UNIVERSITY OF CAPE COAST

CLIMATE CHANGE IMPACTS ON THE HYDROLOGICAL PROCESSES OF DENSU RIVER BASIN (DRB) USING THE SWAT MODEL

JUSTICE ANKOMAH-BAFFOE

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BY

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Thesis submitted to the Department of Soil Science, School of Agriculture of the College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Land Use and Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:..... Date:.....

Name: Justice Ankomah-Baffoe

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:..... Date:.....

Prof. D. T. A. Okae-Anti

Co-Supervisor's Signature: ..... Date:.....

Dr. David O. Yawson

ABSTRACT

The impact of climate change is now posing a greater threat on the hydrological cycle leading to drought and water stress in small basins. Matters of climate change have now become a primary concern to most nations due to the implication on society and humanity. The study used 17 ensemble climate model from the Coupled Model Intercompersion Project Phase 5 (CMIP5) to estimate the future climatic condition for the 2050s (2035 to 2065) under Representative Concentration Pathways (RCP) 4.5 and 8.5. The Soil and Water Assessment Tool (Arc SWAT) model was used in assessing the effect of the generated climate change on the hydrological processes (rainfall, water yield, soil water storage and evapotranspiration) in the Densu River Basin (DRB). After calibration and validation of the SWAT model, there was a strong correlation between the simulated and the observed stream discharge with a coefficient of determination (R^2) of 0.84 for the calibration and 0.77 (validation). The CMIP5 estimated an annual mean increase of 2.7 ^oC and 1.3 ^oC for maximum and minimum temperature respectively and 20.1 mm in rainfall by 2050s. Simulation from ArcSWAT predicted an increase of 60% in actual evapotranspiration and 80 mm increase in soil water storage and a sharp decline of 23 mm in water yield by 2050s. The condition predicted in the future gives an indication that dry condition will occur at the DRB since increase in temperature and soil water aid increased evapotranspiration causing an acute decline in water yield which contribute to stream flow at the basin.

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DEDICATION

To Rev. Canon Edward Baffoe and Mother Cecilia Baffoe

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LIST OF ABBREVIATIONS

AR5	Assessment Report 5
CMIP5	Coupled Model Intercomparison Project Phase 5
DEM	Digital Elevation Model
DRB	Densu River Basin
ET	Evapotranspiration
EU	European Union
FAO	Food and Agricultural Organisation
GCMs	Global Climate Models
GCS	Geographic Coordinate System
GHG	Greenhouse Gas
GLUE	Generalised Likelihood Uncertainty Estimation
GSS	Ghana Statistical Services
HRUs	Hydrologic Response Units
IPCC	Inter-Governmental Panel on Climate Change
NOAA	National Oceanic Atmospheric Administration
NWS	National Weather Service
Parasol	Parameter Solution
PSO	Particle Swam Optimization
RCMs	Regional Climate Models
RCP	Representative Concentration Pathways
SSA	Sub-Saharan Africa
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool model

UN	United Nations
UNCESC	United Nations Committee on Economic, Social and Cultural Rights
UNDP	United Nations Develpoment Programme
UNEP	United Nations Environmental Protection Agency
UNFCCC	United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
WGC	World Geographic Coordinate
WMO	World Meteorological Organization
WRC	Water Resource Commission
WWC	World Water Council

CHAPTER ONE

INTRODUCTION

Climate change in recent years has gained centre stage of attention in the world, due to its effects on many other natural and human systems. The changes in climatic condition have shown significant impact on the hydrological cycle and it is leading to droughts, floods, changes in rainfall, temperature and water stress. According to the Inter-Governmental Panel on Climate Change (IPCC, 2014a), the changing climate will be intensive in sub-Saharan Africa (SSA).

Climate change refers to increase in the average global surface temperatures caused mainly by an anthropogenic increase in the concentration of greenhouse gases, particularly carbon dioxide (CO2) in the earth's atmosphere (Kankam-Yeboah, Amisigio, & Obuobi, 2010).

Historically, there has been a variation in the earth's climate which is mainly by natural and anthropogenic causes. The natural causes slow climate variations and it takes a longer period to occur unlike the anthropogenic. The Fourth Assessment report of the (IPCC, 2007) confirms that since the mid-20th century, the global climate change is directly proportional to anthropogenic drives. The effect of these climate changes has manifested in agricultural and forestry management, human health, industry, settlement and society and water resources.

Water is a requirement for all aspects of human life. Availability and assess to clear, fresh and safe drinking water is considered a basic human right (Gleick, 2009). Availability of water resource in sub-Saharan Africa is important in economic growth and social development particularly in the livelihood of the poor in the Sub-region (Vörösmarty, Douglas, Green, & Revenga, 2005). The economy of Ghana depends on water resource for economic and social activities such as water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation and recreation. Water resources (both quantity and quality) and its management are affected by climate change and most importantly by human activities such as population growth and economic activities.

water resources, population growth and settlement around the banks of water resources present a global concern for the availability and consumption of water (Pereira, Cordery, & Iacovides, 2002). Climate change and its impact on water resources availability in space and time have posed further challenges to the sub-Saharan African (SSA) countries in their aspiration to harness the water and improve food security.

In Ghana, all observed and projected climate change in the 21st century predicts a rise in temperature but that of rainfall is uncertain(Asante & Amuakwa-Mensah, 2014). From the historical records, the temperatures for the coastal savannah regions have increased by 2.35 ^{O}C with an anticipated increase of 1.68 ^{O}C to 2.54 ^{O}C by 2050 (Stanturf et al., 2011). The rainfall pattern along the coastal region has not seen that much changes from the past decades while projected reports show both an increase and decrease pattern by

2050 (Stanturf et al.,). The changes in temperature and rainfall for the past decade have had significant impact on water resources and it has reflected in the area of domestic water supply, hydropower generation (Amisigo, McCluskey, & Swanson, 2015) and crop production (Arndt, Asante, Thurlow, & Rosen, 2015).

The impact of the changing climate has been assessed in some of the major basins in Ghana, notable among than are the Volta and the Pra basins which researcher project an increase in temperature, reduction in rainfall and stream flow by 2050 (Kankam-Yeboah et al., 2010; Kankam-Yeboah et al., 2013; Amisigo et al., 2015). Globally, more attention has been given to the impact of climate change on small basins, not much of these assessments has been reported across the country. All these assessments are essential and help decision makers in formulating policies.

The study intended to focus on how Climate Change affects the hydrological system of the Densu River Basin (DRB) using Soil and Water Assessment Tool (SWAT) model.

Statement of Problem and Justification

According to the Inter-Governmental Panel on Climate Change (IPCC, 2014b), climate change leads to increase in the frequency and intensity of natural disasters and extreme weather conditions such as droughts, floods and storms, changes in temperature and rainfall patterns especially in Sub-Saharan Africa (SSA). Such changes in the climate could lead to an intensification of the hydrological cycle, which in effect could have significant impacts on the

availability (both quantity and quality) and distribution of water resources (Schuol, Abbaspour, Srinivasan, & Yang, 2008).

In Ghana, many parts of the country have experienced this effect of climate changes as reported by IPCC (2014b). In the last decade, flood and drought have become frequent (Asumadu-Sarkodie, Owusu & Rufangura, 2015). A study by UNEP/UNDP (2010) showed that for the past 30 years the sea-level has risen by 2.1 mm per year and is a major challenge to the coastal communities. For the past decade, temperature across the different agro ecological zones has risen by 1 ^{O}C whilst there is a reduction and changes in rainfall patterns (Stanturf et al., 2011; Arndt et al., 2015). Study on future climate projections across the country also predicts an increase in temperature (Stanturf et al., 2011).

Researchers have emphasised on the likely impact of climate change in areas like agriculture and food security (Amisigo et al., 2015) and the economy and livelihood in the country. Assessment of the impact of the changing climate on water resources in the country is scanty. Kankam-Yeboah et al., (2013) focused on the changes in the hydrology of some large river basins in the country on and irrigation.

Though Ghana's contribution to greenhouse gas emission in the world is minimal, about half of the total emissions come from the land-use change and forestry sector (USAID, 2016). The Densu River Basin is noted for such land use change, a report by WRC (2007) shows that, the rampant land degradation which are mainly caused by the indiscriminate wood harvest, agriculture activities (food crops and rearing of animals) (Ayivor & Gordon,

2012a), and most importantly residential land uses (Yorke & Margai, 2007) along the banks of the river that account for 75% of the changes in the basin. The population density in present days in and/or along the basin has increased five times greater than the national average of 103 persons per square kilometre (Ghana Statistical Services (GSS), 2012).

A study by Ayivor and Gordon (2012a) also revealed that mining, inappropriate disposal of solid waste and liquid waste from the local water extraction and infrastructure development including the siting of industries at unauthorized locations also form major land use activities. These activities within the basin are drivers of climate change which also alters the hydrological processes in the basin. The extents to which the hydrology of the basin is or will be altered remain unknown.

Studies within the basin considered areas like water quality (Karikari & Ansa-Asare, 2006; Amoako, Karikari, Ansa-Asare & Adu-Ofori, 2010), pesticide residue (Fianko, 2011), groundwater quality (Tay & Kortatsi, 2008), heavy metals, land use change, runoff, soil erosion etc. (Ayivor & Gordon, 2012a) ; Ashiagbori, Forkuo, Laari & Aabeyir, 2014). However, studies on the impact of climate change on hydrological process within the basin is still on a lower side, with McCartney et al. (2012) and Kankam-Yeboah et al. (2013) focusing on Volta river basin and Pra basin. It is therefore important to understand how climate change would affect the hydrology in smaller basin for appropriate strategies and policy responses.

Purpose of the study

Climate change is manifested in Ghana through rising temperatures, declining rainfall amounts and increased variability, rising sea levels and high incidence of weather extremes and disasters. Hence the intention of this study is to quantify the impact of climate change on water resources in the Densu River Basin (DRB). This information allows for better water management and planning of future developments at DRB in the context of climate change.

General Objectives

The general objective of this study was to evaluate the impact of projected climate change on the hydrology (stream flows) of the Densu River Basin from 2035 to 2065 (2050s).

Specific Objectives

The specific objectives of this study were to:

- Generate the current hydrological processes (rainfall, soil water, actual evapotranspiration and water yield) as a baseline for DRB using Soil and Water Assessment Tool (SWAT) model.
- Predict the hydrological processes (rainfall, soil water, actual evapotranspiration and water yield) of DRB by 2050s using Soil and Water Assessment Tool (SWAT) model under observed climate.
- Provide an indication of the effect of climate change on potential water available in the Densu River Basin.

Limitations of the Study

The study seeks to find out the impact of climate change on the hydrological processes of the Densu River Basin (DRB) using SWAT model. The climate model used for the study did not take into consideration drivers of climate change such as population growth, land cover changes. The future (2050s) prediction was based on the baseline land use/cover changes. The study did not also consider the changes in soil parameters in the future (2050s), since soil properties and erosion affect infiltration of water. No field survey such as soil sampling and soil analysis was conducted.

CHAPTER TWO

LITERATURE REVIEW

Water Resources

Water is one of the most important abundant natural resource that supports human and terrestrial life (Daily, 2003). Water saver's as energy regulator in the ecosystem by acting as a climate ameliorator (absorbed and released energy during heat transformation) and best natural occurring solvents (Davie, 2008). Religious and cultural believes uses water as a medium for cleansing which is a common practice among Christianity, Islamic and Hindus (Davie,).

In Ghana, the importance of water resource is seen in the areas of food production, transportation, industry and domestic use (Kankam-Yeboah et al., 2010) as a source of employment, foreign exchange and revenue to the government and hydro-electric power generation.

Water Resources Challenges

The oceans and terrestrial waters cover about 70 % of the earth surface (Davie, 2008) yet; the globe is faced with the challenge of water insecurity. The UNCESCR in 2003 declared that access to safe freshwater has to be a human right which has now become one of the millennium development goals. Of the numerous plan and policies by international organization such as UNDP, European Union, United Nations and World Water Council to safe

guide access to safe drinking water (Kundzewicz et al., 2007), millions of people still live under water stress.

Water resource still faces massive pressure and threats from increasing population, urbanisation, deforestation, land and soil degradation processes, unsustainable use and water management practices (WRC, 2007), and pollution which reduces the quantity and quality of water resource. These anthropogenic causes are no different from that which causes climate change.

Hydrological Cycle

The natural transformation of water from its states (Gas, liquid and solid) and its circulation between the earth and atmosphere is a hydrological cycle (Raghunath, 2006). Even though the hydrological cycle plays a major role in water balances, changes in the hydrological processes (rainfall, soil water, evapotranspiration, runoff, infiltration, percolation, and condensation.) are driven by climate and non-climatic contributors and this is a challenge to water resources (IPCC, 2014b).

Climate Change

Climate is defined by Barros et al. (2012) as " the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years". The World Meteorological Organization (WMO) defined the period of averaging as 30 years (Arguez & Vose, 2011).

Weather is defined as the description of the atmospheric condition at a single instant of time for a single occurrence (NOAA & National Weather Service, 2007). Climate and weather are described in terms of the same surface variable conditions such as solar radiation, precipitation, temperature, relative humidity, wind and sunshine. Weather only differs from climate in the period of occurrences.

Conditions of climate have not remained constant throughout the years and the world is observing the greatest changes in its climate. According to Barros et al. (2012), climate change is "the state of the climate that can be identified (by using statistical tests) by changes in the mean and/or the variability of its properties over the period, typically decades or longer". Natural (internal) processes or external forces (anthropogenic changes) induce the changes, but litter can humanity do about the natural processes. The United Nations Framework Convention on Climate Change (UNFCCC) definition on climate change emphases on directly or indirectly human activities that alters variability of climate properties over a period and also makes a distinction between variation caused by human activity and natural causes (Barros et al.,).

Most current global challenges on climate change is due to human activities such as urbanization, deforestation, increase in population and burning of fossil fuels (Adger, Huq, Brown, Conway, & Hulme, 2003; Godfray et al., 2010; IPCC, 2014b; Yawson, Adu, Ason, Armah, & Yengoh, 2016). The changing climate has a direct and indirect influence on the hydrological process and water resources.

The Trend of Climate Change

Global temperature change

The greatest contributor to the climate system is human influence through emission of greenhouse gases. Greenhouse gas (GHG) emission such as carbon dioxide (CO_2) (Cox, Betts, Jones, Spall, & Totterdell, 2000), methane (CH_4) and nitrous oxide (N_2O) in recent time have largely increased in concentrations in the atmosphere (Pachauri, 2014) which is mostly influenced by anthropogenic emissions driven by economic and population growth. These changes in the atmospheric concentrations have resulted in the massive warming of global atmosphere (Cox et al., 2000).

Global precipitation changes

Changes in the global precipitation is not uniform throughout the world, some parts of the Northern Hemisphere from observed and projected data show no changes in the precipitation pattern (IPCC, 2014b; Pachauri, 2014) but many regions within the mid-latitude and subtropics are likely face reduction in precipitation. The Extreme precipitation events over most the mid-latitude and tropical regions would likely become more intense and more frequent, with the regions where the impact is strong, the changing climate would altered the hydrological system, water resource, quality and quantity of available water (IPCC, 2014b).

Temperature and precipitation changes in Africa

Over the past century, the surface temperatures in most parts of Africa have experienced an increased by 0.5 °C, with the minimum temperatures increasing faster than the maximum temperatures (Easterling et al, 1997, 2000; Collins & Collins, 2011; Niang et al., 2014).

Over West and Sahel Africa, the surface temperatures have also increased over the years. According to New et al. (2006), colder days and nights have decreased and that of the warmer days and nights have increased since 1961 and 2000 and this period has witnessed an significant increase of 0.5 to 0.8 ^{o}C.

The precipitation pattern on the continent has little to talk about in terms of observed and future occurrences because of inadequate observed data to study the trend in the past (IPCC, 2014b) most importantly West Africa (Vellinga, Arribas & Graham, 2013) which is noted for its monsoonal rainfall (Sultan & Gaetani, 2016). Faramarzi et al. (2013) foresaw that the mean precipitation on the continent will increase but Hagemann et al. (2013) disagree.

The temperature across Ghana has increase in the past decades. An increase of about 1 ^{o}C from the north to the southern regions has been reported by (Stanturf et al., 2011) and an average annual increase of 0.9 ^{o}C along the coastal savannah. Over the past 40 years, the minimum and maximum temperature of the coastal savannah has been experienced an increase of 2.2 and 2.5, respectively (Akon-yamga, Boadu, Obiri, Amoako, & Mboob, 2011).

Future Climate Change Projections

The mean global surface temperature is projected by Pachauri (2014) to change within the period 2016–2035 by a range of 0.3 °C to 0.7 °C and by the end of the 21st century it would exceed 2 °C. Nevertheless, all these projects exclude the natural causes that also contribute to climate change such as volcanic eruptions which increases the concentration of CH_4 and N_2O in the atmosphere (Walther et al., 2002).

Temperature projections for Africa

Temperatures in Africa are projected to rise faster than the global average increase during the 21st century (Christensen et al., 2007; Joshi et al., 2011; James & Washington, 2013). The increasing temperature would be throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics (IPCC, 2014b). According to Engelbrecht et al., (2015) Temperatures are projected to increase over subtropical Africa, whilst smaller increases are projected for tropical Africa.

Temperature projections for West Africa

Temperature projections over West Africa for the end of the 21st century from both the Coupled Model Intercompersion Project Phase 3 (CMIP3) and Coupled Model Intercompersion Project Phase 5 (CMIP5) GCMs ranges between 3 °C and 6 °C above the late 20th century baseline (Allen et al., 2011; Monerie et al., 2012; Sillmann et al., 2013). Regional downscaling produces a similar range of projected change (Patricola & Cook,

2010, 2011; Vizy et al., 2013). Diffenbaugh and Giorgi, (2012) identified the Sahel and tropical West Africa as hotspots of climate change under both RCP4.5 and RCP8.5 pathways.

Findings in Ghana suggest higher temperature and low rainfall for the mid and end of 21st century (Owusu, Waylen, & Qiu, 2008). The Densu River Basin is known to have uniform temperatures but have seen a temperature increase by 10 °C in the past years (WRC, 2007).

Impact of Climate Change on Hydrological Processes

The global water resource is faced with climatic conditions such as precipitation, temperature, and solar radiation but these conditions differ from region to region. The impacts of these conditions alter the hydrological cycle by increasing runoff, the intensity of rainfall and evaporation rate (Kabo-bah, Anornu, Ofosu, Andoh, & Lis, 2014 and Huang, Lee, & Lee, 2014) which is manifested in flooding, drought, changes in rainfall patterns, declining and the drying-up of rivers, lakes, streams, water bodies, and landslides (Faramarzi et al., 2013). Projection from studies shows that the changing climate will increase strongly from decades with higher temperatures and decreased precipitation, accompanied with this is declined water supplies, water quality and increased water demand (IPCC, 2014b) and the northern-Saharan communities are expected to be impacted greatly.

The impact of climate change on surface runoff

In the past decades, studies on runoff in West Africa have been strongly affected by rainfall patterns (Nicholson & Grist (2001). The rainfall variations in West Africa have strong influence on river discharge and a unit decline in rainfall results in three times reduction in runoff (Mahe et al., 2013). Although an increase in temperature is projected over West Africa by the end of the 21st century, , an increase or decrease projection of rainfall and runoff in west Africa cannot be confirmed (Roudier, Ducharne & Feyen, 2014).

In Ghana, the situation is not different from what is happening in other part of West Africa. A study on some river basins in Ghana projects a reduction in stream flow by 22 % to 50 % in 2050s for both Pra and White Volta basins (Kankam-Yeboah et al., 2013) and the Densu River basin (Kasei & Barnabas, 2014). It has been observed in Densu River Basin that, rainfall pattern has reduced by 10 % to 20 % resulting in a decline between 15 to 20 % of the surface runoff (WRC, 2007).

The impact of climate change on soil water

Temperature and rainfall changes are mostly used to examine implications of climate change on soil moisture (Trenberth, 2011). Soil water is more sensitive to temperature change and surface solar radiation than changes in rainfall pattern (Dai, Trenberth & Qian, 2004) but accordiing to Laio, Porporato, Ridolfi and Rodriguez-Iturbe (2001), the intensity of the rainfall and the depth of the soil determine the amount of water to be stored in the soil profile.

Drought condition leads to reduction in soil water and is mostly observed in West Africa. Absence of observational rainfall record before the 20th century (Hulme, 2001) makes it very difficult to conclude on the trend of soil water in the past over the Sub Region. A projection made by Mbaye et al. (2015) under two Representative Concentration Pathways (RCP4.5 and RCP8.5) showed that by the end of the 21st century soil water will decline.

Impact of climate change on evapotranspiration

The movement of water from the soil, canopy interception, and water bodies is referred to as evaporation while transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through leaves stomata into the atmosphere (Jensen & Allen, 2016). The combined effect of these two is known as evapotranspiration (ET) and is considered to be one of the important components in water cycle. ET is influenced by factors such as temperature, relative humidity, wind speed and water availability (Zou, Niu, Kang, Li & Lu, 2017)).

More than half of the solar energy absorbed by land surfaces is used to evaporate water (Trenberth et al., 2009). Climate change is expected to intensify the hydrological cycle and to alter evapotranspiration (Huntington, 2006). Globally, about 60 % of the annual rainfall on land is returned to the atmosphere through ET (Oki & Kanae, 2006). ET can affect rainfall and the associated latent heat flux helps to control surface temperatures (Koster et al., 2004).

Temperatures of the sea and water bodies are expected to increase in Ghana with an increase evapotranspiration across this period (Asante & Amuakwa-Mensah, 2014). The situation is not different in the DRB, a report by WRC, (2007) showed that out of the total amount of rainfall collected in the basin, an average of 77 % returns back as evapotranspiration.

Impact of climate change on groundwater

A common definition of ground water by Han (2010) is "water beneath the ground surface contained in the void spaces". Changes in groundwater storage, level and discharge have influence on land use changes and groundwater abstractions (Stoll, Hendricks Franssen, Butts, & Kinzelbach, 2011) while that which is due to climate change is difficult to observe. Once water infiltrates and becomes groundwater, it is difficult to evaporate except transpiration by deep rooted plants (Davie, 2008). Studies in the past attributed changes in groundwater discharge to reduce rainfall (Shah, Jeelani & Jacob, 2017) but an account by Aguilera & Murillo (2009) show that not only does decline in rainfall reduce groundwater recharge but increase in evapotranspiration is likely to contribute.

Groundwater discharge, recharge rates, and quality will be affected significantly by climate change (IPCC, 2007). Around the coastal areas, climate change is expected to have a strong impact on groundwater aquifers through salinization due to increased evapotranspiration and rise in sea level (Kundzewicz et al., 2007).

Drivers of Climate Change

Although the hydrological processes (rainfall, soil water, evapotranspiration, runoff, etc.) are affected by climate change, the changing climate is driving land cover and land use changes, population growth, etc.

Land Use and Land Cover Changes

Urbanization

According to Yawson et al. (2016), in the next 40 years 67 % of the projected population of the world is likely to cause urbanisation. In developing countries, the urban cities population is rapidly increasing because they seek for better life, financial freedom, trading activities, investment and access to information (Marcotullio et al., 2008). Accompanied with this shift is the greatest inference, economic activities (industrialisation, infrastructure, transportation, etc.) on land cover/use change (Marcotullio et al., 2008). Urbanisation increase pressure on water resources as individuals become more concentrated in an area. Although water withdrawals for domestic and municipal use globally account for a modest part of total water use, they are growing rapidly, especially as a result of population growth in urban areas of developing countries (Vörösmarty, Green, Salisbury & Lammers, 2000; Gleick, 2003).

Degradation

Studies on the impact of urbanisation on land use and soil shows that land and soil in and/or around urban cities are faced with massive degradation, the distraction of plants and trees which result in run off and erosion (Yawson et al., 2016). There is no doubt about the fact that any harm caused to the soil affects the water resource. In Food and Agriculture Organisation (FAO, 2015) report on the status of the world's soil resource revealed that, greater percentage of the terrestrial water is stored in the soil and the quality of the water depends on whether it infiltrates or runoff the surface of the soil. Urban cities are developed to increase water surface runoff and to decrease infiltration which results in a shift in the natural water balances (Gill, Handley, Ennos & Pauleit, 2007).

Industrialisation

Industrial production depends on water for cooling, processing, and disposal of waste products. Demand for water for industrial use is increasing with rapid industrialisation to meet the many needs of the growing population (Bates, Kundzewicz, Wu, Palutikof, & Intergovernmental Panel on Climate Change. Working Group II, 2008). Population growth contributes to this increase. Rapid population growth and urbanisation could expose more people to water shortages (IPCC, 2001, 2007). Rapid industrialisation leads to a decline in water quality and quantity and the high cost of treating water with negative implications for livelihoods, health, and security.

Population Growth

Water symbolises life; therefore where there is water there is life. The demand for water resources deepens, as the world's population grows. Climate change, which is also closely tense to population growth, will also lead to greater pressure on the availability of water resources. The exact population of people on Earth in decades from now is unclear. Melorose, Perroy and Careas (2015) projected the world's population to be 9.7 billion by 2050 and Africa is expected to account for more than half of the world's population growth by 2050. These will have a great impact on water availability on the continent since the demand for water will increase. Arnell (2004) showed that, increase in population is directly proportional to the increase in water stress.

Water may seem abundant, but less than one percentage of the world's water is available, accessible and can be utilised by mankind (Watkins, 2006). Unpredictable rainfall patterns, uneven distribution of water resources, weather variability, and human factors such as population growth and tensions over the shared waters present a significant concern for the availability, access, and utilisation of water resources. Demand for available water is already leading to water scarcity in many places. Nearly 4 billion people are currently living in areas faced with water stress or scarcity ("Population institute," 2010; Mekonnen & Hoekstra, 2016). Water scarcity affects all social and economic sectors and threatens the health of ecosystems.

Population growth is a major contributor to water scarcity. Water is also needed for agriculture and industrial use, and for the removal of waste materials. Population growth increases demand for water for domestic,

industrial, and municipal uses. Areas with high population densities and growth rates with few water resources are mostly faced with water scarcity or stress (FAO, 2012). Population growth limits the amount of water available per person, drives people into urban areas where there is already water stress.

As the population grows, food consumption increases. About 70 % of global water is used on agriculture activities (World bank, 2017). Not only does agriculture requires a large amount of water, but also wastes water (FAO, 2012). Agricultural productivity is a critical component of global food security and, therefore, water and food scarcity are greatly interconnected. According to FAO, (2012), to meet the demand of the world population by the end of 2050, food production is expected to increase by 80 % and to facilitate these the global irrigated areas are expected to expand, which increase the demand on water resource.

Simulating /Modelling Impacts of Climate Change on Water Resources

Soil and Water Assessment Tool (SWAT) Model

The Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model and the Environmental Impact Policy Climate (EPIC) model formerly named the Erosion Productivity Impact Calculator formed the bedrock on which SWAT was established (Neitsch, Arnold, Kiniry, & Williams, 2011). The Water Resources in Rural Basins (SWRRB) model for the management of water and sediment movement in

basins across the U.S. in the early 1980s and modifications from CREAMS which uses daily rainfall hydrology have now become the root of current SWAT (Gassman, Reyes, Green, & Arnold, 2007). Modifications such as prediction of water yield in a basin, groundwater or flow return, a storage capacity of reservoir, the EPIC crop growth model, a weather simulation model including rainfall, solar radiation, and temperature data, sediment transport, flood routing and process for predicting the peak runoff rates were component incorporated into the CREAMS hydrology model (Gassman et al., 2007; Neitsch et al., 2011).

The early 1990s saw the birth of SWAT and since it has experienced a continual expansion and review such as the Multiple hydrologic response units (HRUs), Auto-fertilization and auto-irrigation (AI); Bacteria transport routines (SWAT2000), Nutrient cycling routines (SWAT99.2). Currently, the interfaces of SWAT model have been developed for Windows (Visual Basic), GRASS, ArcView (Neitsch et al., 2011) and Arc GIS interface (ArcSWAT 2012; Arnold et al., 2012). These modifications stretched the model's capability to deal extensively with variety of watershed water quality management problems.

Specific SWAT Application

The SWAT model has been used widely in areas of hydrology only, climate change, hydrologic and pollutant loss, nutrients and pesticides, erosion, land and plant cover and under different climatic conditions worldwide. The Africa continent has witnessed very few of SWAT model with

Ghana recording a countable number of them (Schuol, Abbaspour, Yang, Srinivasan, & Zehnder, 2008; Faramarzi et al., 2013; Kankam-Yeboah et al., 2013).

Hydrologic Studies

All SWAT watershed applications is based on simulation of the water balance equation irrespective of the analysis in question (Gassman, Reyes, Green, & Arnold, 2007; Neitsch, Arnold, Kiniry, & Williams, 2011). The statistical performance of any hydrological model is the ability to complete calibration and verification processes. The SWAT model uses the correlation coefficient (r^2) and the Nash Sutcliffe efficiency (NS) coefficient in estimating model parameters (Mylevaganam, Srinivasan & Singh, 2015). The r^2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause & Boyle, 2005; Gassman et al., 2007; Arnold et al., 2012). The NSE ranges from $-\infty$ (negative infinity) to 1 and measures how well the simulated versus observed data matches the 1:1 line whose slope is equal to 1. An NS value of 1 again reflects a perfect fit between the simulated and measured data. A value of 0 or less than 0 indicates that the mean of the observed data is a better predictor than the model output.

Climate Change Impact Studies

The model SWAT has been used to simulate impact climate change on hydrological system such as the effects of climate changes on stream flow, water quantity and quality, groundwater, runoff , water and sediment yield and fresh water resource (McCartney et al., 2012; Faramarzi et al., 2013; Ross, 2014; Zuo, 2016). SWAT has been recognised as an international hydrological model and a number of studies have been conducted using SWAT in the world on the use of the model for predicting the changes in climate on hydrology. SWAT has been known to be a continuous simulator in predicting predominantly agriculture watershed, stream flow volume, sediment loadings, nutrient losses and known to be consistent (Gassman et al., 2007). The SWAT model has been modified to use an output from a downscaling climate change projections generated by GCMS together with regional climate models (RCMs).

Climate Change Impacts on Hydrology

Faramarzi et al. (2013) used SWAT to analyse the impact of climate change on freshwater availability in some basins in Africa and downscaled climate projections from five global circulation models (GCMs) (HadCM3, PCM, CGCM2, CSIRO2, and ECHAM4) under the emission scenarios (A1FI, A2, B1, and B2) of the IPCC. Faramarzi et al. (2013) found that future water availability for some countries in Africa could increase while countries in West Africa sub regions could experience a decrease.

A second key finding (Schuol et al. 2008) was modelling blue and green water availability in Africa using SWAT and SWAT CUP to assess the uncertainty in the model. Schuol et al. (2008) concluded that the 95% predicted uncertainty of the outputs was due to the difficulty and limitation to related data and therefore recommended that advanced studies on sub basin should be conducted. Schuol et al. (2008) acknowledged that, the use of the SWAT model for the estimation of freshwater availability in the West Africa sub region provided a reliable result.

Sensitivity, Calibration, and Uncertainty Analyses

Sensitivity, calibration, and uncertainty analyses are vital and interrelated features of applying SWAT and other models. Numerous sensitivity analysis approaches have been reported in the SWAT literature, which provide valuable insights concerning which input parameters have the greatest impact on SWAT output (Holvoet, van Griensven & Seuntjens, 2005; Stoll et al., 2011; Arnold et al., 2013; Abeysingha et al., 2016; Zuo et al., 2016). Majority of SWAT applications report some type of calibration effort; SWAT input parameters are physically based and are allowed to vary within a realistic uncertainty range during calibration. Sensitivity analysis and calibration techniques are generally evaluated with a wide range of graphical and/or statistical procedures.

Uncertainty is defined by Shirmohammadi et al. (2006) as “the estimated amount by which an observed or calculated value may depart from the true value.” The SWAT model uses four uncertainty analysis methods,

including GLUE, ParaSol, PSO, and SUFI-2. A report by Abbaspour, van Genuchten, Schulin & Schläppi (1997); Yang, Reichert, Abbaspour, Xia & Yang (2008) and Khoi & Thom (2015) suggested that the SUFI-2 method is a useful tool in calibration and uncertainty analysis to support studies on impact of climate change and human activities on water resource.

CHAPTER THREE

MATERIALS AND METHODS

Study Area

The Densu River Basin was modelled for the study. The Densu river travels from Atiwa-Atwiredu mountain which lies between longitudes 0º 10 W - 0º 37 W and latitudes 5º 30 N - 6º 17 N. It covers a distance of about 116 kilometres (Asante, Quarcoopome & Amevenku, 2008) and an area of 2490 kilometres square. The Densu River traverses the Eastern, Central and Greater Accra regions and 11 other Local Government Assemblies and enters the sea at Bortianor in the Ga Municipality. The Odaw and Volta Basins, Birim Basin, Ayensu and Okrudu Basins form catchment boundary with the Densu Basin (WRC, 2017).

The catchment lies in the Coastal Savannah zone in the southern part and semi-deciduous forest in the northern part of the basin (WRC, 2017). The basin has two rainfall seasons: May to July as the major and September to November as the minor rainfall seasons (Karikari & Ansa-Asare, 2006) with a mean annual rainfall of 846 mm. The average annual temperature is about 27 ºC and daily sunshine hours of 12. The hottest periods start from November to April with temperatures around 32 °C (WRC, 2007), August is the coolest month (23 °C). For the past 20 years, the semi-deciduous forest of the DRB has changed with two different types land cover (semi-forest and settlements) of which settlement is increasing very fast (WRC, 2007).

The Densu River Basin is a home to over 600,000 people with over 200 different settlements around it. The population density for these settlements is 240 persons per square kilometre (WRC, 2017), more than the national average of about 100 persons per square kilometre.

The Densu River serves a number of socio-economic importances to the population in and/or outside the Basin. It is the main source of water supply for a number of surrounding communities. A total of 76.96 million m^3 of water is supplied from the Densu River per year with Weija Reservoir alone supplying 73 million m^3 of water per year to a part of the Accra Metropolitan Authority (WRC, 2007).

Under the Weija Irrigation Project, a total of 4 million m^3 per year of water is being used for irrigation whiles 0.22 million m^3 per year of water is used for the rearing of livestock (WRC, 2007).

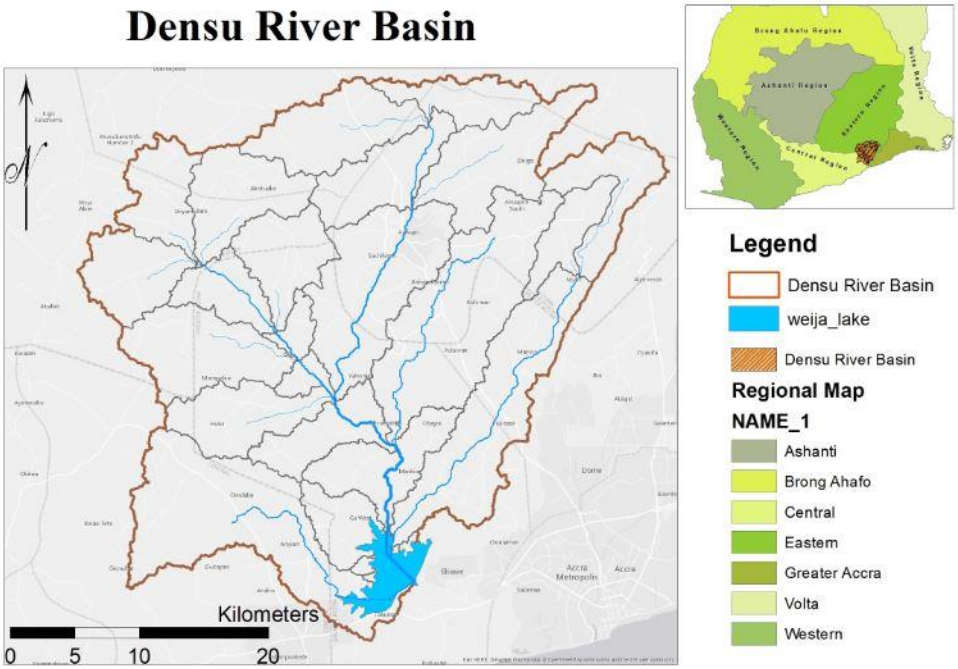

***Figure 1*: Map of the study area**

Modelling Approach

Soil and Water Assessment Tool (ArcSWAT 2012) Model Description

The Soil and Water Assessment Tool (SWAT) model has proven to be an effective tool for assessing water resource, environmental condition and hydrologic modelling for river basins across the globe (Neitsch et al., 2011). SWAT is a basin-scale, continuous-time hydrological model that operates on a daily time step. It was developed by the Agricultural Research Service of the US Department of Agriculture (USDA-ARS) (Neitsch et al., 2011). It is designed to predict the impact of management on water, sediment, and agricultural chemical yields in watersheds (Gassman et al., 2007). The model is physically based, computationally efficient, a continuous simulator over long time periods and has an ArcGIS interface (ArcSWAT 2012) (Gassman et al., 2007).

In SWAT, watersheds are divided into multiple sub basins, which are divided further into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subbasins area and are not identified spatially within a SWAT simulation. The benefit of watershed subdivided into subbasins is to dissimilate dominant land use, soil type, and management within the watershed.

The SWAT uses climatic inputs such as daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data. These inputs could be generated or obtained from records. The SWAT model uses Penman-Monteith, Priestly Taylor and Hargreaves methods in estimating evapotranspiration with vary climatic inputs. The Penman-Monteith or Priestly Taylor methods uses, solar radiation, air temperature and relative humidity. Wind speed becomes necessary only if the Penman-Monteith method is used while Hargreaves method used air temperature only (Gassman et al., 2007).

The hydrological component of SWAT is driven by the soil water balance of a river basin, which is represented as (Neitsch et al., 2011):

$$\mathbf{SWt} = \mathbf{SWo} + \sum_{\mathbf{i=1}}^{\mathbf{t}}(\boldsymbol{R_{day}} - \boldsymbol{Q_{surf}} - \mathbf{E}_{\boldsymbol{a}} - \boldsymbol{W_{\mathbf{seep}}} - \boldsymbol{Q_{gw}}) \qquad \text{Equation 1}$$

Where: SWt is the soil water content (mm), SWo is the initial soil water content on day i (mm), t is time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water

entering the vadose zone from the soil profile on day i (mm), Q_{gw} is the amount of return flow on day i (mm).

The Soil Conservation Service (SCS) curve number (CN) is used by SWAT to estimate surface runoff under different land use and soil types (Neitsch et al., 2011). The SCS curve number equation is:

$$\boldsymbol{Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}} \qquad \text{Equation 2}$$

Where: Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H_2O) and S is the retention parameter (mm H_2O).

The retention parameter is computed from equation 3 (Neitsch et al., 2011).

$$\boldsymbol{S = 25.4\left(\frac{1000}{CN} - 10\right)} \qquad \text{Equation 3}$$

Where: CN is the curve number for the day.

For evapotranspiration, the Penman-Monteith equation used by SWAT is (Neitsch et al., 2011):

$$\boldsymbol{\lambda E = \frac{\Delta(H_{net} - G) + \rho_{air} . c_p . [e_z^o - e_z]/r_a}{\Delta + \gamma . (1 + r_c/r_a)}} \qquad \text{Equation 4}$$

where: λE is the latent heat flux density (MJ m^{-2} d^{-1}), E is the depth rate evaporation (mm d^{-1}), Δ is the slope of the saturation vapor pressure-temperature curve, de/dT (kPa ˚C^{-1}), H_{net} is the net radiation (MJ m^{-2} d^{-1}), G is the heat flux density to the ground (MJ m^{-2} d^{-1}), ρ_{air} is the air density (kg m-

3), c_p is the specific heat at constant pressure (MJ kg^{-1} ˚C^{-1}), e_z^o is the saturation vapor pressure of air at height z (kPa), e_z is the water vapor pressure of air at height z (kPa), γ is the psychrometric constant (kPa ˚C^{-1}), r_c is the plant canopy resistance (s m^{-1}), and r_a is the diffusion resistance of the air layer (aerodynamic resistance) (s m^{-1}).

Data Requirement

The Arc SWAT requires both spatial datasets and non-spatial datasets of the watershed considered. Digital Elevation Model (DEM), Land Use (LU) and Soil Map were the spatial data-sets while the non-spatial data set included Climate Data (Daily climate data on rainfall, minimum and maximum air temperature, relative humidity, wind speed and solar radiation), and a Monthly Stream Discharge. For more details see Arnold et al., (2013).

Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) represents terrain elevations for ground positions at regularly spaced horizontal interval. It is a three-dimensional graphics displaying terrain slope, aspect (direction of slope), and terrain profiles between selected points (USGS, 2017).

The DEM for the current study was a 30 m resolution Shuttle Radar Topography Mission (SRTM) DEM downloaded from the United States Geological Survey (USGS) Earth Explorer website. The downloaded DEM was pre-processed in ArcGIS Desktop version 10.3.1 (ESRI TM). The image was scaled and the area of interest was clipped. The image was then projected

to the Universal Transverse Mercator (UTM) zone 30 N, with World Geodetic system (WGS) 1984 as the geographic coordinate system and datum.

Land Use (LU)

A cloudless Landsat 8 (OLI) satellite imagery with 11 bands was downloaded from the United States Geological Survey (USGS) website. Features of the satellite images are shown in Table 1.

Table 1

Properties of the Landsat 8 Imagery

Satellite	Sensor	Spatial Resolution	Acquisition Date	Source
Landsat 8	OLI/TIRS	30 m	25/01/2017	USGS

The downloaded satellite image was exposed to the preprocessing procedure using ArcMap. The digital numbers were converted to reflectance values in ArcGIS. After this procedure, a composite image was formed from the 11 bands of the original image using a combination of three bands: 6-5-4 (i.e. near-infrared, red and green bands respectively).

A geometric correction was also done so that the geometric representation of the imagery will be the same as the DEM. To this end, the Landsat image was transformed into UTM zone 30N/WGS 84 projected coordinate system. The spatial extent of the Landsat images was far greater than the study area and so the image was clipped to the study area.

Image classification

The main objective of image classification is to classify all pixels in an image into land use and land cover classes (Anavberokhai, 2007). Both unsupervised and supervised classification algorithms were employed for this study.

ISO Cluster Unsupervised classification was done to aid in the exploration of the spectral classes in the image. Water bodies, agriculture land, urban/bare lands and vegetation were the main target classes. High-resolution images from Google Earth and the vegetation image with combination 6-5-4 from the Landsat image were used to identify the spectral classes. A reclassification was done to match spectral classes with the four informational classes (Campbell & Mcgee, 2017). The spatial analyst and image classification tools in the ArcTool box were used.

Training sites were set up for the supervised classification by using the training sample manager Window. The training sites were based on the author's knowledge of the site and ground truth data. An evaluation of the training data was done by using a scatter plot to check overlap between classes. The Maximum Likelihood classifier was used for the supervised classification.

An accuracy assessment was done for supervised classification using random sampling point technique which was compared to Google Earth. The land use/cover generated is shown in Figure 2.

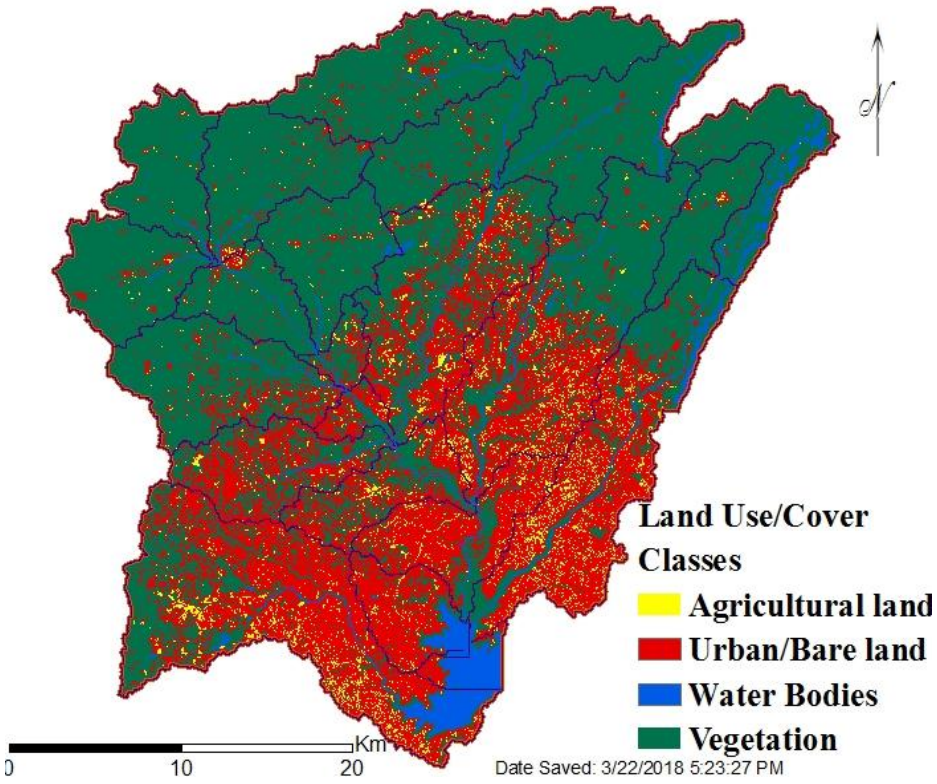

Figure 2: **Land classification map**.

Soil Map

A digital soil map of the world (Version 3.6) with a scale of 1:5000000 from Food and Agriculture Organization of the United Nations (FAO) and UNESCO was used for the study.

The shapefile for Ghana was selected by attribute query and exported. The geographic and projection coordinate system of the shapefile was defined and transformed from an undefined coordinate to WGS/1984/UTM/Zone/30N. A polygon shapefile of the study area with a defined and transformed coordinate was clipped from the Ghana shapefile,

exported and transformed to a raster. The different soil classification and area covered is shown in (Table 2 and Figure 3).

Table 2

Area Occupied by the Different Soil Types

Soil Type	Area (ha)	% Area
Orthic Acrisols 1	58847.26	48.68
Orthic Acrisols 2	9678.122	8.00
Lithosols	8157.328	6.75
Ferric Acrisols	41888.09	34.65
Chromic Vertisols	2322.658	1.92

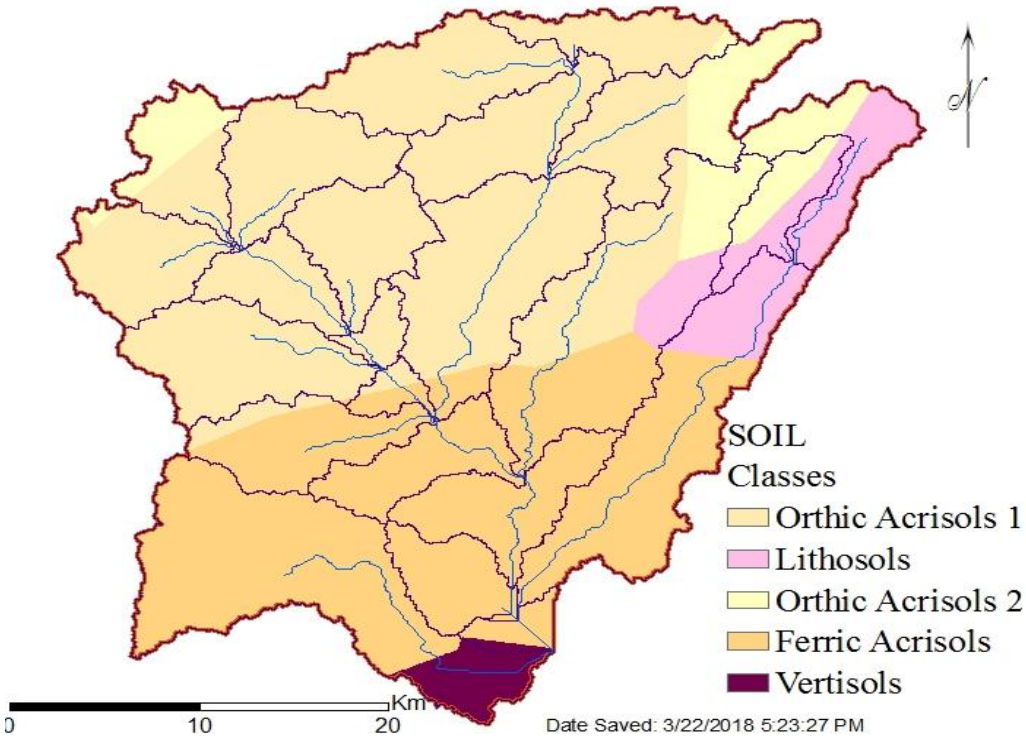

***Figure 3*: Soil map of the study area**

Climate data (Baseline)

Daily rainfall, minimum and maximum air temperature, relative humidity, wind speed and solar radiation were the climate data of the study area obtained from the Meteorological Agency of Ghana for a period of thirty (30) years (1986 to 2015).

Each of the climate data was arranged and organised with Microsoft Excel 2010 package and saved in a text format, for example “pcp.txt”. Missing records in climate data from stations were filled using the WXGEN weather generator offered in SWAT. The average monthly minimum and maximum temperature and rainfall is shown in Figure 4.

Observed Stream Discharge (baseline)

A monthly stream discharge or flow data for a period of 15 years (1986 to 2000) were obtained from the Hydrological Services Department (HSD), which operates a number of river gauging stations within the Densu Basin. Figure 5 depicts the monthly averages of the discharge measured at both Nsawam and Manhea stations.

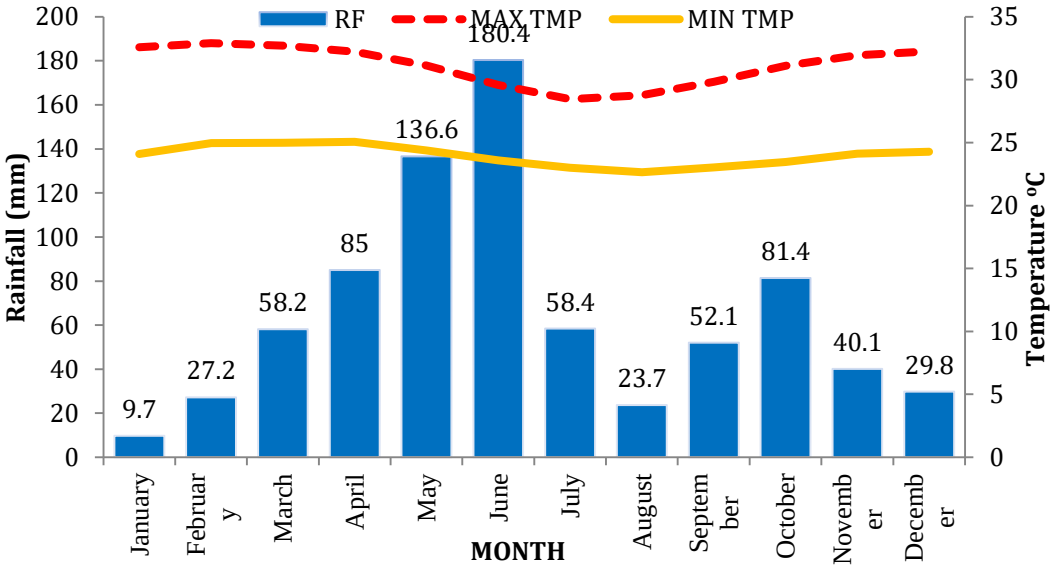

***Figure 4*: Average monthly rainfall, maximum and minimum temperature from 1986 to 2015.**

Note: RF (rainfall), MAX TMP (maximum temperature) and MIN TMP (minimum temperature).

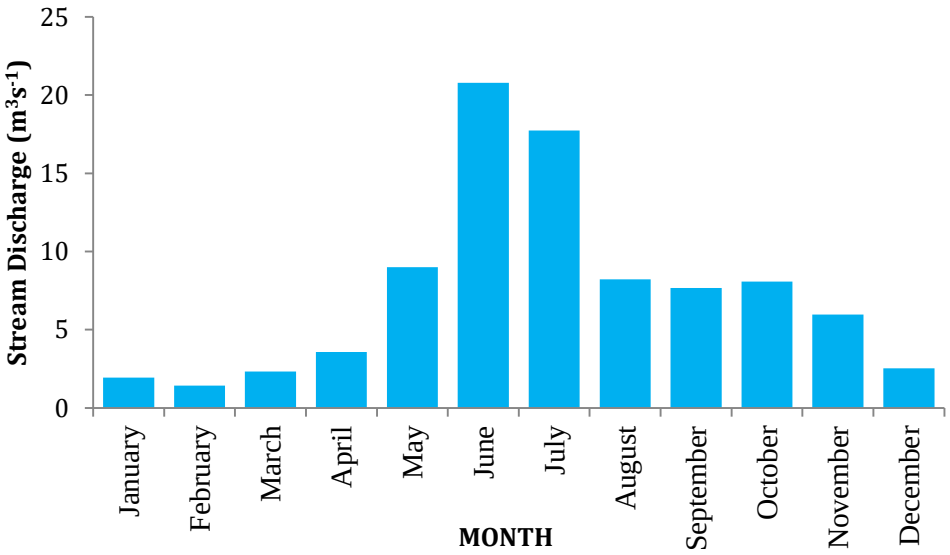

***Figure 5*: Monthly average stream discharge from 1986 to 2000.**

Climate Change Projections

Seventeen (17) Atmosphere-Ocean General Circulation Models (AOGCMs) from Coupled Model Intercomparison Project Phase 5 (CMIP5) were used to project the future climate (Table 4). The future daily generated climate data for the 2050s time slice was performed under CMIP5's two emissions scenario of the Representative Concentration Pathways (RCPs) 4.5 and 8.5 which represent the greenhouse gas concentration trajectories adopted by the IPCC (AR5).

Table 3

The selected 17 Atmosphere-Ocean General Circulation Models (AOGCMs)

Model Name	Institution	Reference	Resolution
BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration	Wu T (2012).	2.8125 x 2.8125
BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological	Wu T (2012).	2.8125 x 2.8125
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research	Collier MA et al. (2011)	1.875 x 1.875
FIO-ESM	The First Institute of Oceanography, SOA, China	Donner LJ et al. (2011).	2.812 x 2.812
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	Dunne JP et al. (2012).	2.0 x 2.5
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	Dunne JP et al. (2012).	2.0 x 2.5
GFDL-	Geophysical Fluid	Dunne JP et	2.0 x 2.5

ESM2M	Dynamics Laboratory	al. (2012).	
GISS-E2-H	NASA Goddard Institute for Space Studies	Schmidt GA et al. (2006).	2.0 x 2.5
GISS-E2-R	NASA Goddard Institute for Space Studies	Schmidt GA et al. (2006).	2.0 x 2.5
HadGEM2-ES	Met Office Hadley Centre	Collins WJ et al. (2011).	1.2414 x 1.875
IPSL-CM5A-LR	Institute Pierre-Simon Laplace	Dufresne JL et al. (2013).	1.875 x 3.75
IPSL-CM5A-MR	Institute Pierre-Simon Laplace	Dufresne JL et al. (2013)	1.2587 x 2.5
MIROC-ESM- CHEM	Atmosphere and Ocean Research Institute (The	Watanabe S et al. (2011).	2.8125 x 2.8125
MIROC5	Japan Agency for Marine-Earth Science and	Watanabe M et al. (2010).	1.4063 x 1.4063
MRI-CGCM3	Meteorological Research Institute	Yukimoto S (2012).	1.125 x 1.125
NorESM1-M	Norwegian Climate Centre	Kirkevag A et al, (2008)	1.875 x 2.5

MarkSim Weather File Generator

MarkSim GCM produces output in two formats: as annual charts of daily rainfall, maximum and minimum air temperatures and solar radiation, and as annual data files. The current MarkSim GCM has Google Earth satellite imagery and maps interface which help in the location of anywhere in the world. It is updated with the 17 individual climate models that were part of the IPCC's Fifth Assessment Report (CMIP5) and with greenhouse-gas emissions pathway called "Representative Concentration Pathways" which ranges from low, moderate and high emissions pathways.

MarkSim weather generator procedures

The Weija Water works area of latitude 5.58, longitude -0.33 and elevation of 63 (m) was selected from the Google map of the Marksim weather file generator interface. All the 17 CMIP5 (GCMs) of the interface were selected and an annual daily generated climate data with a replicate each from 2035 to 2065 period representing 2050s time slice was generated with two emissions scenario of the Representative Concentration Pathways (RCPs) 4.5 and 8.5.

SWAT Input Data Pre-processing

The Digital Elevation Model (DEM) and Land Use and/or Land Cover was formatted into a raster format whiles the Soil map in a vector shapefiles was converted into a raster format to enable compatibility. All the spatial datasets were projected into a common geographical coordinate system and reference. The non-spatial datasets collected for the study was formatted in accordance to the SWAT input and output format (Arnold et al., 2013).

Simulation in SWAT

SWAT can simulate single or multiple watersheds. The watershed is first divided into subbasin and then into Hydrologic Response Units (HRUs) based on the land use/cover and/or soil distributions. The Procedures in SWAT are as follows (Winchell, Srinivasan, Di Luzio & Arnold, 2013):

Watershed delineation

In the watershed delineation process, the DEM was used to define the stream network of the study area, the outlet and inlet sources, create a number

of sub-basin and delineate the basin. ArcSWAT use the DEM to simulate a topographical report such as elevation distribution within the basin.

HRU analysis

The land use and soil data are loaded into the ArcSWAT interface under the HRU analysis. The land use, soil and slope which is created in ArcSWAT interface is used to create a unique HRU (land use/soil/slope) combination for each sub-basin.

Import weather data

All the weather data (rainfall, air temperature, relative humidity, wind speed and solar radiation) and locational information on weather station were imported into ArcSWAT. The weather data were assigned to the sub-basins.

SWAT simulation

Simulations were run from 1986 to 2015 with a three-year warm up period (1986–1989) that allowed the model to stabilise prior to simulation.

Calibration and Validation

The SWAT-CUP provides a decision-making framework that incorporates a semi-automated approach for calibration and incorporating sensitivity and validation analysis. The SWAT-CUP was used to calibrate and validate SWAT model setup for this study.

Sequential Uncertainty Fitting 2 (SUFI-2)

In SUFI-2, the uncertainties parameters are estimated from all the sources, including climatic data, soil data, land use data, observed data, and parameters. The uncertainty in the model output variables is expressed as a 95% prediction uncertainty (95PPU, known as the p-factor) which is calculated at the 2.5 % and 97. 5% levels of the cumulative distribution of an output variable (Yang et al., 2007). The p-factor and r-factors are the two statistics used by the model to quantify the fitness between the simulated result and the observed (measured stream flow or discharge). The p-factor ranges from 0 to 1 while the r-factor ranges from 0 to infinity.

The percentage of the observed data wrapped in the 95PPU defines the p-factor and the wideness denotes the r-factor. A p-factor of 1 and r-factor of 0 is a simulation that exactly equals the observed data, which is an ideal but impossible case due to uncertainties from the measurements and other different sources. A higher value of the p-factor can be attained at the cost of a higher r-factor. Thus, a balance must be achieved between the two factors, which will result in decreasing parameter uncertainty.

Calibration and validation were performed using Sequential Uncertainty Fitting 2 (SUFI 2) where Coefficient of determination (R^2) was set as the objective function type. The Coefficient of determination (R^2), Nash Sutcliffe (NS), Percentage Bias (PBIAS), and Root Mean Square Error (RMSE) which were used to determine the Performance of the model are represented in equation 5, 6, 7 and 8 respectively.

$$\mathbf{R^2} = \frac{[\sum_i (Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)]^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2} \quad \text{Equation 5}$$

$$\mathbf{NS} = \mathbf{1} - \frac{\sum_i (Q_m - Q_s)^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \quad \text{Equation 6}$$

$$\mathbf{PBIAS} = \mathbf{100} \times \frac{\sum_{i=1}^{n} (Q_m - Q_s)_i}{\sum_{i=1}^{n} Q_{m,i}} \quad \text{Equation 7}$$

$$\mathbf{RMSE} = \frac{\sqrt{\sum_{i=1}^{n} (Q_m - Q_s)_i^2}}{\sqrt{\sum_{i=1}^{n} (Q_{m,i} - \bar{Q}_m)^2}} \quad \text{Equation 8}$$

Where Q is the discharge variable, m is measured discharge, s is the simulated discharge and i is the ith measured or simulation data.

Model Sensitivity Analysis

The parameters to be used in calibration were first subjected to sensitivity analysis to identify the key parameters required for the calibration process. The model uses multiple regression systems to generate sensitive parameters and the Latin Hypercube generated parameters against an objective function that were used in sensitivity analysis. In order to determine the significance between each of the parameters used, the model uses t-test and ρ-value to test its sensitivity. The t-stat measures the regression coefficient for each parameter and divided it by their standard errors. In the sensitivity analysis, parameters with larger value for t-stat and the smaller ρ-value are considered more sensitive. The Global Sensitivity analysis (GSA) was employed and the Parameters involved and their range selected to calibrate SUFI 2 is specified in Table 5.

Out of the 22 parameters selected for calibration analysis, fourteen were found to be sensitive of which six (6) in Table 4 shows the most sensitive output of SWAT with their ρ- value less than 0.05 (Abbaspour, 2014). The most sensitive input parameters among this six were ALPHA BF.rte, EPCO.hru, and OV N.hru with their ρ- value nearly zero.

Table 4

Most Sensitive Parameters and their t- stat and ρ- value

Rank	Parameter Name	t-Stat	ρ-Value
9	V__ALPHA_BNK.rte	2.09	0.04
17	R__SLSUBBSN.hru	-2.20	0.03
1	R__CN2.mgt	-2.43	0.02
8	V__CH_K2.rte	2.69	0.01
22	R__EPCO.bsn	-3.14	0.00
2	V__ALPHA_BF.gw	-3.67	0.00
14	V__OV_N.hru	7.56	0.00

The first sensitive input parameter OV_N (Manning's "n" value for overland flow), followed by ALPHA_BF (Baseflow alpha factor), EPCO (Plant uptake compensation factor), CH_K2 (Effective hydraulic conductivity in main channel), CN2 (SCS runoff curve number), SLSUBBSN (Average slope length) and final ALPHA_BNK (Baseflow alpha factor for bank storage).

Table 5

SWAT Parameters used in the Calibration Process

	Parameter Name	Description	Min value	Max value
1	CN2.mgt	SCS runoff curve number f	-0.2	0.2
2	ALPHA_BF.gw	Baseflow alpha factor (days)	0	1
3	GW_DELAY.gw	Groundwater delay (days)	50	500
4	GWQMN. gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	2
5	OV_N.hru	Manning's "n" value for overland flow	0.01	1
6	ESCO.bsn	Soil evaporation compensation factor	0	1
7	EPCO.bsn	Plant uptake compensation factor	0.01	1
8	FFCB.bsn	Initial soil water storage expressed as a fraction of field capacity water content	0	1
9	SOL_AWC.sol	Available water capacity of the soil layer	0	1
10	SURLAG.bsn	Surface runoff lag time	0.05	15
11	SOL_ALB.sol	Moist soil albedo	0	1
12	SOL_K.sol	Available water capacity of the soil layer	0	500
13	SLSUBBSN.hru	Average slope length	0	10

Table 5 continued

14	GW_REVAP.gw	Groundwater "revap" coefficient	0.02	0.2
15	CH_K2.rte	Effective hydraulic conductivity in main channel alluvium	0	150
16	CH_ERODMO.rte	Jan. channel erodability factor	0	1
17	CH_N2.rte	Manning's "n" value for the main channel	0.01	0.2
18	REVAPMN.gw	Threshold depth of water in the shallow aquifer required for “revap” to occur (mm)	0	150
19	SOL_Z.sol	Soil depth	0	500
20	ESCO.hru	Soil evaporation compensation factor	0	1
21	EPCO.hru	Plant uptake compensation factor	0.01	1
22	RCHRG_DP.gw	Deep aquifer percolation fraction	0	1

Note: Min value is minimum value and Max Value (Maximum value)

Calibration and Validation

The fourteen sensitive parameters analysed during the sensitivity analysis were also used during the auto-calibration procedure. In the SUFI-2 algorithm, 500 simulations were performed in each iteration in the calibration and validation.

Data Analysis

Data analysis was mainly done in Microsoft Excel 2010 and descriptive statistics were used to describe data.

CHAPTER FOUR

RESULTS

Model Calibration and Validation

The calibration and validation statistics given in Table 6 shows the model calibration results for six (6) year (1989 to 1994) period and 1995 - 2000 for model validation. Overall, the model performance was efficient in monthly simulation, with an NS value of 0.76 and an R^2 value of 0.84 , value of PBIAS = 25.6 % and RMSE = 0.49 for the calibration whiles the validation statistics displayed model performance, with an R^2 value of 0.77 and NS value of 0.70 with PBIAS of 22.2 % and that of RMSE = 0.54. Hydrographs in Figure 6 and Figure 7 show the performance of the model calibration and validation.

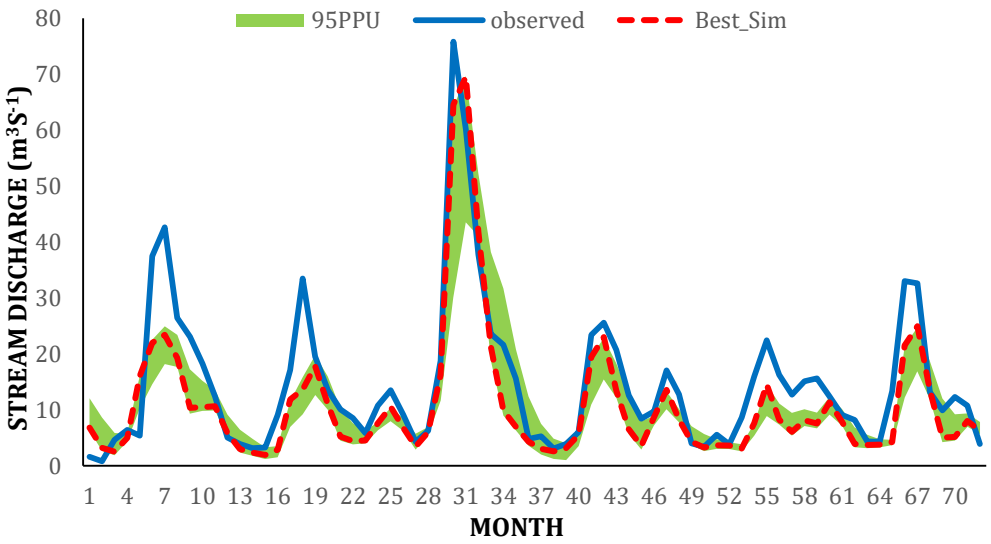

***Figure 6*: Hydrographs for calibration period from 1989 to 1994**

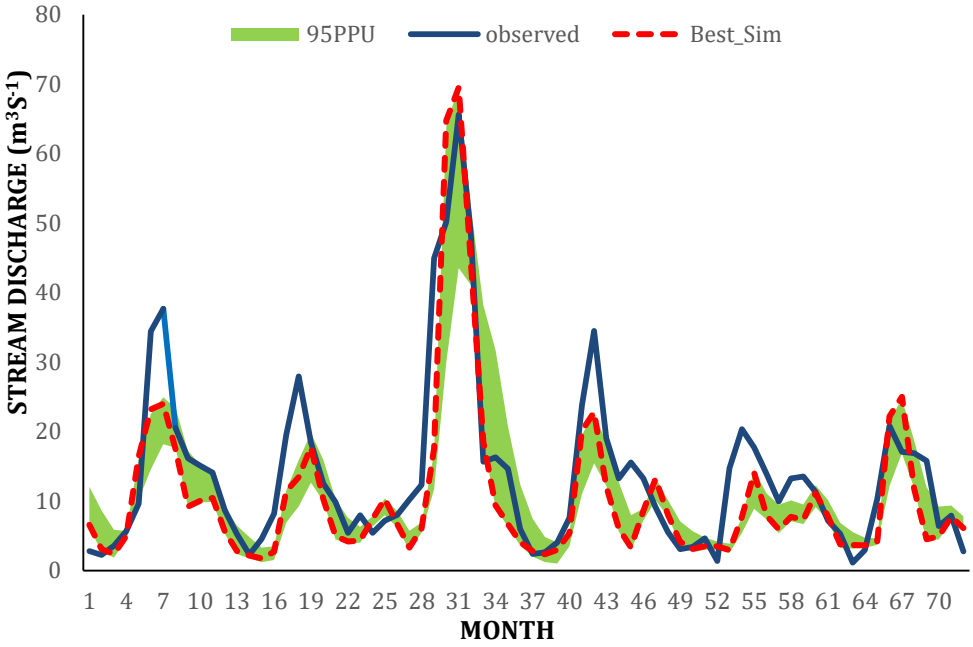

Figure 7: **Hydrographs for validation period from 1995 to 2000**

Note: 95ppu (95% Prediction Uncertainty), observed (observed discharge) and Best sim (best simulation). The numbers from 1 to 72 represent months from 1989 to 1994 and 1995 to 2000 respectively.

Table 6

Calibration and Validation Statistics Using Soil and Water Assessment Tool Coupled with Semi-Automated SWAT-CUP

Objective Function	Calibration (1989-1994)	Validation (1995-2000)
R^2	0.84	0.77
NS	0.76	0.70
PBIAS	25.6%	22.2%
RMSE	0.49	0.54

R^2 is coefficient of determination, NS is Nash-Sutcliffe Efficiency, PBIAS is Percentage bias and RMSE is Root mean square error.

Hydroclimatic Conditions for the Baseline Period (1986 - 2015)

Rainfall (RF)

The mean annual rainfall for the baseline period was 64.9 (mm) (Table 7) with a monthly mean ranging from 9.6 (mm) as the lowest (January) to 180.2 (mm) (June) as the highest. The rainfall increase from a mean margin of 19.2 (mm) to 42.3 (mm) from January to June but the greatest mean margin was observed between June and July (123.6 mm) (Figure 4).

Evapotranspiration (ET)

An average maximum and minimum evapotranspiration of 196.8 mm and 1.9 mm were recorded over the observed period (1986-2015). The average monthly evapotranspiration ranged from 18.7 mm in August to 32.7 mm (April) with an annual average of 24.4 mm (Table 8) and a standard deviation (STD) of 29.3 mm.

Soil Water Storage (SW)

The amount of water in the soil profile is referred to as soil water. The baseline distribution of average maximum soil water ranges from 788.3 mm to 834.9 mm across the period (1986-2015) while the minimum average is 1.4 mm. The month February had the lowest monthly average soil water stored (51.8 mm). The standard deviation shows nearly equal values between months (Table 9).

Table 7

Annual and Monthly Descriptive Statistics of Observed Rainfall (mm) for the Baseline Period (1986-2015)

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	9.6	26.8	60.2	90.9	137.9	180.2	56.6	22.5	51.8	77.8	35.1	29.3	64.9
MAX	47.2	137.8	213.9	269.4	403.8	419.3	184.2	118.1	151.4	198.7	133.5	113.5	419.3
MIN	0.0	0.0	0.0	6.1	16.6	35.9	0.0	0.2	7.5	2.0	0.0	5.7	0.0
STD	11.3	34.8	55.5	59.5	85.4	96.8	41.4	26.1	42.2	56.8	27.3	33.6	71.9
TOTAL	6710	18779	42244	63801	96792	126514	39739	15811	36337	54645	24629	20558	546558

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Table 8

Annual and Monthly Descriptive Statistics of Observed Evapotranspiration (mm) for the Baseline Period (1986-2015)

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	19.4	20.3	26.1	29.9	32.7	31.9	20.8	18.7	21.4	27.3	23.0	21.6	24.4
MAX	164.2	164.9	196.8	192.9	182.4	154.9	130.6	116.2	135.1	172.4	155.9	173.1	196.8
MIN	2.7	2.7	1.9	6.5	11.1	11.8	5.9	3.9	4.2	4.4	3.9	2.3	1.9
STD	32.2	32.5	34.3	34.5	30.6	23.9	20.4	20.7	22.6	30.1	29.6	31.3	29.3
TOTAL	13635	14241	18322	21019	22918	22033	14620	13102	14991	19176	16170	15160	205388

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Table 9

Annual and Monthly Descriptive Statistics of Observed Soil Water Storage (mm) for the Baseline Period (1986-2015)

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	53.8	51.8	52.8	54.8	61.4	69.1	68.7	65.5	66.3	64.9	61.4	57.9	60.7
MAX	792.1	788.3	789.6	791.4	810.5	819.1	834.9	823.7	816.2	814.3	804.4	798.3	834.9
MIN	3.1	1.4	3.5	4.5	7.2	7.5	9.3	7.3	8.8	6.7	6.1	4.0	1.4
STD	153.3	153.3	153.3	153.4	153.5	153.7	153.7	153.5	153.4	153.3	153.3	153.3	153.4
TOTAL	37771	36373	37080	38480	43074	48507	48227	45944	46559	45550	43129	40686	511378

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Table 10

Annual and Monthly Descriptive Statistics of Observed Water Yield (mm) for the Baseline Period (1986-2015)

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	7.6	18.2	41.1	63.5	101.2	153.9	59.1	15.2	32.5	57.4	38.9	21.8	50.9
MAX	47.7	101.9	188.4	209.1	299.3	392.8	177	77.0	121.4	181.4	157.4	71.7	392.8
MIN	0.0	0.0	0.2	2.9	7.5	33.7	7.0	0.3	2.1	3.7	0.1	0.0	0.0
STD	11.3	25.6	40.7	45.9	59.3	89.8	40.2	18.7	32.5	46.1	34.8	22.6	59.2
TOTAL	5363	12752	28848	44601	71005	108002	41515	10637	22826	40319	27323	15310	428500

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Water yield

Water yield, is the net amount of water that leaves the sub basin including surface runoff, lateral flow and groundwater contribution, less transmission losses that contribute to stream flow. The monthly average water yield in Densu river basin (DRB) ranged from 7.6 mm to 153.9 mm with an annual average of 50.9 mm and a standard deviation of 59.2 mm (Table 10). Figure 8 shows the average distribution made by each sub basin in DRB on soil water, ET and water yield over the observed period (1986-2015).

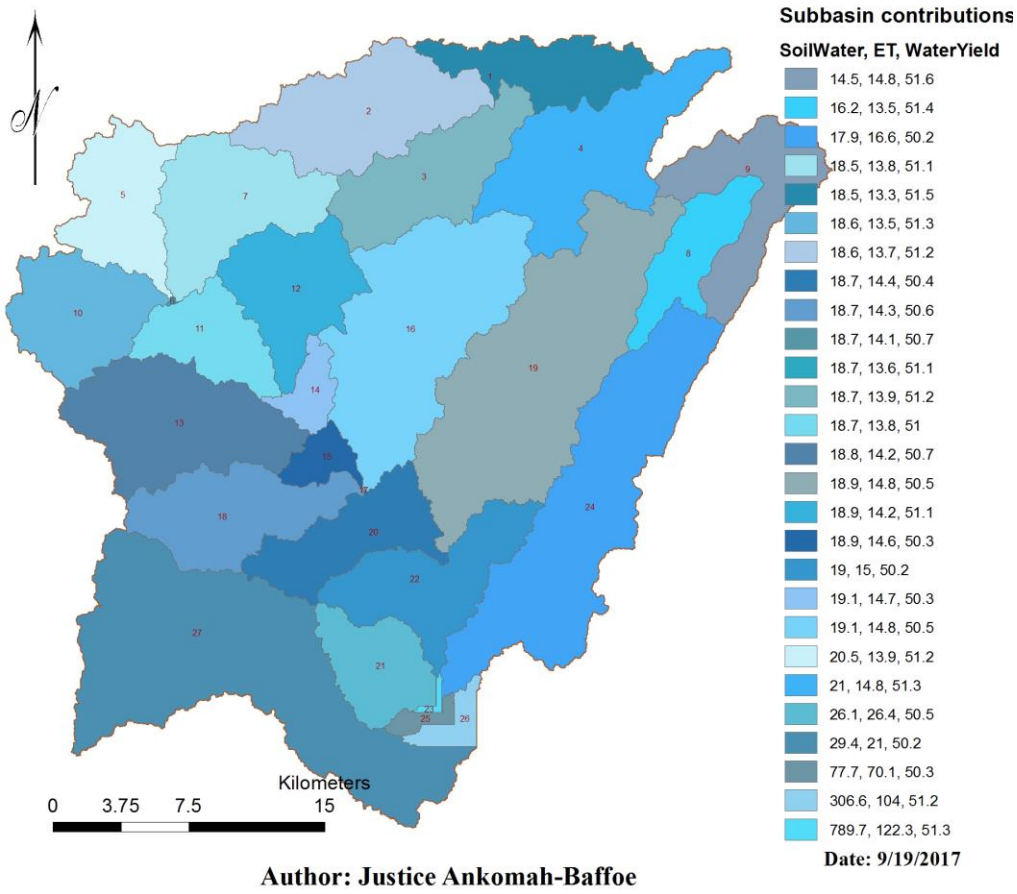

***Figure 8*: Distribution of total soil water, ET and water yield over the DRB for the baseline period (1986-2015)**

Hydroclimatic Conditions for the DRB in the 2050s

Projected Temperature in 2050s

The average monthly maximum temperature under RCP4.5 emission scenario for the 2050s shows a projection range of 28.60 - 36.14 ^{o}C while that of the RCP 8.5 ranges from 29.84 - 36.14 ^{o}C (Figure 9). Both scenarios (RCP4.5 and RCP8.5) projected an annual average maximum temperature of 32.61 and 33.83 ^{o}C, respectively. Minimum temperature projection by RCP4.5 and RCP 8.5 indicated an annual average of 25.24 and 26.49 ^{o}C with a monthly average projection ranging from 23.67 - 27.95 ^{o}C and 24.91 - 29.07 ^{o}C respectively.

Projected Rainfall for the 2050s

In the 2050's, the monthly average rainfall for DRB is expected to fall within a range of 3.7 mm to 291.5 mm for RCP 4.5 and RCP 8.5 pathways. Under the RCP 4.5 pathway scenario, five months (March, April, May, June and October) were projected to have a monthly average above 100 mm whereas, four months (April, May, June and October) were projected to be above 100 mm and remaining seven months have averages below 50 mm for RCP8.5 (Figure 10). The projected maximum and minimum rainfalls were around 305.8 mm to 2.2 mm (RCP4.5) and 400.3 mm to 2.1 mm (RCP8.5), with standard deviation of 89.4 and 95.7 respectively (Tables 11 and 12).

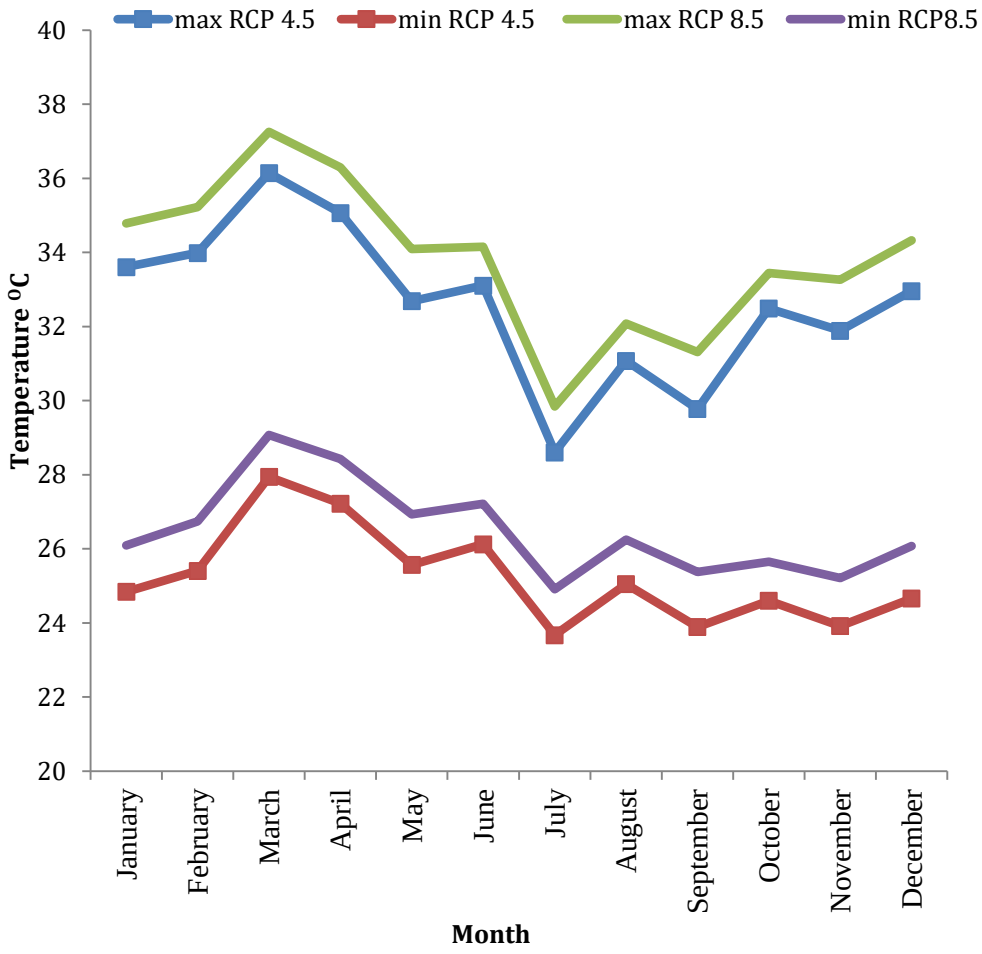

Figure 9: **The projected average monthly Maximum and Minimum temperature for the 2050s under RCP 4.5 and RCP 8.5 scenarios.**

Note: max RCP4.5 and min RCP4.5 (Maximum and Minimum temperature under Representative Concentration Pathways 4.5); max RCP8.5 and min RCP8.5 (Maximum and Minimum temperature under Representative Concentration Pathways 8.5)

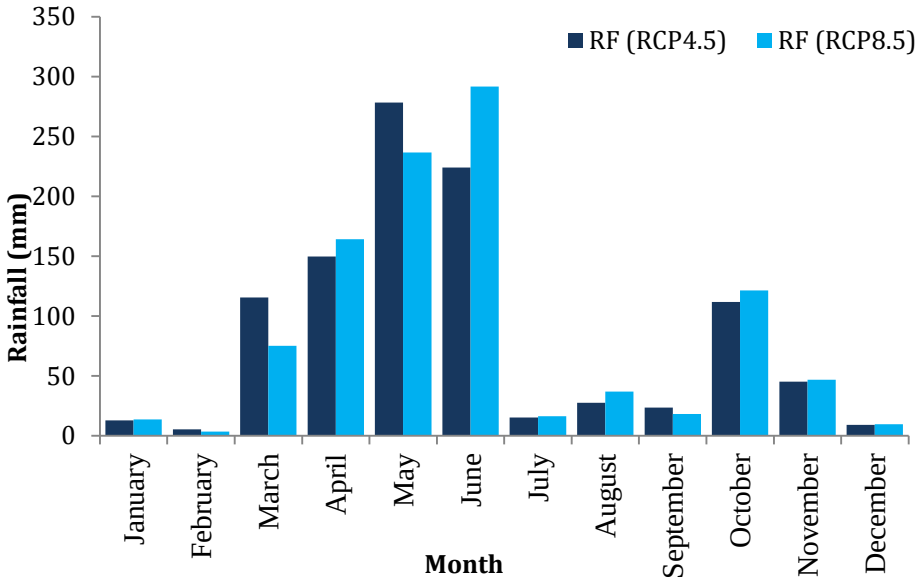

***Figure 10*: Projected monthly rainfall for RCP 4.5 and RCP 8.5 in the 2050s**

Note: RF (RCP4.5) is the rainfall for Representative Concentration Pathways 4.5 and RF **(**RCP8.5) is the rainfall for Representative Concentration Pathways 8.5.

Projected Evapotranspiration (ET)

The actual evapotranspiration (ET) from soil and plant show similar trends in both emission scenarios with an annual average evapotranspiration (ET) of 62.5 mm and 63.1 mm for RCP 4.5 and RCP8.5 respectively (Tables 11 and 12). The maximum and minimum ET were projected to be around 154.1 mm (RCP4.5), 155.0 mm (RCP8.5) and 9.9 mm (RCP4.5) and 10.1 mm for (RCP8.5). An increase is projected to be from March to June which is the peak with values 114 mm in both scenarios. The lowest projected average is expected to occur in February (28.4 mm and 30 mm for the two scenarios, respectively).

Table 11

Annual and Monthly Descriptive Statistics of Future Rainfall and Evapotranspiration under RCP4.5

Rainfall (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	12.9	5.4	115.5	149.8	278.5	224.1	15.4	27.6	23.7	111.7	45.3	9.2	84.9
MAX	13.0	6.0	173.7	170.1	305.8	285.6	16.2	40.2	26.4	113.1	45.9	9.8	305.8
MIN	12.8	2.2	88.3	121.2	233.2	186.4	14.7	22.9	23.0	107.4	44.4	8.9	2.2
STD	0.0	1.1	19.3	12.1	25.5	36.5	0.4	4.1	0.8	1.4	0.5	0.3	89.4
TOTAL	9755	4101	87332	113279	210522	169406	11626	20898	17906	84451	34250	6958	770483
Evapotranspiration (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	34.9	28.4	92.7	94.8	95.2	113.4	48.6	35.9	35.2	72.9	51.9	45.7	62.5
MAX	148.5	151.1	146.3	129.1	117.8	152.0	137.6	95.0	123.2	143.8	138.9	154.1	154.1
MIN	18.7	9.9	52.1	69.1	79.3	95.0	31.5	25.2	20.9	53.0	34.9	28.7	9.9
STD	31.6	32.9	18.6	11.2	6.8	10.7	24.5	15.5	23.9	19.1	23.6	29.7	36.1
TOTAL	26399	21482	70110	71671	71963	85712	36725	27130	26616	55090	39258	34568	566725

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Table 12

Annual and Monthly Descriptive Statistics for Future RCP8.5 Rainfall and Evapotranspiration

Rainfall (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	13.8	3.6	75.3	164.2	236.8	291.8	16.2	36.9	18.3	121.4	46.9	9.8	86.2
MAX	18.3	5.9	126.6	213.2	300.2	400.3	23.6	41.3	23.8	146.3	50.9	10.5	400.3
MIN	12.8	2.1	49.7	152.4	211.3	193.1	13.2	30.1	4.5	111.2	44.7	8.9	2.1
STD	2.0	1.6	31.9	20.5	30.2	58.6	3.3	4.1	8.3	12.6	2.1	0.5	95.7
TOTAL	10417	2757	56921	124141	178999	220617	12282	27864	13851	91765	35429	7411	782455
Evapotranspiration (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	36.0	30.1	82.7	92.9	95.1	113.9	52.9	38.3	37.8	75.9	53.1	48.3	63.1
MAX	150.7	154.5	152.9	130.9	122.1	150.2	142.0	90.1	126.4	146.9	144.1	155.0	155.0
MIN	19.2	10.1	43.1	70.5	77.5	98.0	33.2	27.5	23.0	54.3	35.7	30.0	10.1
STD	31.8	33.2	21.4	11.1	8.5	9.8	24.7	13.1	24.0	19.1	24.4	29.4	34.9
TOTAL	27220	22779	62513	70260	71925	86106	40022	28931	28612	57383	40152	36518	572421

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation

Soil Water (SW) Storage

Not much difference exist between the two emission scenarios in terms of monthly average soil water storage which ranged from 86.7 mm to 161.0 mm and an annual average of 140.0 mm and 141.1 mm, respectively for the RCP 4.5 and 8.5 scenarios. The annual average standard deviation projected for the DRB is 162.1 in RCP 4.5 and 8.5 scenarios (Table 13 and Table 14).

Projected Water Yield

The projected amount of water that contributes to stream flow from the sub basin ranges from 0.54 mm to 109.04 mm (RCP4.5) annually and 0.26 mm to 149.8 mm (RCP8.5). The month of February is likely to have the lowest in terms of maximum and minimum water yield by 2050s for both RCP 4.5 (0.97 mm and 0.03 mm) and RCP8.5 (0.91 mm and 0.02 mm) as shown in (Table 13 and Table 14).

Table 13

Annual and Monthly Descriptive Statistics of Future Soil Water and Water Yield Under RCP4.5

Soil Water (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	111.6	100.7	103.9	128.6	192.2	178.7	151.6	145.3	139.0	154.9	149.8	123.4	140.0
MAX	860.8	847.6	884.4	904.1	944.5	928.2	897.7	897.0	890.7	911.3	904.0	874.7	944.5
MIN	23.7	17.8	23.4	38.0	77.6	75.0	52.0	44.2	39.5	57.1	52.5	31.9	17.8
STD	159.2	158.6	157.5	160.6	161.2	160.5	160.2	160.1	160.1	160.5	160.5	159.7	162.1
TOTAL	84404	76109	78584	97186	145309	135133	114576	109871	105063	117106	113277	93306	1269926
Water Yield (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	1.96	0.54	22.93	34.84	98.96	109.04	11.61	9.07	4.00	30.33	7.5	1.30	27.67
MAX	3.43	0.97	60.08	67.01	132.54	153.56	26.54	16.38	6.85	43.81	12.5	2.38	153.56
MIN	0.95	0.03	5.43	11.36	53.40	71.65	2.34	2.07	1.87	20.91	3.8	0.7	0.03
STD	0.59	0.22	9.65	11.52	16.88	22.58	4.74	2.57	1.16	5.59	2.19	0.35	37.12
TOTAL	1480	406	17338	26338	74816	82435	8780	6857	3022	22927	5638	986	251022

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Table 14

Annual and Monthly Descriptive Statistics of Future RCP8.5 Soil Water and Water Yield

Soil Water (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	114.6	100.5	86.7	125.0	184.0	187.2	155.9	154.6	141.3	161.0	155.5	126.9	141.1
MAX	863.2	845.7	854.9	903.7	941.8	943.6	906.5	903.7	890.7	918.0	913.3	875.7	943.6
MIN	27.3	21.2	22.2	41.0	80.9	84.7	57.8	52.4	46.1	63.4	57.7	36.5	21.2
STD	158.9	158.1	156.6	160.0	161.1	160.1	159.7	159.7	159.5	160.0	160.2	159.3	162.1
TOTAL	86649	75998	65512	94492	139091	141512	117869	116906	106796	121683	117566	95941	1280015
Water Yield (mm)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
MEAN	2.09	0.26	12.31	36.68	73.46	149.79	10.22	9.53	3.05	33.15	8.42	1.46	28.37
MAX	4.62	0.91	43.69	88.11	135.89	238.41	36.61	22.72	6.78	54.65	17.90	4.53	238.41
MIN	0.95	0.02	2.34	14.15	38.89	79.26	1.70	2.88	0.24	21.24	3.86	0.72	0.02
STD	0.70	0.26	10.44	14.07	22.93	39.90	7.49	3.83	1.61	7.07	2.98	0.52	44.36
TOTAL	1580	199	9309	27731	55533	113243	7724	7207	2307	25062	6367	1106	257368

Note: MAX (Maximum), MIN (Minimum), STD (Standard Deviation)

Differences between Baseline and Future Hydroclimatic Parameters

The annual average differences between the baseline period (1986-2015) and the future (2050s) temperatures are represented in Appendix A and Appendix B.

Rainfall (RF)

On an annual basis, RCP 4.5 scenario projects an increase of 20.05 mm rainfall above baseline and RCP8.5 indicates an increase of 21.37 mm above baseline (Table 15). But not all months within the years (2050s) will show an increase in rainfall pattern. February, July, September and December are month's anticipated to show a decline in rainfall by both scenarios (Figure 11).

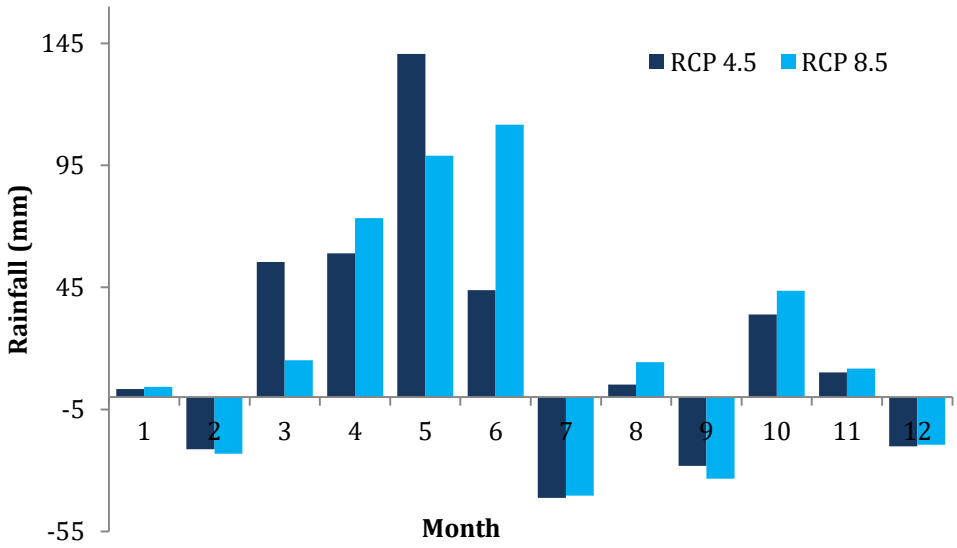

Figure 11: **Difference between projected (RCP4.5 and RCP8.5) monthly mean rainfall and baseline monthly mean rainfall.**

Note: RCP4.5 and RCP8.5 (Representative Concentration Pathways 4.5 and 8.5). The numbers 1 to12 represent the mothes of January to December. The negative (-) values indicate a reduction amount of rainfall.

Evapotranspiration (ET)

Over 60% increases in actual evapotranspiration (ET) is projected to occur in the future under the two climate scenarios. For the RCP 4.5 and RCP 8.5 scenarios, 81.99 mm and 82.51 mm increases in ET respectively, is anticipated for June. ET is expected to decline in the month of July to September. On an annual basis, an average increase in ET of 38.4 mm is anticipated for RCP4.5 and RCP8.5 scenarios (Figure 12 and Table 15).

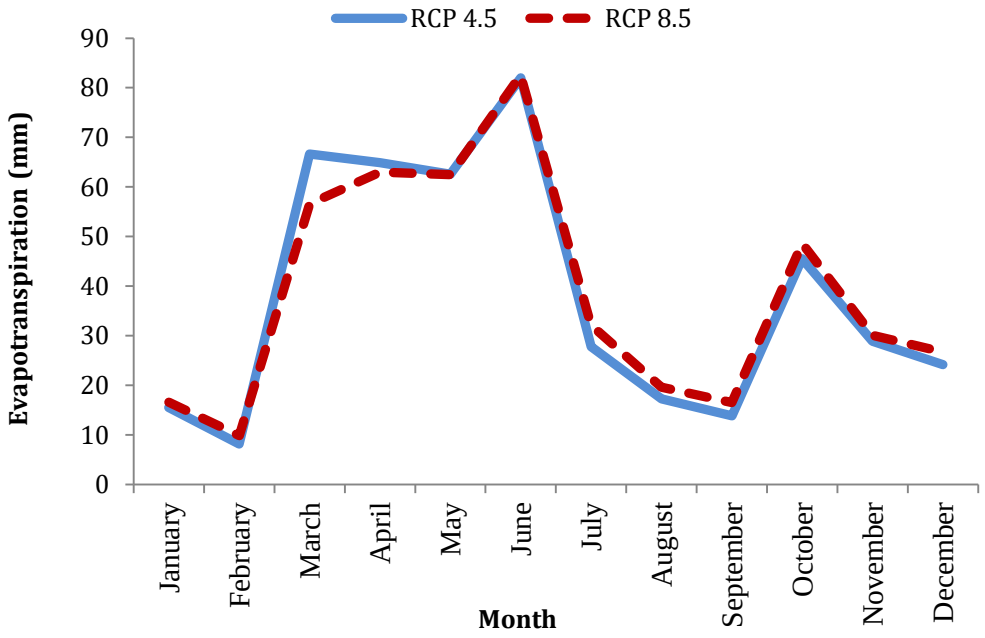

***Figure 12*: Difference between projected (RCP4.5 and RCP8.5) monthly mean evapotranspiration and baseline monthly mean evapotranspiration.**

Note: RCP4.5 and RCP8.5 (Representative Concentration Pathways 4.5 and 8.5)

Soil Water Storage (SW)

An increase of 80 mm in SW storage is anticipated for the two scenarios, with RCP 4.5 (79.3 mm) and RCP8.5 (80.39 mm). For both scenarios (RCP4.5 and RCP8.5), May and June were months of higher soil water storage with May recording 130.9 mm and 109.7 mm and June 122.6 mm and 118.1 mm respectively (Figure 13 and Table 15).

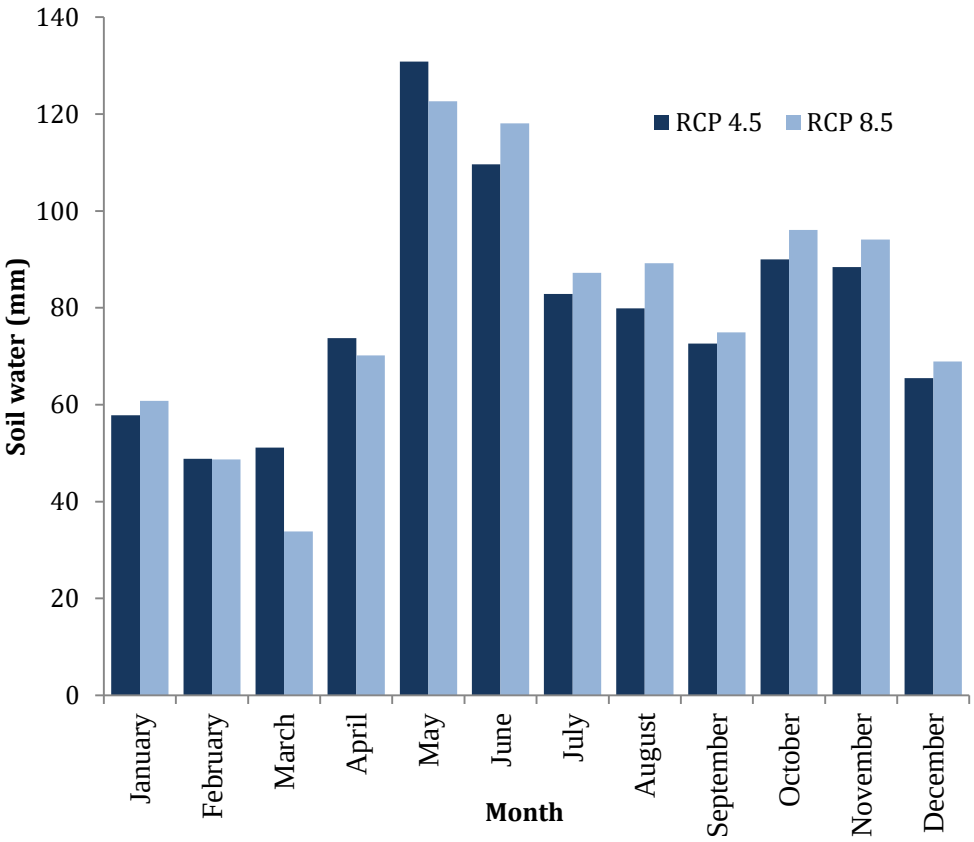

***Figure 13*: Difference between projected (RCP4.5 and RCP8.5) monthly mean soil water (SW) and baseline monthly mean soil water storage**

Note: RCP4.5 and RCP8.5 (Representative Concentration Pathways 4.5 and 8.5).

Water Yield (WY)

A reduction of about 22.5 mm to 23.2 mm in WY is anticipated for the two climate change scenarios on an annual basis. Both scenarios projects a reduction for all months (Figure 14 and Table 15).

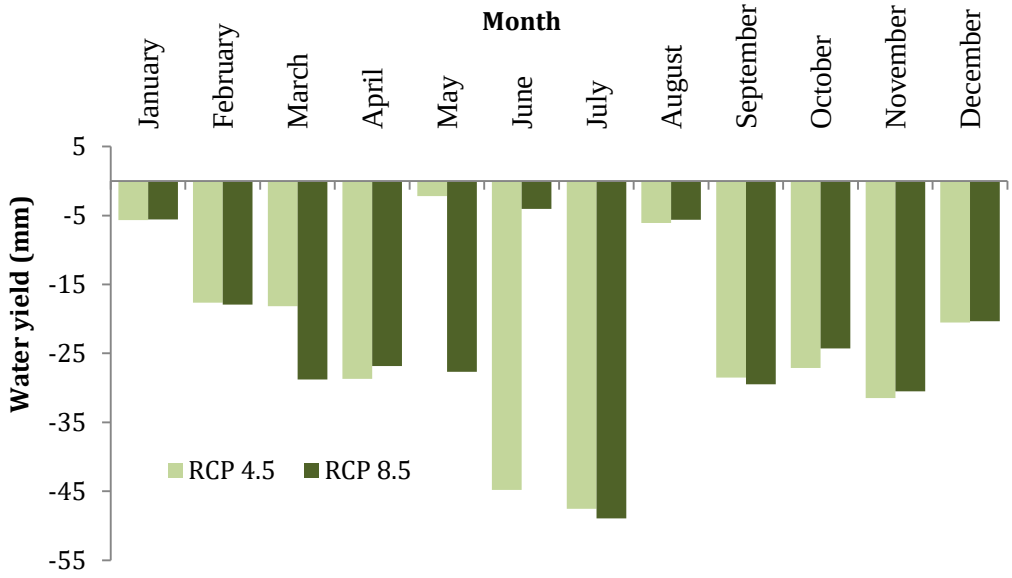

***Figure 14*: Difference between projected (RCP4.5 and RCP8.5) monthly mean water yield and baseline monthly mean water yield.**

Note: the negative (-) values indicate a reduction amount of water yield

Table 15

Annual Difference between Baseline and Projected Mean Rainfall, Evapotranspiration, Soil Water and Water Yield

Mean month	Rainfall (mm)	Evapotranspiration (mm)	Soil Water (mm)	Water Yield (mm)
RCP 4.5	20.05	38.09	79.28	-23.20
RCP 8.5	21.37	38.72	80.39	-22.50

Note: RCP4.5 and RCP8.5 (Representative Concentration Pathways 4.5 and 8.5).

CHAPTER FIVE

DISCUSSION

This study was conducted with the view of assessing the impact of climate change on the hydrological processes of Densu River Basin under different climate change scenarios in the 2050s.

Model Calibration and Validation

The hydrograph in Figure 6 and Figure 7 shows a closely related monthly observed and simulated stream discharge for the calibration and validation analysis. The result obtained from the simulation shows acceptable accuracy, considering the NS, R2, PBIAS and RMSE values in Table 6. The closeness of the NS and R2 to 1 in both calibration and validation shows that the model closely predicted the observed values of discharge (Gassman et al., 2007). The positive value of PBIAS shows an underestimation between the simulated and observed discharge. (Krause & Boyle, 2005; Gassman et al., 2007; Arnold et al., 2012).

The inability of SWAT model to model higher flows has been reported by many researchers (Arnold et al., 2012; Khoi & Thom, 2015; Abbas et al., 2016). The possible reasons could be incomplete soil and land use database or inaccurate GIS information which has been a general concern of hydrological models (Wu and Chen, 2015).

Rainfall

The average annual rainfall projection by the two scenarios shows an increase (Table 15) but the increase is not evenly distributed across the months (Figure 11). Stanturf et al., (2011) predicted a similar increase of (2.65 ± 13.96 %) rainfall in the wet season along the coastal savannah by 2050.

The increase and decrease in the rainfall pattern has been reported by Faramarzi et al. (2013) that the rainfall pattern in west Africa sub region is expected to increase but Sultan & Gaetani, (2016) disclosed that simulation of future rainfall in west Africa is governed by uncertainties. In Ghana, a decrease and highly variable rainfall amount should be expected (Kasei & Barnabas, 2014). The WRC (2017) has reported that in the past decade the amount of rainfall at the Densu River Basin has reduced.

The projected monthly rainfall by RCP4.5 and RCP8.5 in the future which are less than the baseline periods may be due to the projected increase in temperature (Asante & Amuakwa-Mensah, 2014). According to WRC (2017), November to April is noted to be the hottest period for the basin. Meanwhile, Owusu et al. (2008) reports that, the country is now witnessing a change in the rainfall system with longer dry seasons and a disappearing wet season and may have altered the major and minor rainfall regimes by 2050s.

Evapotranspiration (ET)

One of the most important components of the hydrological cycle is evapotranspiration. ET is related to the energy exchanges in the atmosphere, ground surface and plant root zone. The WRC (2017) has reported that, about 70% of the annual rainfall in the Basin returns back to the atmosphere as ET but the baseline ET estimated shows that about 38% of the annual rainfall returns to the atmosphere. The increase in temperature and reduction in rainfall for some months by 2050s within the DRB is expected to cause an increase in evapotranspiration. More than 60% increase in evapotranspiration was projected (Figure 12) to occur in the 2050s by both RCP 4.5 and RCP 8.5.

The increase in temperature over Densu River Basin may lead to more water losses, since water loss to the atmosphere is regulated by higher temperature (Mehan, Kannan, Neupane, Mcdaniel, & Kumar, 2016). According to Asante & Amuakwa-Mensah, (2014) an increase in temperature also increases transpiration in plant and more evaporative losses due to warming and abundant energy availability (Trenberth et al., 2009) would result in a drier condition.

The rise in temperature would not be the only driving force responsible for the high projected ET by 2050s but land use/cover changes and anthropogenic activities (Mehan et al., 2016) could be a contributing factor. The DRB according to Ayivor & Gordon, (2012b); Yorke & Margai, (2007) and Yorke & Margai, (2014) is greatly affected by land use /cover and anthropogenic activities.

Soil Water Storage

The amount of water stored in the soil profile of DRB from the baseline is reasonably high comparing the amount of rainfall and ET (Tables 7, 8 and 9). The annual projected soil water stored (Table 15) in the basin is expected to have an increase in annual average of 80 mm by 2050s. The highest future monthly soil water recorded (Figure 13) corresponded with the months of higher rainfall (Figure 11) by the two pathways (RCP 4.5 and RCP8.5). Shah et al., (2017) linked the changes in soil water to the changes in rainfall duration and intensity.

The ET from a surface is related to the soil water, part of which is used to meet the ET demand. This shows that abundant soil water result in an increase in ET (Mehan et al., 2016). Both evapotranspiration and rainfall contribute to soil water balance (Aguilera & Murillo, 2009).

Water Yield

Water yield is the amount of water in runoff, lateral flow, ground water contribution to the stream flow, less transmission losses through channels. The projection for the future (2050s) water in the DRB is estimated to decline below the baseline period (Figure 14). An annual average reduction of 23 mm off the baseline period of 50.9 mm (Table 10) is anticipated for the 2050s.

The projected decline in the future water yield may result from the increase in temperature despite the increase in rainfall (not seen in all

months) (Figure 11) and soil water stored. Higher temperature difference (Appendix A and Appendix B) and evapotranspiration (Figure 12) occurs around months (March to June) of high rainfall (Figure 11). The temperature changes around these months are however higher than months within dry season. A similar temperature differences around these months (March to June) have been projected by Stanturf et al. (2011) along the coastal savannah for 2050.

The increase temperature and high evapotranspiration should result in soil water loss which according to Dai et al. (2004) is more sensitive than rainfall. Evapotranspiration does not occur only in the soil, it depends on water availability and according to Williams, (2006); Jensen, & Allen, (2016) more water evaporate from opening waters (lakes, rivers, streams and puddles) than the soil and that soil type, organic matter, vegetation cover and capillary force aid in soil water retention (Chenu, Bissonnais, & Arrouays, 2000). Hence the reductions in water yield in the basin.

The assessments from the SWAT model projects that DRB will be confronted with a dry condition by 2050s. The projection shows increases in the hydrological components such as rainfall and soil water storage but this increase does not contribute to stream flow (decline in water yield) due to the rise in temperature and evapotranspiration. The combined effect of increase in temperature and ET leads to drier conditions and more water loss from streams and rivers. The effect will be more than just decrease in water supply but smaller rivers or their tributaries may dry up. This particularly threatens the demand of water for domestic, industrial, commercial and agriculture

(irrigation and livestock) purposes within and out of the basin.

The key uncertainty related to the study is land use/cover which remains unchanged throughout the study. According to Ayivor & Gordon, (2012), agriculture activities and settlement are the main causes of land use/cover changes within the basin. These activities have to do with conversion of forest land into crop lands and crop land to residential land. Any change in the land use/cover of the basin will alter the hydrological processes. If land use/cover changes occur within the projected years 2050, more dry condition should be anticipated and will pose a threat to available water supply and agriculture water demand for irrigation activities.

All the projections under the two different climate change scenarios indicate that Densu River Basin will face a decline in water yield, with an increase in ET losses and an increase in soil water.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATION

Conclusions

The performance of SWAT model was measured in terms of NSE, R^2, PBIAS and RMSE, which revealed that there was strong correlation between observed and simulated stream flows for baseline period. The calibration process considered 22 different parameters with the aim of capturing all the major factors dominant in the watershed. The SWAT was found to be reliable for watershed assessment for climate change impact studies.

It can be concluded from the study that there is an increasing amount of water stored in the soil profile (soil water) and that is what contributes to stream flow (water yield) within the DRB in present state. This present increase in soil water and water yield may be due to the rainfall amount which exceeds ET.

An overall increase in rainfall, temperature, soil water storage and evapotranspiration is anticipated in the 2050s. However, there will be reduction in water yield in the 2050s. This can be related to the increase in temperature and a rise in evaporative losses which extremely surpasses amount of rainfall. Therefore, these conditions could lead to dry conditions projected to prevail in Densu River Basin under the impact of the climate change in the 2050s.

The dry conditions in effect will reduce the amount of water supply by the basin for domestic industry and agriculture purposes. The threat will be

extended to food production since it is directly related to water availability. Livelihoods that depend on water supply by the basin for their survival will be affected.

Recommendations

Future studies to investigate the effect of land use/cover change on the hydrological parameters especially water yield.

Despite increase in rainfall and soil water storage, the projected reduction in water yield should be an input to discussions on adaptive management of water resources and the basin as a whole by Ghana Water Company Ltd. and Water Resource Commission.

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APPENDICES

Appendix A

Temperature (^{O}C) Difference between Observed and Representative Concentration Pathways (RCP4.5)

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	ANNUAL
Min TMP	0.75	0.45	2.95	2.17	1.18	2.53	0.67	2.39	0.86	1.14	-0.21	0.39	1.28
Max TMP	1.04	1.08	3.43	2.84	1.57	3.53	0.15	2.33	-0.04	1.40	-0.05	0.72	1.49

Appendix B

Temperature (^{O}C) Difference between Observed and Representative Concentration Pathways (RCP8.5)

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	ANNUAL
Min TMP	2.0	1.8	4.1	3.4	2.5	3.6	1.9	3.6	2.3	2.2	1.1	1.8	2.5
Max TMP	2.2	2.3	4.5	4.1	3.0	4.6	1.4	3.3	1.5	2.4	1.3	2.1	2.7

Min TMP is minimum Temperature, Max TMP is Maximum Temperature