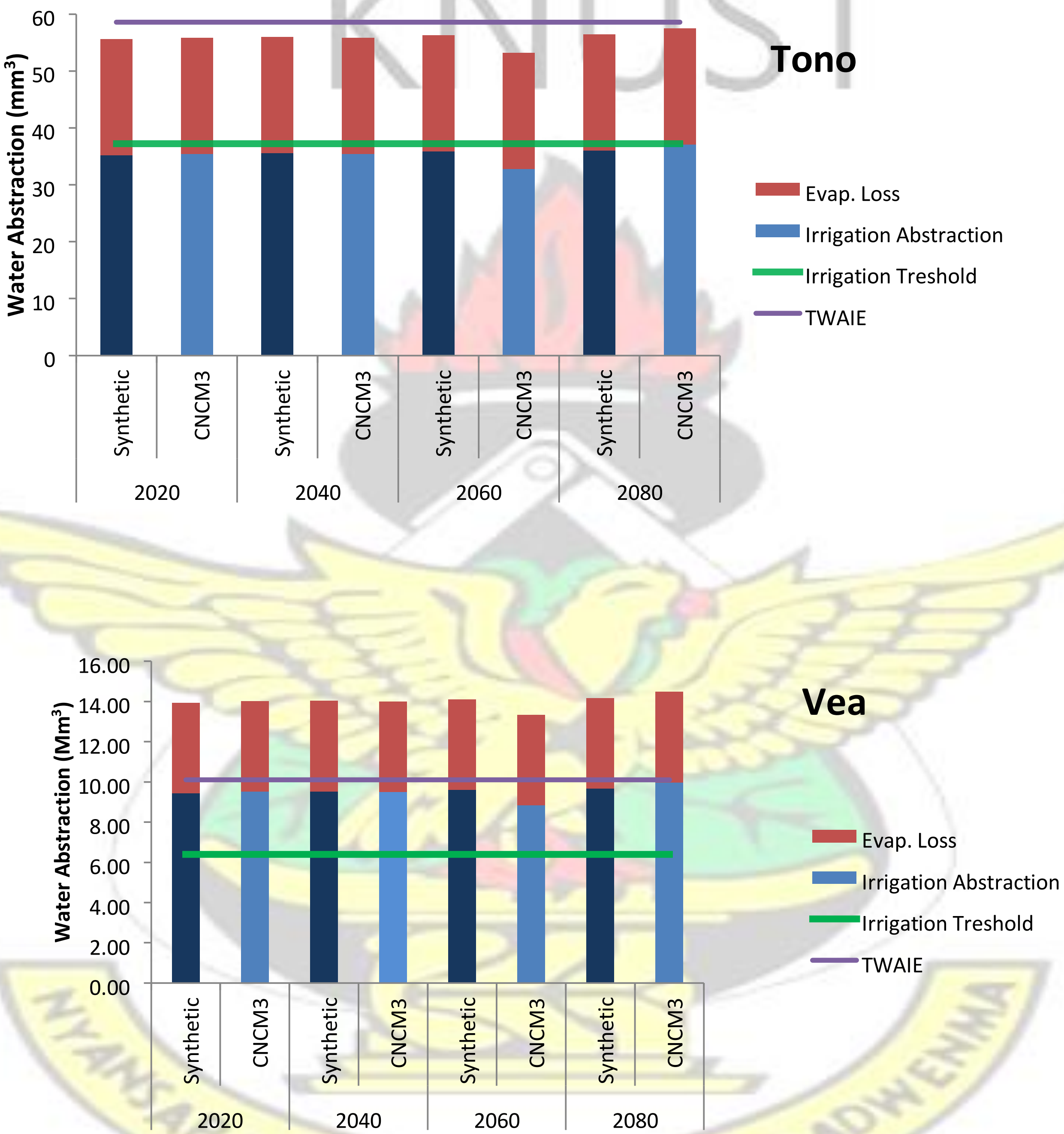


Figure4. 8: Future estimated irrigation abstraction (Mm^3) from Tono and Vea reservoirs when maximum land areas between 1985 -2010 are cultivated

The estimated total water abstracted (ETWA) from the Tono in Figure 4.9 is the combination of irrigation abstraction and evaporation losses on the reservoir.

Currently, the reservoirs also supplies domestic water and it is expected that the quantities abstracted for domestic use might increase in the future as a result of population growth and improved livelihood. The Tono reservoir, which has no historic domestic-water-supply abstraction data per design have capacity to supply 4.44Mm^3 of domestic water annually to the Navrongo Township. Nonetheless, from present (2012) investigations, the domestic water abstracted from the reservoir is negligible. This is because the villages served, have a population less than 500 people hence, future rise in domestic water abstraction would be relatively insignificant as deduced from Figure 4.9.

On the other hand, the projection of future ETWA for the Vea Irrigation scheme exceeds the 63% (10.08Mm^3) allocated for irrigation water use in all the future climate change scenarios (Figure 4.8). The future irrigation abstraction is expected to exceed the irrigation threshold between 3.23 – 4.37Mm^3. This means the reservoir might not suffice under such extreme conditions, as irrigation needs of the crops cannot be met otherwise resorting to cultivate these crops under this extreme condition would mean an adverse impact on other sector users of this water resource such as domestic water supply and livestock rearing. An antievaporation practices such as tree planting along river bodies and water conservation practices should be encouraged.

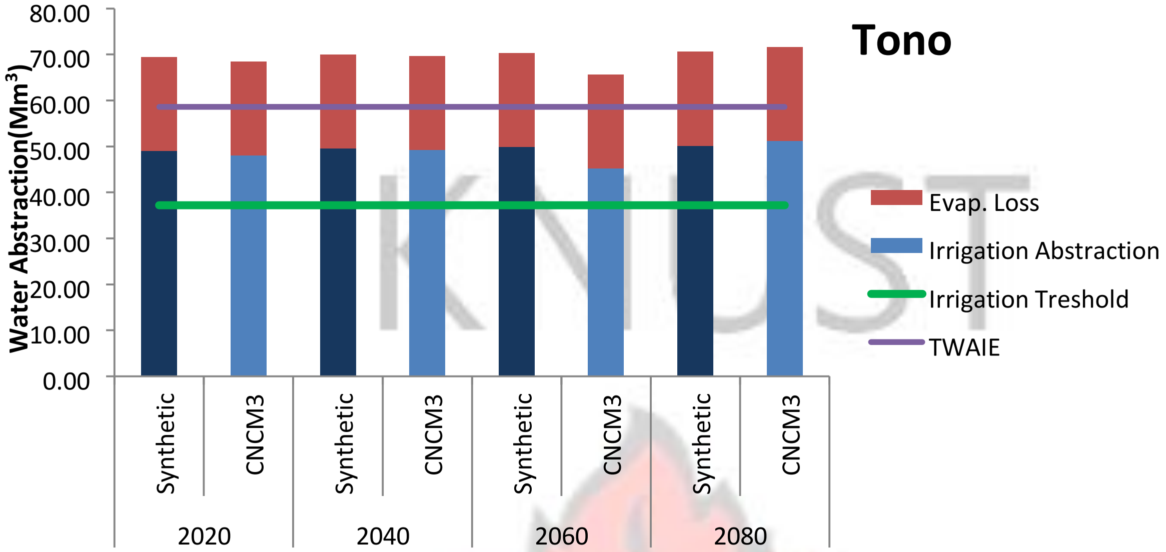
The 2011 annual report of the Ghana Water Company Limited (GWCL) indicates that 148,958m^3 of water was abstracted from the Vea reservoir in the dry season for the Bolgatanga Township (which has a population of about 66,685 people) as domestic water.

This domestic water use, represent about 0.93% of the maximum storage volume of 16Mm^3.

With a national growth rate of 2.5% (GSS, 2012) the dry season‟s domestic water abstraction is expected to increase to about 182,473.55m^3; 256,952.55m^3 , 331,431.55 m^3 and 405,910.55m^3 for the years 2020, 2040,2060 and 2080 respectively when projected linearly. The domestic abstraction for the dry season in the years 2020, 2040, 2060 and 2080 are about 1.14%, 1.63%, 2.01% and 2.54% respectively of the maximum storage. This projection indicates that in the future, the impact of climate change on the reservoir might be dreadful as anticipated by Asante (2010), who projected that by the year 2050 the volume of water abstracted for irrigation and domestic purposes would be over 85% of the maximum storage of the Vea instead of the projected 63% by this study without evaporation loss included. hence, measures should be put in place since with the expected increments, other sectors such as livestock rearing and fish ponding might not have sufficient water for their production.

4.6.2 Future Cultivation Based On Rice Production on All Irrigable Areas of Reservoirs

This extreme scenario considers the production of rice only. This is because rice is a crop that relatively consumes a lot of water for its cultivation as compared to the other crops grown during the dry season and also current market forces (i.e. consumer‟s preference for Burkina Faso‟s cultivated tomatoes) is driving majority of the farmers into sole rice production. Figure 4.10 shows the cultivation of only rice, on the total irrigable lands of Tono and Vea reservoirs respectively, for the future time slices.



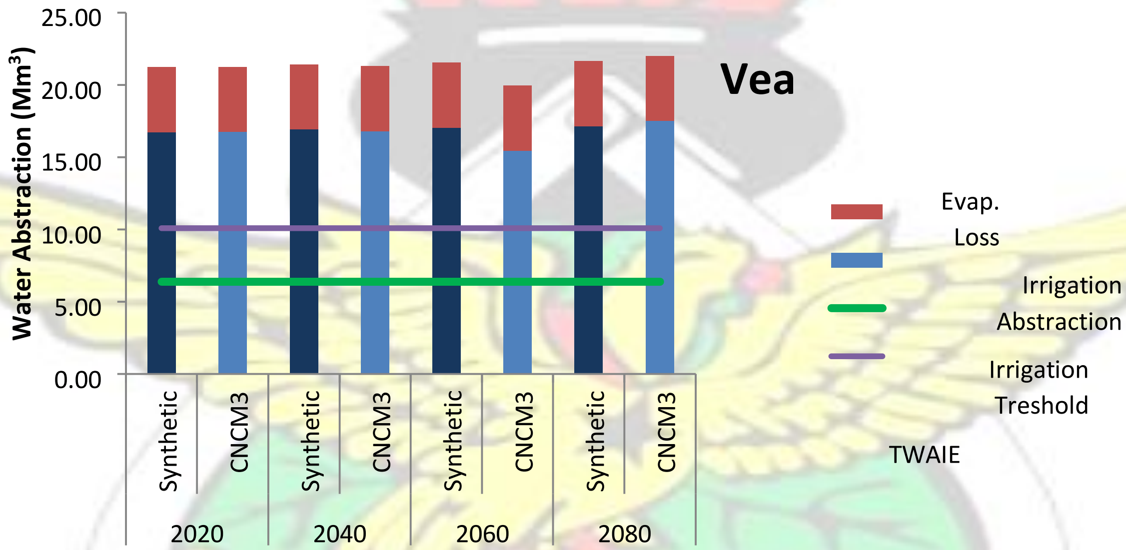


Figure 4. 9: Future estimated irrigation abstraction (Mm^3) fromTono and Vea reservoir when the total irrigable area is cultivated with rice only

From the figure above, it can be deduced that although the future irrigation abstraction from both reservoirs would exceed the TWAIE (i.e.63% reservoir-design-allocation for irrigation and evaporation purposes), the impact of climate change would be more pronounced on the

Vea reservoir than of Tono in the instance of cultivating rice only on their respective total irrigable lands.

On the average, from the synthetic and empirical downscaled climate scenarios, the Tono reservoir in the future , if rice is solely cultivated on its total irrigable areas ,would have its ETWA exceed its TWAIE by 7.80% - 13.99 % representing a volumetric change of about 7.25Mm^3 – 13.01Mm^3. This change might not have much significant impact on the other purpose-usage of the reservoir, such as domestic water abstraction, fish and livestock rearing among others; only if, enough water is stored during the rainy season and good reservoir management practices such as planting of trees along the boundaries are adhered to.

In the case of the Vea reservoir, there would be a significant impact of climate change in the instance of growing only rice on its total irrigable lands. The synthetic scenarios claims for growing only rice in the future, there would be the need to have an additional 3.95Mm^3 6Mm^3 of water in order to fully cultivate the crops. This would mean, the reservoir will not be in the capacity to cater for the other sectors (i.e. domestic water supply, livestock rearing and fish ponds) as more water would be required for the cultivation of the crops. On the average, the reservoir would require between 124.7% and 137.5% of the reservoirs storage capacity for irrigation in the dry season for the cultivation of rice only on its total irrigable lands not to consider losses through evaporation

This would deny other sector users, adequate access of water for their activities thence, ICOUR the project managers could therefore consider cultivating less water demanding crops at Vea during the dry season and shift more water demanding crops like rice to Tono reservoir where there is relatively abundance of water amidst good water conservation practices.

4.7 Climate Change Adaptation Measures

Plausible adaptation mechanisms and measures that can be implemented in the region was solicited via review of literature of areas of similar characteristics and discussions with some of the major stakeholders in irrigation and farming practices such as officials of ICOUR, IDA, MOFA and EPA. It is highly recommended that the Draft Formulation of a Regional Framework for the Adaptation of West African Agriculture to Climate Change and the Ghana Climate Change adaptation policy should be enforced.

Some adaptation measures that surfaced as key adaptation options to be observed by the community and the stakeholders in agriculture in the region should include diversification of livelihood activities, institutional architecture (including rules and norms of governance), adjustments in farming operations, income generation projects and commercialization of labor.

Bearing in mind of the fact that people can only adapt to climate change if they know the activities that cause it, is imperative that the 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 below and this hinges on areas such as the development of new crops varieties, time-change in operations, agro-forestry, biodiversity, soil and land management, water management and government support and policies.

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 foremost research institute namely, Crop Research Institute (CRI) are involved in the development of plant varieties that are more tolerant to adverse climate conditions.

Changes in the timing of operations are another adaptation measure worth considering. This involves changes in 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, mulching, planting, seeding and tillage. Changing the timing of these farm activities has the potential to maximize farm productivity during the growing season and to avoid heat stresses and moisture deficiencies.

The modification of current management of agricultural systems would greatly help mitigate global anthropogenic emissions. Rosenzweig and Tubeillo (2007), claims agriculture and its associated land use changes emit about a quarter of the carbon dioxide (via deforestation, soil organic carbon depletion, machine and fertilizer use); half of the methane and three-fourths of the nitrous oxide annually released into the atmosphere, hence a positive attitude by stakeholders towards tree planting would help in places like the Vea Reservoir area to curb the impact of climate change there..

In order to adapt to the impacts of climate change in the Upper East Regions, a higher resilience strategies against both excess water due to high intensity rainfall and lack of water due to extended droughts should be employed. The application of organic matter, instead of only inorganic manure to the land is a key approach that can effectively respond to these adverse conditions. 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 erosion and further downstream flooding. Also, the organic matter also improves the water absorption capacity of the soil during extended drought. Hence, farmers should be encouraged to apply organic matter fortified with inorganic fertilizer to reduce the impact of climate change. The cultivation of cover crops such as alfalfa on bare lands, maintenance of permanent soil cover and surface mulching have the capacity to increase soil organic matter, reduce impacts of flooding, drought, evaporation losses and a reduction in crop water requirements by about 30%.

During field visits on both reservoirs, it was observed that a greater percentage of water abstracted for irrigation did not get to the crops due to losses in the system via poorly constructed furrows by the farmers and ill-maintained canals of the schemes. Education on proper construction of furrows and irrigation technologies such as drip and micro-spray techniques should be introduced as it is being done on the Tono irrigation project. A culture of harvesting water such as run-offs and rainwater during wet seasons should be encouraged among farmers especially those near the Vea reservoir. Also as a good water management strategy, mulching should be encouraged, this would foster an increase in moisture retention in the face of decreasing rainfall and increasing evaporation and further curb the practice of over-irrigating leading to the incidence of salinization.

In places, such as Vea reservoir; where future projections indicate possible inadequacy of water for crop irrigation in the future, the substitution of growing cash crops such as mango which has a lower crop water requirement for rice cultivation is advised. Also, the transport of virtual water ought to be advocated for. In that, because it is water-costly to cultivate crops such as rice on our reservoirs; Rice can be either planted on bigger reservoirs that has enough capacity for its cultivation or imported from elsewhere, in order to have the reservoirs serve the communities without stress.

Government through its stakeholders in agriculture such as the Ministry of Food and Agriculture (MoFA) and the Environmental Protection Agency (EPA) should promote and enforce the adoption of adaptation measures through dissemination of information on climate change, possible impacts and vulnerabilities, potential adaptation options, among others.

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

4.8 Limitations of the Study

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

4.8.1 CROPWAT model limitations

The net irrigation requirements estimated neglected the impact of increased atmospheric CO_2 concentrations on crop physiology.

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

4.8.2 Empirical/Statistical Downscaling Models

The future climate for the Upper East region was modeled based on only one emission scenario, AIB. Other emission scenarios were not available for consideration for the region of study.

The downscaling portal did not have data for minimum temperature for the area. Hence, the future net water requirement from the crop model has its minimum temperature values being estimated as an average of the baseline period (i.e. 1971-2000).

The tropical regions with the study area being inclusive have strong ocean-atmosphere coupling which makes the simulation of future precipitation difficult.

GCMs generally do not consider the effects of increased CO_2 concentrations on plant physiology, which possibly leads to an underestimation of regional warming and an overestimation of humidity (and cloudiness) in particular over tropical continents (IPCC, 2001).

4.8.3 Overall limitation of the study

The study assumed that the future weather variations are only due to climate change. Other interesting factors such as the inter-annual and multi-decadal variability were not taken into account. These drivers have to be considered for more exhaustive analysis as they may have the ability to influence future weather trends, exacerbating and ameliorating the impacts of climate change.

Future plant adaptations, such as an increase in water use efficiency through a decrease in bulk stomata conductance as a result of increased atmospheric concentrations of CO_2 were neglected.

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

The inadequate data in the evaporation data for the area is of great concern.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Historical water abstraction for irrigation from Tono and Vea reservoirs ranged from 9.994 Mm^3 to 28.15Mm^3 and 1.162 Mm^3 to 9.133 Mm^3 respectively. The cultivation of the four crops in the dry season was far less than the respective maximum storage capacity of the reservoirs. Also, using the nine-year consecutive data of evaporation for the semi-arid region it was estimated that the total water loss via evaporation for the 7-month dry season was 1067.5mm/ dry season period. This means with evaporation losses in the semi-arid region the historical ETWA from the Tono and Vea Dams were at 39.062 Mm^3 and 8.776 Mm^3 respectively for the dry season. This also represents 42.04% and 54.8% respectively of their total respective storage capacities.

The results of the study, using the synthetic scenarios and empirically downscaled GCMs for future climate projections showed that with an increase in temperatures between 1°C - 3°C and a concurrent decrease in amount of annual rainfall (i.e. 1.3% -35.5%) in Upper East region there will be an incremental effect in the crop evapotranspiration which will further cause an increase in the irrigation requirements for all the crops between 1.4% to 9.8%. This will result in an increase in water abstraction from the reservoirs, therefore stored water in the reservoir should be utilized efficiently and the irrigation practice improved to minimize losses.

The impact of climate change on the Tono would be relatively small as compared to that of the Vea reservoir in the dry season. In the instance of cultivating the historical maximum land areas between 1985 and 2010 however, in the instances when all the maximum irrigable area is utilized for rice cultivation solely; the ETWA would exceed the TWAIE and this is likely to have minimal impacts on other sectors of the reservoir usage such as domestic water supply and livestock rearing.

Climate change would have drastic impact on the Vea reservoir in the future dry seasons under both extreme conditions; in that, in the instance of cultivating the historical maximum land areas for crops production for1985 to 2010; the water abstracted exceeds the TWAIE for the dam about 20.20% to 27.30% across the time slices. This means additional water resources would be required to cater for the unmet irrigation demand for the cultivation of rice only on the total irrigable area in the future. Hence, the reservoir would not have the capability to support other sectors of the community.

5.2 Recommendation

1. Studies into the inter-annual and multi-decadal variability of the climate, which contributes to climate change, should be considered in future studies.
2. Farmers should be encouraged on climate change adaptation measures through agroforestry, soil and water management such as conservation and application of organic manure.
3. Alternative sources of water for crop irrigation should be encouraged such as stern water harvesting culture during the raining season and groundwater usage.
4. Crop variations tolerant to adverse climate conditions should be cultivated because of future increase and reduction in temperature and rainfall, respectively.
5. Further studies on the impact of climate change in Upper East region using other downscaling portals and other GCMs scenarios should be employed.

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APPENDICES

Appendix A: Downscaling Model Validation results

Variable	IQR	Median	Missing	P90	Max	Sigma	Min	Mean	P10
Max.Temp.	5.5	35.3	18.75	40	44	3.60	22.8	35.16	30.6
Precipitation	0	19.80	8.85	7.6	148.2	8.81	0	2.68	0

THORNTHWAITE'S EVAPOTRANSPIRATION FORMULA

MONTH	Temp °C	Monthly Heat index, $j=(0.09*t^{3/2})$	Yearly Heat Index,I	a =(0.016J + 0.5)	ETx $42(10t/J)^a$	Number of Days,D	Average Number of Hrs,T	Evaporation(mm /month),PE=(DT/ 360)	Potential Evaporation ,ETo (mm/day)
Jan	**28.12**	13.42	171.42	3.24	208.95	**31**	**11.60**	208.71	**6.73**
Feb	**30.34**	15.04	171.42	3.24	267.34	**28**	**11.80**	245.36	**8.76**
Mar	**32.15**	16.40	171.42	3.24	322.61	**31**	**12.10**	336.14	**10.84**
Apr	**32.50**	16.67	171.42	3.24	334.14	**30**	**12.40**	345.28	**11.51**
May	**31.19**	15.68	171.42	3.24	292.55	**31**	**12.60**	317.42	**10.24**
Jun	**28.63**	13.78	171.42	3.24	221.49	**31**	**12.70**	242.22	**7.81**

July	**27.60**	13.05	171.42	3.24	196.79	**30**	**12.60**	206.63	**6.89**
Aug	**27.38**	12.89	171.42	3.24	191.75	**31**	**12.40**	204.74	**6.60**
Sept	**27.69**	13.11	171.42	3.24	198.76	**30**	**12.90**	213.67	**7.12**
Oct	**29.00**	14.05	171.42	3.24	230.91	**31**	**11.90**	236.62	**7.63**
Nov	**29.04**	14.08	171.42	3.24	232.07	**30**	**11.70**	226.27	**7.54**
Dec	**27.87**	13.24	171.42	3.24	203.10	**31**	**11.50**	201.12	**6.49**

Appendix B: Baseline Abstraction for Tono and Vea Irrigation Scheme

YEAR	Irrigation Abstraction (Mm^3) TONO	VEA
1985 - 86	11.374	5.020
1986 - 87	12.991	5.937
1987 - 88	21.720	7.487
1988 - 89	23.451	2.247
1989 - 90	15.109	9.133
1990 - 91	13.610	5.164
1991 - 92	12.923	3.454
1992 - 93	15.610	2.650
1993 - 94	14.011	5.781
1994 - 95	18.177	2.775
1995 - 96	20.204	6.390
1996 - 97	25.121	4.730
1997 - 98	11.425	4.272
1998 - 99	23.776	5.074
1999 - 00	21.406	3.747
2000 - 01	28.510	4.607
2001 - 02	21.938	6.108
2002 - 03	19.570	5.578
2003 - 04	20.677	2.138
2004 - 05	23.157	1.882
2005 - 06	9.994	2.404
2006 - 07	12.392	5.114
2007 - 08	17.230	3.666
2008 - 09	22.447	2.789
2009 - 10	23.588	1.877

2010 - 11	21.794	1.162
AVERAGE	18.538	4.272

Appendix C: Crop Irrigation Requirements of Major Crops grown in the Dry Season

YEAR	CROP IRRIGATION REQUIREMENT			
	RICE	TOMATO	PEPPER	ONION
1985 - 86	1034	618.3	510.3	408.6
1986 - 87	821.2	530.1	434.9	405.8
1987 - 88	976.5	584.3	514	402.8
1988 - 89	1006.5	588.1	484.1	407.8
1989 - 90	994	568	470.4	380.1
1990 - 91	1000.1	577.8	473.3	392.2
1991 - 92	952.8	581.2	491.9	402.9
1992 - 93	975.7	601.4	497.5	412.5
1993 - 94	1039.7	618.8	514.3	414.9
1994 - 95	944	575.3	485.5	403.1
1995 - 96	968.8	602	498.8	415.1
1996 - 97	1000.3	624.4	519.2	424.4
1997 - 98	977.6	603	505.3	411.3
1998 - 99	967.3	598.8	498.6	402.3
1999 - 00	968.5	600	496.9	411.1
2000 - 01	999.7	613.9	511.7	412.7
2001 - 02	1063.7	632.6	528.3	421.5
2002 - 03	942.5	581	479.2	422
2003 - 04	965.4	602.9	497.2	421.5
2004 - 05	1004	618.8	520.3	422.5
2005 - 06	996.9	618.4	512.6	417.1
2006 - 07	974.1	608.3	504.1	421.1
2007 - 08	1043	625.8	516.6	416.2
2008 - 09	970.7	602.5	496.6	408.9
2009 - 10	963.1	586.8	496.1	399.2
2010 - 11	953.2	589.3	489.3	405.5
AVERAGE	**980.9**	**598**	**498**	**410.1**

Appendix D: Historical Climate 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	9.4	37.8	113.1	179.2	248.8	142.4	447.7	41	5.8	1234.6
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	20.5	13.7	226.1	179	189.3	88.3	28.7	0	0	750.1
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 (°C) FOR NAVRONGO IN THE UPPER EAST REGION OF GHANA

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	
1971	35.7	36.8	36.6	34.9	33.1	31.2	29.7	29.5	30	32.7	35.4	34.6	
1972	36.2	38.1	37.1	34.4	32.7	31.7	31	30.2	30.5	32.5	35.2	35.2	
1973	36.4	38.8	38.3	37.5	35.4	31.9	30.7	8.6	30.1	33.8	36.3	36.3	
1974	34.5	37.3	37	36.4	34.8	31.9	29.5	29.6	29.9	33	35	34.3	
1975	34.4	37.1	37.5	34.5	33.4	31.3	29.4	30.2	30.3	32.6	35.6	34.4	
1976	34.8	38.6	39	33.5	34.7	31.7	31.8	30.3	31.9	32	34.7	35.5	
1977	36.2	3.2	38.1	38.8	36.2	33.5	31.5	30.2	31.3	34	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	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	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	35.6	34.8	
1983	32.1	38.2	39.6	40.6	36.1	32.5	32	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	36.3	36.4	39.4	38.9	37.4	33.5	30.8	30.2	30.7	35.2	37.4	33.6	.
1987	36.5	39.2	38.5	40.2	39	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	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	31.9	34.7	35.5	36.2	
1993	33.9	37.8	39.2	39.2	38.4	35.4	30.9	31	31.2	34.8	37.7	35.6	
1994	33.9	37.8	39.8	39.6	36.1	32.6	31.8	30	31.2	32.7	35.6	34.5	
1995	34	36.8	40.1	39.1	37.1	34.3	31.7	30	32.2	34.4	37.4	36.7	

1996	37.8	39.1	40	39.1	36.7	32	31.5	30.8	31	33.3	36.4	36.8	
1997	37	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	36.7	33.4	32	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	32	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	
2007	34.4	38.7	40.2	37.1	34.7	33.1	31.5	29.9	32.0	35.2	37.6	36.0	
2008	32.8	37.2	39.6	39.0	36.6	34.2	31.2	30.3	31.3	34.1	37.5	36.6	
2009	34.7	38.7	39.7	38.5	36.5	33.7	31.6	31.0	31.8	33.8	36.4	37.7	
2010	37.9	40.0	40.4	39.4	36.0	32.7	31.2	30.8	31.2	33.0	36.9	36.5	

MONTHLY MEAN MINIMUM TEMPERATURE (°C) FOR NAVRONGO IN THE UER OF GHANA												
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**

1971	19.1	23.1	24.6	24.1	23.5	22.2	21.9	21.9	21.3	21.9	20.9	20.6
1972	19.3	23.3	24.3	24.4	23.5	22.2	22.6	21.9	22.2	22	19.8	20.8
1973	21.5	23.7	25.3	25.6	24.5	22.9	22.9	22.2	21.8	22.5	20.3	19.8
1974	20.5	24.4	25.3	25.1	23.8	23	22	22.8	21.4	22.1	20	17.2
1975	17.6	22.4	24.4	24.3	24.1	22.7	22.2	22.3	21.9	22.1	21.1	19.3
1976	18.6	23.4	25.3	27.1	24.5	22.4	22.6	21.9	22.2	22	20.9	17.9
1977	20.6	17.7	24.3	27.1	25.5	23.9	23	22.3	22.3	21.8	19.5	18.8
1978	20	22.7	25.2	24.5	24.2	23.8	22.3	22.4	22.1	22.6	20.6	19.5
1979	20.6	21.4	26.3	27	24.8	23.2	22.4	22.7	22.3	22.8	21	19.8
1980	21.1	23.5	25	26.5	25.7	24.1	23.5	22.6	22.7	23	21.1	18.3
1981	19.3	22.8	25.6	26.7	25.2	24	22.9	22.6	2.2	22.4	20.2	18.6
1982	19	23	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	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	22.3	19.4	18.3
1987	20.4	22.5	24.6	26.9	27.3	24.1	24.1	23.2	22.7	22.9	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	26.2	24.4	24.3	23.1	22.9	23.2	22.2	20	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	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	25.9	24.5	23.2	22.5	23	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	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	22.7	22.3	22.4	20.5	18.7
2000	21.8	21	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	19.6	18.4
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	20.4	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
2007	19.4	22.5	25.4	26.0	24.8	24.3	23.1	22.3	22.9	23.4	21.8	20.3
2008	18.1	22.0	24.7	26.0	25.6	24.3	23.1	22.7	22.7	22.7	19.0	20.7
2009	19.3	24.0	26.5	26.2	25.7	23.9	23.0	22.9	23.0	22.9	21.0	19.1
2010	19.0	23.6	27.2	27.4	26.1	24.2	23.4	22.9	22.8	23.0	21.0	18.2

Appendix E: Baseline Climate For Navrongo (1971-2000)

MONTH	RAINFALL (mm)	MAX. TEMP (°C)	MIN. TEMP (°C)	RELATIVE HUMIDITY (%)	WIND SPEED (km/d)	DURATION OF SUNSHINE (hr)	Eto (mm/d)
JAN	0.19	35.4	20.03	25	104	9.1	4.94
FEB	1.09	36.3	22.47	27	112	8.9	5.55
MAR	16.26	38.96	25.39	37	112	8.5	6.09
APR	47.36	38.11	26.39	50	130	7.7	6.13
MAY	104.8	35.87	25.18	62	138	8.5	5.81
JUN	130.85	32.88	23.55	74	121	8.1	4.92
JUL	184.23	31.2	22.8	79	104	6.5	4.2
AUG	276.43	29.83	22.56	81	95	5.2	3.83
SEP	149.84	30.43	21.67	81	78	6.4	4.03
OCT	64.45	34.18	22.39	73	78	9.1	4.85
NOV	2.95	36.63	20.38	50	69	9.3	4.58
DEC	3.28	35.24	19.34	36	78	9.1	4.35

Appendix F: Future Climate Scenarios

Empirical Downscaling- AR4-CNCM3 Model

	2020		2040		2060		2080	
MONTHS	**TEMP**	RAINFALL	**TEMP**	RAINFALL	TEMP	**RAINFAll**	TEMP	RAINFALL
JAN	36.2	0	35.2	0	34.7	0	38.6	0
FEB	38.2	0	39.1	0	39.6	0	40.6	0
MAR	38.9	1.8	39.5	0	39.3	0	40.2	10.4
APR	38.6	61.3	39.7	68.2	39.1	30	39	52
MAY	37.2	205.3	36.8	202.2	37.8	246.1	37.4	89.6
JUN	33.7	83.3	33.9	42.6	34.6	54	35.4	106
JUL	32.4	111.4	33.3	169.1	32.3	120.3	33.8	72.2
AUG	32.2	196.4	33	210.6	32.3	161	35.2	133.5
SEPT	33.7	128.6	33.8	104.9	32.5	237.4	34.9	128
OCT	35.6	73	35.4	69.8	36.1	87.6	36.6	41.4
NOV	37.7	0	37.4	0	37.4	80.8	39.9	0
DEC	36.4	0	35.8	0	36.6	0	39.8	0

Synthetic Scenarios –

Maximum and Minimum Temperatures

	BASELINE (19712000)		2020(+1° C)		2040(+1.25° C)		2060 (+1.75° C)		2080	
MONTHS	BSL	Min. Temp BSL	2020	Min. Temp 2020	Max Temp 2040	Min. Temp 2050	Max Temp 2060	Min. Temp 2080	2080	Min. Temp
JAN	35.4	20.03	36.4	21.03	36.65	21.28	37.15	21.78	37.4	22.03
FEB	36.3	22.47	37.3	23.47	37.8	23.72	38.05	24.22	38.3	24.47
MAR	38.96	25.39	39.96	26.39	40.46	26.64	40.71	27.14	40.96	27.39
APR	38.11	26.39	39.11	27.39	39.61	27.64	39.86	28.14	40.11	28.39
MAY	35.87	25.18	36.87	26.18	37.37	26.43	37.62	26.93	37.87	27.18
JUN	32.88	23.55	33.88	24.55	34.38	24.8	34.63	25.3	34.88	25.55
JUL	31.2	22.8	32.2	23.8	32.7	24.05	32.95	24.55	33.2	24.8
AUG	29.83	22.56	30.83	23.56	31.33	23.81	31.58	24.31	31.83	24.56
SEPT	30.43	21.67	31.43	22.67	31.93	22.92	32.18	23.42	32.43	23.67
OCT	34.18	22.39	35.18	23.39	35.68	23.64	35.93	24.14	36.18	24.39
NOV	36.63	20.38	37.63	21.38	38.13	21.63	38.38	22.13	38.63	22.38
DEC	35.24	19.34	36.24	20.34	36.74	20.59	36.99	21.09	37.24	21.34

Rainfall (mm)

MONTHS	BSL	2020	2040	2060	2080
JAN	0.19	0.17	0.17	0.16	0.15
FEB	1.09	0.98	0.95	0.90	0.87
MAR	16.26	14.63	14.23	13.41	13.01
APR	47.36	42.62	41.44	39.07	37.89
MAY	104.8	94.32	91.70	86.46	83.84
JUN	130.85	117.77	114.49	107.95	104.68
JUL	184.23	165.81	161.20	151.99	147.38
AUG	276.43	248.79	241.88	228.05	221.14
SEPT	149.84	134.86	131.11	123.62	119.87
OCT	64.45	58.01	56.39	53.17	51.56
NOV	2.95	2.66	2.58	2.43	2.36
DEC	3.28	2.952	2.87	2.706	2.624

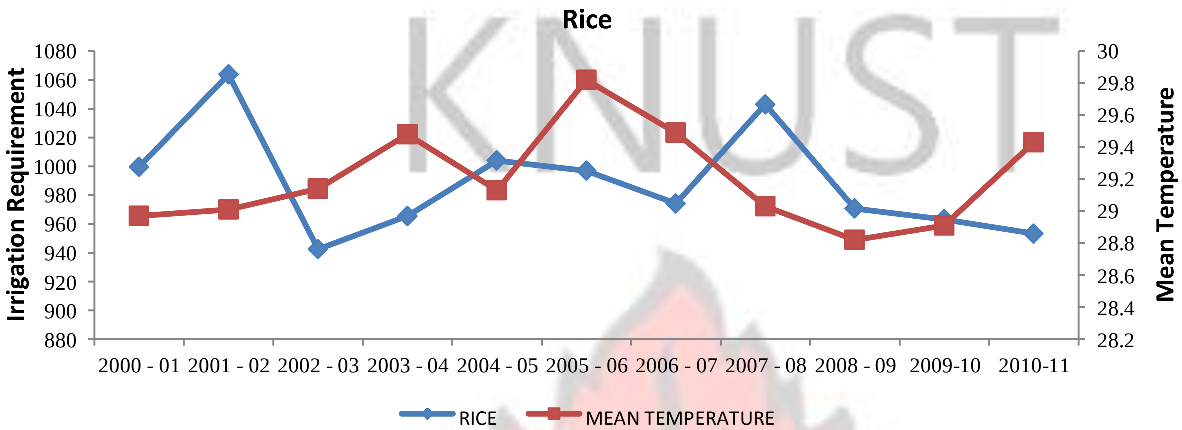
Appendix G: Land Areas under Cultivation

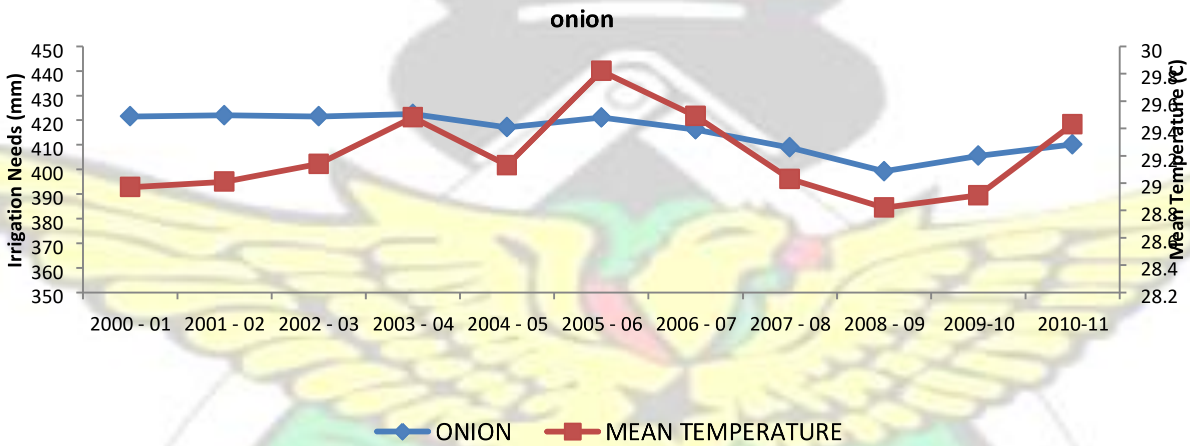
TONO IRRIGATION SCHEME					
YEAR	CULTIVATED AREAS (ha)				TOTAL
	RICE	TOMATO	PEPPER	ONION	
1985 - 86	550	0	0	0	550
1986 - 87	791	0	0	0	791
1987 - 88	1090	37	0	0	1127
1988 - 89	1165	0	0	0	1165
1989 - 90	736	42	0	0	778
1990 - 91	603	134	0	0	737
1991 - 92	572	174	0	0	746
1992 - 93	636	266	0	0	902
1993 - 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
2006 - 07	622	22.54	-	-	-
2007 - 08	685.62	152.46	85.63	24.28	947.99
2008 - 09	1050.51	170.35	-	-	-
2009-10	1114.17	146.4	39.09	3.85	1303.51
2010-11	1088.35	52.91	41.88	2.27	1185.41
2011-12	1227.74	17.53	72.16	9.14	1326.57

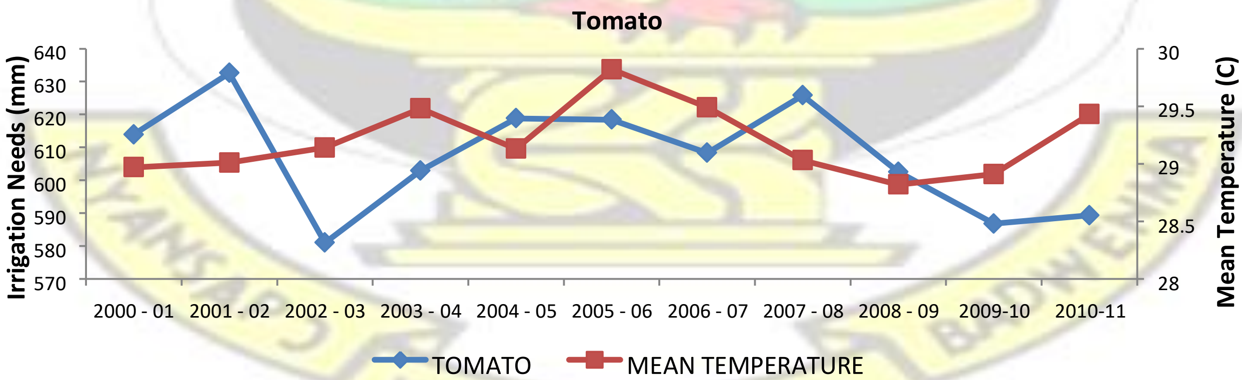
VEA IRRIGATION SCHEME					
YEAR	CULTIVATED AREAS (ha)				TOTAL
	RICE	TOMATO	PEPPER	ONION	
1985 - 86	162	136	0	0	298
1986 - 87	213	230	0	0	443
1987 - 88	217	278	0	0	495
1988 - 89	0	191	0	0	191
1989 - 90	280	314	0	0	594
1990 - 91	205	92	0	0	297
1991 - 92	80	166	0	0	246
1992 - 93	60	123	0	0	183
1993 - 94	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	167	198	2	5	372
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
2006 - 07	134.18	205.46	0	0	339.64
2007 - 08	136.02	65.63	0	1.31	202.96
2008 - 09	111.49	47.65	2.5	5	166.64
2009 - 10	75.28	31.84	3.2	4	114.32
2010 - 11	47.36	19.76	1.6	2	70.72
2011 -12	46.42	29.38	3.58	7	86.38

Appendix H: Irrigation Requirement of Rice, Tomato and Pepper







Appendix I: Estimation of Future Irrigation Abstraction for Tono and Vea Using Extreme Scenarios

Future estimated irrigation abstraction (Mm^3) from Tono and Vea reservoirs when maximum land areas between 1985 -2010 are cultivated

	TONO							
	2020		2040		2060		2080	
	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Irrig. Abstraction	35.21	35.42	35.59	35.43	35.85	32.81	36.06	37.08
Evap. Loss	20.40	20.40	20.40	20.40	20.40	20.40	20.40	20.40
Irrig. Threshold	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20
TWAIE	58.60	58.60	58.60	58.60	58.60	58.60	58.60	58.60
ETWA	55.61	55.82	55.99	55.83	56.25	53.21	56.46	57.48

	VEA							
	2020		2040		2060		2080	
	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Irrig. Abstraction	9.43	9.51	9.53	9.50	9.61	8.83	9.66	9.97
Evap. Loss	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Irrig. Threshold	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40
TWAIE	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10
ETWA	13.93	14.01	14.03	14	14.11	13.33	14.16	14.47

Future estimated irrigation abstraction (Mm^3) from Tono and Vea reservoir when the total irrigable area is cultivated with rice only

	TONO							
	2020		2040		2060		2080	
	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Irrig. Abstraction	49.00	48.10	49.57	49.20	49.92	45.25	50.21	51.21
Evap. Loss	20.40	20.40	20.40	20.40	20.40	20.40	20.40	20.40
Irrig. Threshold	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20
TWAIE	58.60	58.60	58.60	58.60	58.60	58.60	58.60	58.60
ETWA	69.40	68.5	69.97	69.6	70.32	65.65	70.61	71.61

	VEA							
	2020		2040		2060		2080	
	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3	Synthetic	CNCM3
Irrig. Abstraction	16.73	16.76	16.92	16.80	17.04	15.45	17.15	17.50
Evap. Loss	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Irrig.Threshold	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40
TWAIE	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10
ETWA	21.23	21.26	21.42	21.3	21.54	19.95	21.65	22