CLIMATE CHANGE IMPACT ON WATER RESOURCES AVAILABILITY IN THE GUINEA AND SUDANO-SAHELIAN ECOLOGICAL ZONES, NIGERIA

BY

SALIHU, Abdullahi Chado

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DEPARTMENT OF GEOGRAPHY

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

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ABSRACT
Water resources have been threatened in the Guinea and Sudano-Sahelian ecological zones by the persistent impact of climate change. Many previous studies in the area were based on historical trend analysis or hypothetical assumptions in projecting climate change impacts on water resources. Considering the sensitivity of the hydrological system to climate change, there is the need to adopt the current global paradigm shift from the use of historical trend analysis to the use of General Circulation Models (GCMs) with Representative Concentration Pathways (RCPs). This is yet to be adopted within the study area, which constitutes the research gap this thesis has identified. Thus, the aim of the thesis was to examine the impact of climate change on water resources availability in the Guinea and Sudano-Sahelian ecological zones of Nigeria. The objectives were to: analyse the sensitivity of the Guinea and Sudano-Sahelian ecological zones of Nigeria to climate change; determine the potential impact of climate change on water yield; identify the trend in the occurrence of extreme rainfall indices; and estimate the water stress resulting from climate change in the study area. The data used (observed and simulated) were from the archive of the Royal Netherlands Meteorological Institute Known as the KNMI Climate Explorer. The respective coordinates of each basin were used to derive the observed and simulated data. Mann Kendal statistical test was used to analyses trends in all the time series at the 0.05 significance levels. Projections were produced for three future periods namely: 20192048, 2049-2078 and 079-2100 using the multi-model ensemble mean of CMIP5 GCMs under RCP2.6, RCP4.5 and RCP8.5. The metrics were root mean square error (RMSE), Mean Absolute Error (MAE) and Nash-Sutcliffe Efficiency (NSE). The errors between the observed and simulated were within the acceptable threshold. Regional trend analysis of seasonal and annual temperature confirm significant positive trends for (2019-2048), (2049-2078), and (2079-2100) with respect to highest emission trajectories. On the other hand, seasonal and annual rainfall projections for the same time horizons confirm high level of variability unlike temperature. However, regional trend analysis confirms that Guinea and Sudano-Sahelian ecological zones of Nigeria will experience decreasing dry season water yield. As for wet season, it reveals that under 2019-2048 period there are no significant increasing trends. This is with respect to high emission scenario (RCP8.5) but significant in low and middle emission scenarios (RCPs 2.6 and 4.5). Furthermore, it is evident that regional trend analysis of maximum 5-day rainfall demonstrated that under 2019-2048 period there will be no significant positive trend. Regional trend analysis of heavy rainfall days point out that there will be no significant positive trends for RCP2.6 with respect to the three projected periods but significant with respect to 2049-2078 for RCP4.5 as well as RCP8.5. Regional trend analysis of CWD established that there will be no significant negative trends. Conversely, CDD will increase within the range of 2-5 days and 6-10 days for all the three RCPs under the two baseline periods of (1959-1988) and (19892018) respectively. However, regional trend under the influence of population growth at constant climate observed that there will be significant positive trends in water stress for the three projected periods. This implies that future water scarcity is imminent and will be primarily caused by population growth and only secondarily by climate change in the Guinea and Sudano-Sahelian ecological zones of Nigeria. It was recommended amongst others that future research should explore the comparative analysis of CMIP5 and CMIP6 in reproducing historical seasonal as well as annual temperature and rainfall in the Guinea and Sudano-Sahelian ecological zones of Nigeria. This will facilitate a robust climate projection for the study area

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LIST OF ABBREVATIONS AND ACRONYMS

ACRU:	Agricultural Catchment Research Unit
AR4:	Fourth Assessment Report
AR5:	Fifth Assessment Report
AWB:	Australian Water Balance
BAU:	Business -As- Usual
CLSM:	Catchment Land Surface Model
CMIP:	Couple Model Intercomparison Project
CORDEX:	Coordinated Regional Climate Downscaling Experiment
CRU:	Climate Research Unit
DIAS:	Data Integration and Analysis System
DNP:	Dinder National Park
DRP:	Dinder River Basin
ECHAMS:	European Centre Hamburg Model
ET:	Evapotranspiration
EDCDF:	Equidistant Cumulative Distribution Functions
FAR:	First Assessment Report
GCMs:	General Circulation Models
GRDC:	Global Runoff Data Centre
GWR:	Geographically Weighted Regression
HadCM:	Hadley Centre Couple Model
HadGEM:	Hadley Centre Global Environmental Model
HBV:	Hydrologiska Byrans Vattenbalansavdelning
HIRHAM:	High Resolution Limited Area Model
IPCC:	Intergovernmental Panel on Climate Change
KLB:	Kainji Lake Basin
KNMI:	Royal Netherlands Meteorological Institute
KYB:	Komadugu-Yobe Basin
MAE:	Mean Absolute Error
MDGs:	Millennium Development Goals

ModHypma: Hydrological Model based on Least Action Principle

NIHSA: Nigerian Hydrological Services Agency

NSE: Nash-Sutcliffe Efficiency

NWI: National Water Initiative

NWRI: National Water Resources Institute

OECD: Organisation for Economic Co-operation and Development

PET: Potential Evapotranspiration

RCMs: Regional Climate Models

RCPs: Representative Concentration Pathways

RMSE: Root Mean Square Error

RUWASSA: Rural Water Supply and Sanitation Agencies

SAR: Second Assessment Report

SDGs: Sustainable Development Goals

SDMs: Statistical Downscaling Models

SimHyd: Simplified Hydrology

SPEI: Standard Precipitation Evapotranspiration Index

SPI: Standard Precipitation Index

SRES: Special Report on Emission and Scenarios

SWAT: Soil and Water Assessment Tool

SWIM: Soil and Water Integrated Model

TAR: Third Assessment Report

UNDESA: United Nations Department of Economic and Social Affairs

UNEP: United Nations Environment Programme

UNFCC: United Nations Framework Convention on Climate Change

UNGA: United Nations General Assembly

WCI: Water Crowding Index

WEAP: Water Evaluation and Planning

WMO: World Meteorological Organisation

WRG: Water Resources Group

WSI: Water Stress Index

VIA: Vulnerability Impact and Adaptation

VIC: Variable Infiltration Capacity

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Water resources include all sources of water that are valuable to humans (Habets *et al.,* 2013). This includes groundwater, rivers, streams, lakes, reservoirs, basins and runoffs. It is imperative since it is required for life existence. Agricultural, industrial, domestic, recreational and environmental activities are the various uses of water. Nearly all of these human uses require fresh water. Felix *et al.* (2017) asserted that sustainable management of water resources is a function of the hydrologic cycle such that climate change has a vital link with it. Yang *et al.* (2011) state that the consequence of climate change on water resources is evident on the changes in water and its quality that are caused by climatic factors such as rainfall and temperature changes. The total amount of water resources in Nigeria are exaggerated by the alliance of climate change and human factors. The spatial pattern of climate, rainfall distribution as well as hyrdo-geological units from the coastal parts of the southern to the extreme northern Nigeria provide an outline for the recognition of the threats in terms of the quality and amount of water available.

It is known and established in literature that there is intrinsic connection linking climate change and water resources. This is even more so as empirical studies in the recent past have shown the impact of the former on the later (Hagemann *et al.*, 2013; Wenchao *et al.,* 2014; and Adam, *et al.,* 2016). Generally, global water resources are under heavy stress owing to the amplified climate change impact which varies from one region to another. However, its availability is controlled by the hydrostratigraphy of Nigeria that trail the pattern of prevalence of the aquicludes, aquitards or aquifers. The Intergovernmental Panel on Climate Change (IPCC) (2014), defined climate change as alteration in the state of the climate that can be identified using statistical tests to determine changes in the mean or the variability of its properties which persists for an extended period usually decades or longer. Eric *et al.* (2017) stated that it refers to any alteration in climate over time whether due to human activity or as a result of natural variability. This definition varies from that of the United Nations Framework Convention on Climate Change (UNFCCC).It defines climate change as the change of climate that is ascribed directly or indirectly to human actions that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods. However, the study adopts IPCC (2014) definition.

1.2 Statement of the Research Problem

The ecological zones of the Guinea and Sudano-Sahelian cover approximately 79% of the whole land mass of Nigeria. It is inhabited by over 50% of the country's 167 million people (Asemota *et al.*, 2016). It is home to over two-thirds of the country's 250 ethnic groups (Asemota *et al.*, 2016).Agriculture provides the major source of employment for the vast majority in these zones and presents the quickest way of reducing poverty (Babatolu and Akinnubi, 2014). About 80% of the inhabitants are engaged in crop and livestock production as well as fishing (Abdullahi *et al.*, 2014). These zones allow for a diversity of crop production such as: sorghum, millet, maize, groundnuts, rice, cowpea, cotton, cassava and yam. Thus, making agriculture the largest water user (69%), then domestic (21%) and industrial (10%) (Doll *et al.*, 2012; Schewe *et al.*, 2013).

However, these water resources have been threatened by the persistent climate change impact. This is visible from the occurrence of drought to the continuous decrease in the quality and volume of water owing to the declined river flows and reservoir storage, drying up of wetlands and aquifers, as well as lowering of water tables (Esther *et al.*, 2012). Lake Chad for example has shrinked from its initial 25,000km^2 in 1960s to

1350km^2 in 2005 (Yunana *et al.*, 2017). Streams in these zones which hitherto were perennial have now become seasonal such that water can only be found in them during the wet seasons with little or no water in the dry seasons. Furthermore, a cursory examination of existing literature indicates that quite a lot of research has been undertaken in the areas of water resources and climate change. Notably, Yang (2011), Mohammed and Abdurrahman (2013), Wenchao *et al.* (2014), Jayasekera and Kaluarachchi (2015), Gijs *et al.* (2016), Heejun (2016), Hosea *et al*. (2016), Amar *et al*. (2017), Dehua*et al*. (2017), and Pengpeng *et al*. (2017) all of which were carried out off the shore of Nigeria. Other researchers like Aizebeokhai (2011), Olaniyi *et al*. (2013), Ifabiyi and Ojoye (2013), Abdullahi *et al*. (2014), Babatolu and Akinnubi (2014), Salami *et al.* (2015a), Asemota *et al*. (2016), and Ojoye *et al.* (2016) were undertaken in Nigeria. A common feature of these previous studies in Nigeria is that they were based on historical trend analysis or hypothetical assumptions in projecting the climate change impact on water resources availability.

Considering the hydrological system's sensitivity to climate change, there is the need for the current global paradigm shift from the use of historical trend analysis, to the application of Global Climate Models (GCMs) with Representative Concentration Pathways (RCPs).This is yet to be adopted within the study area; which constitutes the research gap this thesis has identified. Thus, it becomes inevitable to identify the impending impact on water availability of the area under consideration due to climate change.

1.3 Aim and Objectives

The aim of the thesis was to examine the impact of climate change on water resources availability in the Guinea and the Sudano-Sahelian ecological zones of Nigeria.

The objectives are to:

(i) Analyse the sensitivity of the Guinea and Sudano-Sahelianecological zones of Nigeria to climate change using climatic variables of temperature and rainfall.

(ii) Determine the potential impact of climate change on water resources in the study area.

(iii) Identify the trend in the occurrence of extreme rainfall indices under future climatic conditions in the study area.

(iv) Estimate the water stress resulting from climate change in the study area.

1.4 Research Questions

(i) What is the sensitivity of the Guinea and Sudano-Sahelian ecological zones of Nigeria to climate change?

(ii) What are the potential impacts of climate change on water availability in the study area?

(iii) What is the trend in the occurrence of extreme rainfall indices under future climatic conditions in the study area?

(iv) What is the likely state of water stress resulting from climate change in the study area?

1.5 Justification for the Study

Understanding of climate change is continually improving, but the future climate remains uncertain (Ammar, 2015). Globally, it is estimated that by 2050 between 150 and 200 million people could be displaced as a consequence of phenomena, such as sea level rise and increased extreme weather events (Doll *et al.*, 2012; Scheffran *et al.*, 2012; Sadoff *et* *al.*, 2015; Michael *et al.*, 2017). In addition, the Global Environmental Outlook's Baseline Scenario projects increasing strains on water resources through 2050, with an additional 2.3 billion people expected to be living in areas with severe water stress, especially in North and South Africa as well as South and Central Asia (Harding *et al.*, 2014). Kwak *et al.* (2013) predicts the world could face a 40% global water deficit by 2030 under a business-as-usual (BAU) scenario. Africa's rising population is driving demand for water under accelerated degradation of existing water resources. More so, about 66% of Africa is arid or semi-arid and more than 300 of the 800 million people in sub-Saharan Africa live in a water-scarce environment (Charles *et al.*, 2016). These statistics on the global and continental trend are indeed mind-bogging which calls for a study of this nature at local scale to unravel the impact of climate change on water resources.

Moreover, due to many changes, the climate in recent years in Nigeria has witnessed considerable variability across the various ecological zones. According to Babagana (2017), the Sahelian drought that started in 1969 which lingered on till 1973 to 1983-84 affected northern Nigeria and the calamity has had tremendous socio-economic impact on the area where pressure on available resources result in hydrological imbalance such as inadequate water supply, empty reservoirs, dry-upwells and crop damage. The severity of the drought was gauged by the degree of moisture deficiency, its duration, and the size of the area affected. This is also supported by details Chukwuma (2015) who contend that over the years, the Nigerian government had not given the much needed attention to the issue of climate change, particularly in the semi-arid northern Nigeria. The net effects were the shrinking of the Lake Chad and insecurity occasioned by the farmer-herder clashes and population displacement. For this reason, it is of vital importance to reflect on arrays of possible future climate conditions across these zones if any meaningful development is to take place in the water resource management and agricultural sector which has been of utmost priority in recent times (Mohammed *et al.,* 2014).

1.6 Scope and Limitation of the Study

Spatial scope of this study covers the Guinea and the Sudano-Sahelian ecological zones of Nigeria. The study is limited to three basins namely: Kainji Lake Basin (KLB), Sokoto – Rima Basin (SRB) and Komadugu – Yobe Basin (KYB) that cut across the Guinea and Sudano-Sahelian ecological zones of Nigeria. The respective coordinates of each of the three basins were used to derive the observed and simulated rainfall and temperature records as well as evapotranspiration. The temporal scope covers scenario projections generated for three future periods namely: near-term (2019-2048), mid-term (2049-2078) and long-term (2079-2100) using the multi-model ensemble mean of CMIP5 GCMs under three CO_2 emission trajectories (RCPs 2.6, 4.5 and 8.5) with references to the two baseline periods of (1959-1988) and (1989-2018).

1.7 The Study Area

1.7.1 Location of the study area

The study area lies between Longitudes 3°E and 15°E of the Greenwich meridian and Latitudes 8°N to 14°N of the equator. The area covers the Guinea and the Sudano-Sahelian Ecological Zones of Nigeria. It is bordered to the north by the Niger Republic, to the east by the Republic of Cameroun, to the south by the tropical rainforest and to the west by the Benin Republic.

1.7.2 Climate of the study area

The two predominant air masses that influence the weather and climate of these zones are the Tropical Continental (cT) air mass and the Tropical Maritime air mass (mT)(Abdulkadir *et al.,* 2015). The former is dry and dusty which originates from the Sahara Desert, while the latter is dense and moist whichoriginates from the Atlantic Ocean. The Guinea savannah is located around the middle part of the country and is the most extensive of all the zones. With a unimodal rainfall distribution, it shows a mean of 1120mm but attain 1500mm on the Jos Plateau. The temperature shows an annual mean of 24°C to 30°C. The Sudan zone is found in the Northwest. It has an annual average rainfall of about 700-1100mm with a prolonged dry season of about 6-9 months. The Sahel is located in the extreme northeastern part of the country. The region is also associated with greater extremes of temperature as high as 44°C before the onset of the rains and can drop to as low as 6°C during the cool harmattan air around December to February. In this zone dry season can last for as long as 9 months and the maximum annual rainfall is about 600mm (Abdullahi *et al.,* 2014).

1.7.3 Relief and Geology of the study area

In general, the topography of the area consists of plains interrupted by plateaus and hills. The Sokoto Plains lie to the northwestern corner of the country, while the Borno Plain is in the northeastern corner extending as far as the Lake Chad basin. The Lake Chad basin and the western parts of the Sokoto region in the far northwest are underlain by soft, geologically young sedimentary rocks. Gently undulating plains, which become waterlogged during the rainy season, are found in these areas. The characteristic landforms of the plateaus are high plains with broad, shallow valleys dotted with numerous hills or isolated mountains, called inselbergs; the underlying rocks are crystalline, although sandstones appear in river areas (Abaje *et al.,* 2013). The Jos Plateau rises almost in the centre of the country; it consists of extensive lava surfaces dotted with numerous extinct volcanoes.

1.7.4 Hydrology of the study area

The Guinea and Sudano-Sahelian ecological zones of Nigeria are well drained with a close network of rivers and streams. Some of these, particularly the smaller ones are seasonal. Out of the four major drainage systems in Nigeria, two are found in the Guinea and the Sudano-Sahelian ecological zones. They are: The Niger River Basin Drainage System with its major tributaries of Benue, Sokoto-Rima, Kaduna, Gongola, Katsina-Ala, Donga, Tarabe, Hawal and Anambara Rivers; and the Lake Chad inland Drainage System comprising the Kano, Hadejia, Jama'are, Misau, Komadougou-Yobe, Yedoseram and Ebeji Rivers (Ojoye *et al.,* 2016).

The Hadejia/Nguru Wetlands in the northeast of the country receive their water from the Hadejia and Jama'are rivers, which meet to form the Komadougou-Yoberiver, flowing northeast into the Lake Chad. So far, more than half of the wetlands have been lost due to drought and upstream dams. New development could divert still more water from the wetlands for irrigated agriculture in upstream areas, affecting both the ecology and the irrigated agricultural production in the floodplain using water from the shallow groundwater aquifer, as recharging would decrease further. Inappropriate agricultural practices, such as lack of crop rotation, adoption of maximum tillage, inadequate or total lack of fallowing, inadequate fertilization, overgrazing, absence of mulching, and the opening up of riverbanks have led to silting of riverbeds and loss of watercourses.

1.7.5 Water use in the study area

Long-term average internal renewable surface water resources are estimated at 214 000 million m^3/year and renewable groundwater resources at around 87 000 million m^3/year, but 80 000 million m^3/year is considered to be overlap between surface water and groundwater, which gives a value of total internal renewable water resources (IRWR) of 221 000 million m^3/yea**.** Total annual water withdrawal was estimated at 12 475 million m³ for the year 2010. Agriculture is the sector withdrawing the largest share of water, with about 5 510 million m³ (44 percent) made up of 4 549 million m³ for irrigation, 233 million m³ for livestock and 728 million m³ for aquaculture (Aizebeokhai, 2011). Around three quarter of the municipal water withdrawal is from groundwater resources, the remaining coming from surface water. Industry is the sector with the smallest withdrawal with 1965 million m³ (14 percent). Figure 1.1shows the study area.

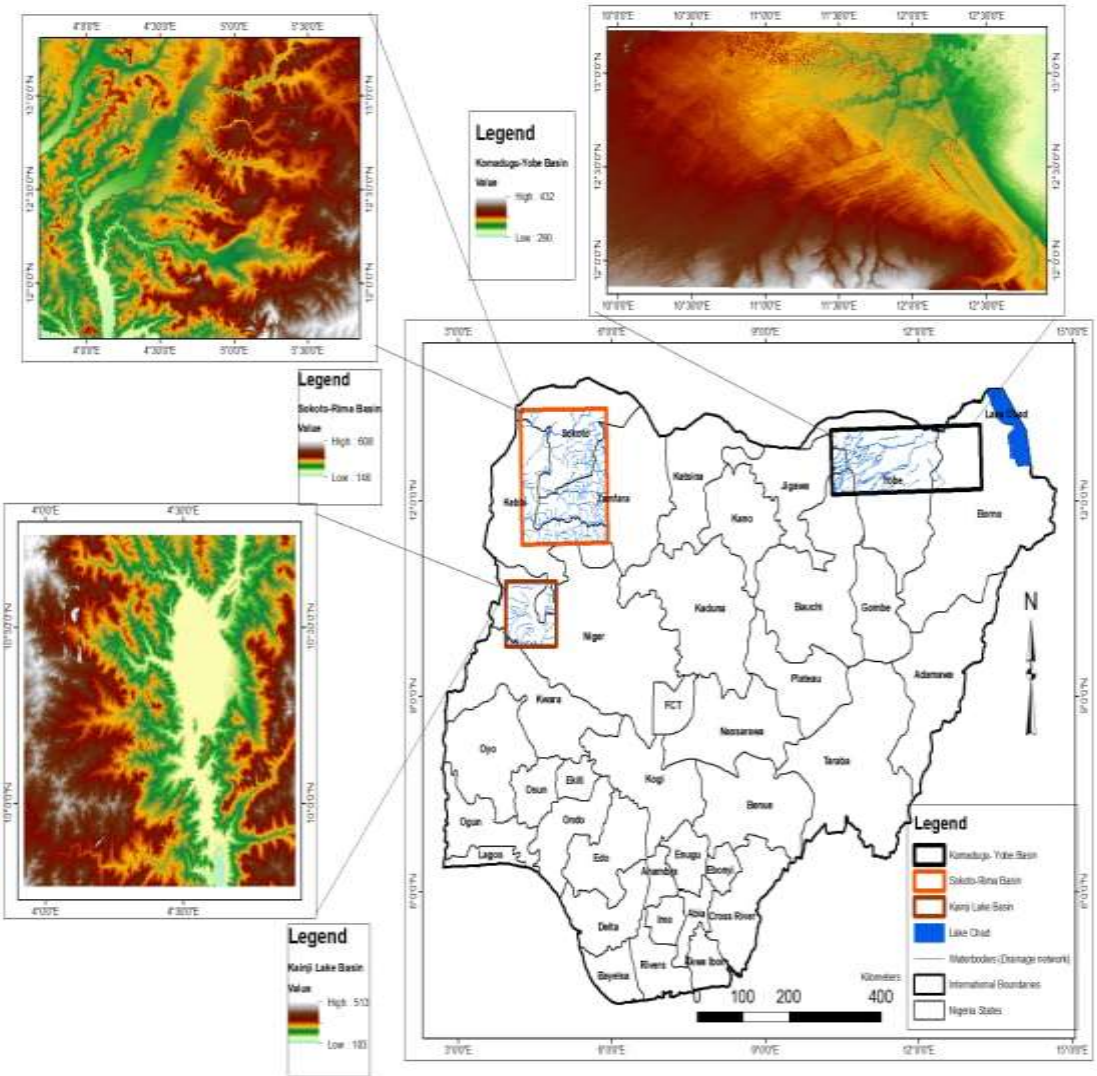


Figure 1.1: The Study area

Source: Adapted and modified from Abdullahi *et al.* (2014)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water Resources and Related Concepts

2.1.1 Global hydrological cycle

Water covers about three-quarters of Earth's surface and is a necessary element for life. During their constant cycling between land, the oceans, and the atmosphere, water molecules pass repeatedly through solid, liquid, and gaseous phases (ice, liquid water, and water vapor), but the total supply remains fairly constant. A water molecule can travel to many parts of the globe as it cycles. Water vapor redistributes energy from the sun around the globe through atmospheric circulation. This happens because water absorbs a lot of energy when it changes its state from liquid to gas. Aich *et al.* (2016) posit that even though the temperature of the watervapour may not increase when it evaporates from liquid water, this vapor now contains more energy, which is referred to as latent heat. Atmospheric circulation moves this latent heat around Earth, and when water vapor condenses and produces rain, the latent heat is released. Very little water is consumed in the sense of actually taking it out of the water cycle permanently, and unlike energy resources such as oil, water is not lost as a consequence of being used. However, human intervention often increases the flux of water out of one store of water into another, so it can deplete the stores of water that are most usable (Chewe, and Levermann, 2017). For example, pumping groundwater for irrigation depletes aquifers by transferring the water to evaporation or river flow. Our activities also pollute water so that it is no longer suitable for human use and is harmful to ecosystems.

There are three basic steps in the global water cycle: water precipitates from the atmosphere, travels on the surface and through groundwater to the oceans, and evaporates or transpires back to the atmosphere from land or evaporates from the oceans. Most of the precipitation that is not transpired by plants or evaporated infiltrates through soils and becomes groundwater, which flows through rocks and sediments and discharges into rivers. Rivers are primarily supplied by groundwater, and in turn provide most of the freshwater discharge to the sea (Lobanova *et al*., 2017). Over the oceans evaporation is greater than precipitation, so the net effect is a transfer of water back to the atmosphere. In this way freshwater resources are continually renewed by counterbalancing differences between evaporation and precipitation on land and at sea, and the transport of water vapor in the atmosphere from the sea to the land. Nearly 97 percent of the world's water supply by volume is held in the oceans. The other large reserves are groundwater (4 percent) and icecaps and glaciers (2 percent), with all other water bodies' together accounting for a fraction of 1 percent. Residence times vary from several thousand years in the oceans to a few days in the atmosphere (Table 2.1).

Table 2.1: Estimate of the World Water Balance

	Surface area (million km)	**Volume (million km)**	**Volume (%)**	**Equivalent depth (m)**	**Residence time**
Oceans and seas	361	1,370	94	2,500	~4,000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1 to 10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks to 50 years
Groundwater	1301	60	4	120	2 weeks to 100,000
Ice caps and glaciers	17.8	30	2	60	10 to 1,000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

Source: Bridget *et al.,* 2007 cited in Amah, (2015)

2.1.2 Rivers in Nigeria

The main Rivers in Nigeria by geopolitical zones are presented in Table 2.2.

Table 2.2: Main Rivers in Nigeria by Geopolitical Zones

Rivers in the North West	Rivers in the North East	Rivers in the North Central
Rima river	River Hadeja	River Belwa
River Sokoto	River D. Gaya	River Sanro
River Gurata	River Katagun	River Oli
River Guma	River Chatawa	River Mim
River Karami	RiverJamare (Bunga)	River Ram
River Melendo	River Bajel	River Menchum
River Dinya	River Lere	River Bantaji
RiverSarkinwaria	River Gongola	River Benue
River Mariga	River K. gona	River Nurka
River Galma	River Anuma	River Mayoyin
River Kaduna	River Ruhu	River Suntai Banta
River Tubo	River Hawal	River Gashaka
River Kuntagoa	River Ngodoa	River Donga
River Mashi	River Goma	River Katsina
River Teshi	RiverYedseram	River Niger
River Kano	River Kilunga	River Gamana
River Gaminda	River Watari	River Mada
River Goulbidede Maradi	River Missau	River Dauda
River Gagere	River KomaduguGnana	River sheman
River Bunsuru	River Pai	River Wase
	River Faro	River wuru
	River Gururu	
Rivers in the South West	**Rivers in the South East**	**Rivers in the South South**
River Ominta	River Anambra	River Ikan
River Shasha	River Aloma	River Orashi
River Tesi	River Abione	River Kwaibo
River Oshin	River Manu	River Ase
River Ogun	River Imo	River Okwa
River Kobo	River Aya	River Great Kwa
River Otan	River Aba	River Atapko
River Erinle	River Otamiri	River Calabar
River Yelwa	River Akwayafe	Niger Distrubutories;
River Oshun	River Ekulu	Escrovos river
River Oueme	River Oyi	Forcados river
River Okpara		Chanomi creek
River Oyan		Nun river
River Ofiki		River Osiomo
River Ona,or Awna		River Ikpoba
River Ogunpa		River Ogbese
River Oba		River Ethiope
River Osse		River Owena Ramos river

Source: Adapted from World Atlas, 1985 cited in Agbebaku, (2015)

There are over eighty major rivers in Nigeria and the biggest among these include; River Niger which has its sources from Equatorial Guinea and River Benue. River

Benue drains to join rivers Niger at Lokoja popularly known as the conference town. These two rivers (as River Niger) drain together into the Atlantic Ocean. As they drain down the Atlantic Ocean, some other tributaries and rivulets join the river while at South South region of Nigeria, this River Niger forms a delta popularly known as Niger Delta (Agumagu and Todd, 2015). Geographically, three states of Nigeria are found in this Niger Delta region which include; Delta State, Bayelsa State and River State. Other major river in Nigeria to note include; River Gongola, Calabariver, Osun River, River Sokoto, River Ogun, River Kaduna etc.

2.1.3: River basin development authorities in Nigeria

In 1961, eleven river basin development authorities were established to ensure effective exploitation of inland water resources in Nigeria (Abdussalam, 2015).

They have similar function and are evenly distributed along river basins of Nigeria (Table 2.3). In Nigeria, river basin authorities are charged with functions which include;

• Irrigation

• Water supply facilities (construction and management) e.g. reservoir, dams, borehole etc Fishery and its control

• Basin management and pollution control

• Hydro- electric power generation and control and management

• Recreational facilities

• Fishing regulations

Table 2.3: River Basin Development Authorities in Nigeria

Name of authority	Area of operation	Headquarter
Anambra-Imo river basin authority	The whole of Anambra and Imo State.	Owerri
Benin-Owena river basin authority	The whole of Benin, Delta, Ondo State excluding those parts of Bendel State drained by the Benin, Escravos, Forcados and Ramos river creek system.	Benin
Chad river basiauthority	The whole of Borno State excluding those parts drained by the Jama'are and Misau river system but including those parts of Gongola (Adamawa and Taraba) State drianes by Yedseram and Goma river systems.	Maiduguri
Cross river basin authority	The whole of Cross river State	Calabar
Hadejia-Jama'are river basin authority	The whole of Kano State and those parts of Bauchi and Borno State drained by the Jama'are and Misau river system.	Kano
Lower Benue river basin	The whole of Benue and Plateau State.	Markurdi
Niger Delta river basin authority	The whole of River State and those parts of Delta State drained by Benin, Escravos, Forcados, and Ramos river creek system.	Portharcourt
Niger river basin authority	The whole of Kwara and Niger State, the Federal Capital Territory. Whole of Kaduna Sate excluding Katsina State	Minna
Ogun-Osun river basin authority	The whole of Oyo, Ogun, Osun and Lagos State	Abeokuta
Upper Benue river basin authority	Those parts of Bauchi State drained by the Gongola River system. The whole of Taraba State excluding those parts drained by the Yedseram river system.	Yola
Sokoto-Rima river basin	The whole of Sokoto State and Kastina State.	Sokoto

Source: Agbebaku, (2015)

2.1.4: Significance of river basins in Nigeria

Nigeria is blessed with numerous river basins and they often provide numerous benefits to mankind. The significances of these river basins in Nigeria include;

Drinking water provision: River basins in Nigeria serve as a source of portable water to many rural areas of the country. These river systems also play a role in ground water recharge through seepage in.

Food: River basins are major source of fish food production in Nigeria. The fishes gotten from river basins serve as food. Aquatic organisms such as macrophytes and algae can be a good source of nutrition for man. Water hyacinth is native to Brazil and it has been used fresh for feeds to pigs in southwest Columbia (Carlos and Veronica, 2017). It was substituted for 20 percent of commercial feed without toxicology problem. Silage composed of water hyacinths can be used for ruminant diets with excellent result for acceptability palatability. Water hyacinth is high in protein, potassium, calcium. Phytoplankton such as chlorella and spirulina are both super food and food supplements made from chlorella and spirulina can be found in different super markets in Nigeria. Larger zooplanktons (meso planktons) such as copepeda and cladosera can be used as feed. Other resources in river basin that can be used as food include crayfish, snails, different animals and palatable plants etc.

Habitat: River basins serve as a habitat for organisms that live in the river system. Such include; fishes, crayfish, macrophyte, microalgae, zooplanktons, aquatic birds and other animals.

Accumulation of fossil information: The river system can serve as a good fossil reserve to ascertain past events and inhabitation. This aids chronological measurement.

Transportation: River basins in Nigeria serve as a means of transportation and navigation. People can travel from one place to another through the river system.

Recreation: Water contained in the river basins in many occasions has served for recreational purposes. For example, in the construction of beaches and resorts.

Hydro-electric power provision: This involves construction of dam along a water fall in a river system for generation of electricity such as the kainji dam in river Niger.

Building and Construction: The soil (white sand) found in and around river basins is very useful in building and construction in Nigeria and such is exploited at Onitsha, along river Niger.

Erosion control: By the virtue of the ability of river basins to serve as an end point to water run-off in cities and towns, they help to control erosion.

Flood control: As river collects and store inland water run-off as a result of rainfall, they help to manage and control flooding.

Oceanic recharge: Rivers flow into oceans and help recharge the system. In Nigeria, more than three quarter of the river basins drain into Atlantic Ocean.

Pollution control: Vast number of companies and industries in Nigeria use river basins as end-point for their waste discharge.

2.1.5: River basin development planning and management

Chanapathi *et al.* (2018) stated that River Basin Development Planning and Management is the process of identifying the best way in which a river and its tributaries may be used to meet competing demands while maintaining river health. It includes the allocation of scarce water resources between different users and purposes, choosing between environmental objectives and competing human needs and choosing between environmental objectives and competing human needs and choosing between competing flood risk management requirements (Fan and Shibata, 2015). However, increasing development and population pressure, the complexity of many of the river basins have increased and many serious crises related to floods, degradation of water quality, acute water shortage and degradation of ecological health have been experienced. Approaches to basin planning have evolved over time and a basin planning is ultimately playing significant roles to the adaptation of these local circumstances.

2.1.6: Goals of river basin development planning and management

• To avoid environmental degradation

• To coordinate the uses of shared basin (multiuser, interstate and international).

• To promote sustainable development of the basin.

• To integrate land and water management

• To promote sustainable provision of water through irrigation for agriculture

• To promote the excessive use of water and water resources that can lead to environmental fragility and deterioration.

• To promote integrated, optimal development of natural resources, agriculture, infrastructure, social services etc.

• To promote rural development.

• Development into a basin remote area will counter the pull of large cities in favoured area.

• To decentralize planning and management and make it adaptive.

• To integrate environmental dimensions with other aspects of planning and management.

2.1.7: Types of river basin development planning and management

• Single purpose

• Dual purpose

• Multipurpose

• Comprehensive

• Integrated

Single purpose: Early efforts were mainly single purpose for example flood control. Such approaches that involve just one purpose is said to be single purpose.

Dual purpose: This involves combining two development goals using single methods. For example, a reservoir can be utilized for water supply and flood control.

Multipurpose: This seeks to pursue a number of goals. For example, a dam can be used for water supply, irrigation supply, flood control, electricity generation (Lobanova *et al.,* 2016).

Comprehensive: Klutse (*et al.,* 2018) defined this as a planned, complex, continuous and interdisciplinary process which is controlled on a system analysis bases. It considers both land and water resources development and how they inter-relate the goal being "optimal development of resources" (Lobanova *et al.,* 2016). Comprehensive RBDPM puts less emphasis on promoting human welfare than integrated RBDPM.

Integrated: This is sometimes regarded as comprehensive in some text. Integrated and comprehensive approach share;

• Adoption of a basin-wide program

• Comprehensive regional development

• Multipurpose development

Integrated approach is used for approach that goes further than comprehensive RBDPM in this ways;

• To actively use water as a tool for social and economic development or engine of development.

• To deal with relationships between basin activities, demands, needs etc. for example, construction of beaches as a resort and source of social and economic development.

2.1.8: Problems of river basin development planning and management

• Inability to control the whole basin

• Lack of baseline data and inadequate monitoring hinders RBDPM.

• Politics is another problem. It can determine who is to be employed, what is on the agenda and how RBDPM proceeds (Klutse, *et al.,* 2018).

2.1.9: Approaches to sustainable water management in Nigeria

Because water supply is on the concurrent legislative list in the constitution and that means all tiers of government have responsibilities for the provision of water supply to the people. Realizing the significant role played by potable water supply and clean environment in ensuring good and healthy individual, family and communal lives, government has embarked on certain policies and strategies to improve the coverage level of rural water supply and sanitation facilities. According to Yanga *et al.* (2013) the water supply is to ensure that all Nigerians have access to clean water and sanitation at an affordable price. The viable options/solution to the Nigerian water problem is a unified and integrated approach to water resources planning and the provision of reliable information on the following:

(i) The nature and magnitude of available water resources

(ii) The future demand for water for domestic, agricultural and industrial purposes

(iii) How these demands can be faithfully met within the ambit of available resources.

Thus, the issues raised above can be adequately addressed through groundwater resources mapping. Not only can the information be obtained at regular intervals but their accurate state, can also be updated. In this context, efficient water policy is imperative if sustainable water utilization is to be realized (Yanga *et al.*, 2013). Water management policies therefore, will need to address a multitude of issues including, but not restricted to the following:

(i) Management of supplies to improve water availability in time and space

(ii) Management of demands including efficiency of water use, sectoral interaction with economic activities etc.

(iii) Balancing competing demands and preservation of the integrity of water dependent ecosystem.

Aside from the above mentioned water management options, there is need for the following:

(i) Encourage user participation in the water resources administration

(ii) Propose and coordinate actions geared towards the protection, defense and knowledge on water use

(iii) Proper coordination between the different tiers of government and the public, realistic tariff structure to cover cost of services, research into local production of materials required in the water sector, training of professionals and education of the public about water conservation (iv) Promote, organize, participate and undertake all kinds of activities, courses and seminars, outreach programmes, training, and specialization on water, and any other relevant collaboration with different public administrations.

Consequently, sustainable water management not only requires proper assessment of available resources and understanding of the interconnection between surface and groundwater system, but also actions required for proper resource management and prevention of the adverse effects of uncontrolled development of water resources (Scherrer *et al.,* 2016). The component of action-driven water policy must be to consider and manage water as an economic as well associal good, and importantly, to manage water at the lowest appropriate level with users involved in the planning and implementation stages.

2.1.10: Impediments to sustainable water resources management in Nigeria: major issues and trends

In Nigeria, suitable machinery for the effective and sustainable management of water resources has not yet evolved. This is because the authorities have put up institutions for this purpose, but at the same time set up rival agencies to carry out very overlapping functions. The overall implication is waste of available resources, leading to lack of progress in water development and management. Generally, the Nigerian water problem revolves round two critical issues, namely:

(i) Inadequate access/poor distribution of water resources in time and space in relation to the needs of the people and

(ii) Inadequate planning and management of these resources.

The above mentioned problems have further manifested themselves in the form of incessant water shortages, poor access to public water supply and water-borne diseases, poor environmental quality causing water pollution, improper or partial distribution of public wells due to lack of water well statistics and favouritism, poor maintenance and often sabotage in the development and operational process of public wells, and proliferation of shallow private/commercial wells of poor standard by individuals who are financially less capable of standard wells drilled with adequate drilling tools.

According to Ajay *et al.,*(2018) the major obstacles for sound water management include: absence of or ineffective legal/institutional and regulatory framework, poor maintenance culture, poor technical and institutional capacity, lack of coordination, multiple programmes, lack of data and information for planning, shortage of well-trained/committed manpower with appropriate local technology, irregular recruitment and limited manpower occasioned by the civil- service structure and the over-bearing bureaucratic control by supervising ministries, lack of professional input on water programmes and projects, absence of professionalism due to politicization, career stagnation and the lure of private practice, lack of community participation and inadequate revenue generation by water agencies, inadequate funding as shown by poor budget allocations, irregular disbursements of subventions, limited sources of aids and grants (particularly from foreign sources), inappropriate infrastructures as well as lack of adequate quality monitoring and evaluation. In Nigeria, for instance, data on groundwater levels are not widely published or made available outside government organizations. Extraction and recharge estimates are also unreliable. As a result, discussions on groundwater over-exploitation and depletion are always based on unrealistic data (Asemota *et al.*, 2016). However, it is a fact that falling water tables and depletion of economically accessible groundwater reserves will have serious socio-economic consequences in a country like Nigeria. Therefore, it is needless to point out that there is an urgent need for conservation of this vital resource for sustainable development and management.

In the light of the foregoing, it is highly likely that the future expansion in water will continue to take place in Nigeria. This is primarily due to the relatively high population growth rate, combined with the unprecedented rise in industrialization and welfare, which tends to increase the average per capita water use. Dile *et al.* (2013) confirmed that the largest single consumer of water is, and will continue to be agriculture with urban and industrial uses on the rise. Though the generalizations made here may not be totally justified, as differences exist in different parts of the country. Current water use is characterized, as earlier noted, by uncoordinated development and supply to all sectors: rural and urban users, small and large scale users, industrial and agricultural users. This, in part, is attributable to the intrinsic properties of the resource. The general prevalence and stability in time and space of groundwater, for instance, makes it a reliable and widely-accessible resource, easily amenable to private, local, and on – demand exploitation. Therefore, options/strategies for significant improvements in water supply are in the areas of formulation of adequate, efficient and effective water policies, funding/appropriate infrastructures as well as monitoring and evaluation (Babatolu and Akinnubi 2014).

2.1.11: Threats to water resources development in Nigeria

Water resources development includes the Construction, harnessing, distribution and protection of both surface and groundwater infrastructures for the domestic, agricultural and industrial needs of the society. The exploitation of Nigeria's water resources has progressively increased with the return to civil rule. Despite the progress that has been made in water supply development since the first waterworks in Nigeria was commissioned in Lagos in 1915, many Nigerians still have inadequate access to modern water supply. Water shortages exist periodically in almost every major town and are present in many rural areas of the country (Olaniyi *et al.,* 2013). Areas that are provided with water more often than not revert to water distress due to the unsustainable nature of the infrastructures, making statistics of access unreliable. The turning point for water resources development and management in Nigeria occurred after the severe drought of the 1960s.

The Government's response to the catastrophe was the initiation of strategies for co-ordinated and effective water resources development, culminating in the mid-1970s in the creation of the Federal Ministry of Water Resources and the River Basin Development Authorities. The activities of these institutions were further strengthened in 1981 by the establishment of the National Committee on Water Resources, and by the Water Boards at the state level. Later the National Water Resources Institute (NWRI), the Nigerian Hydrological Services Agency (NIHSA), the Rural Water Supply and Sanitation Agencies (RUWASSA) were added. These bodies were charged with taking an inventory, and ensuring rational and systematic planned management and conservation, of the country's water resources (Salami *et al.,* 2015b). This is further boosted by the various interventions by government, donor agencies and the setting up of many agencies at the national and sub-national levels. In spite of the robust structure in place for the development of Nigeria's Water Resources, there are numerous threats militating against the achievement of the MDGs Goal 7. Development is threatened when the quantity and quality of water available in an environment is insufficient to meet the various needs of the population and future expansion is hampered by the depletion and or quality deterioration of the resources resulting in water poverty or distress.

2.1.12: Implications for surface water bodies

- Climate Change manifesting in increased evapo-transpiration and the attendant moisture deficit, decreasing precipitation with accompanying water level lowering in shallow aquifers and decreasing surface flows. These threats impact more on the sub-Sahelian region.
- Climate change manifesting in increased coastal floods and saline water intrusion into upper coastal aquifers especially in the tropical rainforest zones.
- Oil spills that pollute the creeks and surface waters and groundwater in the Niger Delta.

- Indiscriminate disposal of industrial effluents into surface water bodies due largely to regulation lapses nationwide.
- Impoundment of surface water for irrigation purposes and use of fertilizers for agriculture which result in decreased downstream flows and pollution of shallow aquifers by leachates.
- Poor management of water resources leading to infrastructural decay that result in unsustainable development and unsafe exploitation of ground water.

2.1.13: Patterns of occurrence of water resources development threats in Nigeria

Threats due to climate change in the Sahelian zone. Part of the northern Nigeria falls within the Sahel or sub-Sahelian region characterized by scanty rainfall, vegetation and extreme temperatures. The groundwater systems in the area are such that the aquifers-basement or sedimentary, shallow or deep are all under one form of threat or the other. The Sahel region is populated by farmers who depend on water supply for their livelihood. They need water for their crops and animals. Because of the scanty vegetation, overgrazing has further depleted the soil cover exposing the soil to denudation and moisture deficit (Yunana *et al.,* 2017). These farmers often resort to the digging of wells in the shallow basement aquifers to augment surface water resources furnished by various dams in the area. Due to dwindling precipitation, the water levels of these shallow wells are being lowered. The surface water quality is often impaired by excessive use of sulphate fertilizers and the authorities are not immediately sensitized to the present and future implication of the leachate into surface and ground water systems (Stella *et al.,* 2019). The implication of the state of affairs is that both surface and ground water systems in the north are under threat of impairment and or depletion. A well-articulated Integrated Water Resources Management involving the Ministry of

Agriculture, Ministry of Water Resources and the Ministry of Environment must be vigorously pursued to adapt to the natural threats and prevent the human threats.

2.2 General Circulation Models (GCMs) and its Concepts

2.2.1 General circulation models

The climate model is a mathematical description of the Earth's climate system, broken into a number of grid boxes and levels in the atmosphere, ocean and land. At each of these grid points, equations are solved which describe the large-scale balances of the momentum, heat and moisture (Gebre *et al.,* 2015). General circulation models (GCMs) are useful for providing climate change scenarios as a basis for estimating the impacts of climate change. To provide scenarios of water resources and extremes, results from GCMs can be applied in hydrological models to identify climate change impacts (Umesh and Pouyan, 2016; Ahmed *et al.,* 2017). However, GCMs do not usually provide sufficient spatial resolution for regional and local applications, that is, the scale usually needed to make effective decisions for climate impact studies. According to Dehua *et al.* (2017) coastlines in GCMs are generally very roughly represented and topography is much smoother than in reality. This is especially an issue in applications where precipitation plays an important role, since precipitation distribution is very sensitive to land/sea contrasts in surface roughness and temperature and to complex topography where precipitation can be orographically forced or damped. Consequently, GCMs need to be regionalized in order to identify climate change impacts on water resources and extreme events, that is, in order to effectively support decision making at a local scale (Teng *et al.,* 2012).

However, at this point it is pertinent to point out that aside GCMs; there are two other categories of climate change scenarios (IPCC, 2014). They are: a) Arbitrary or Synthetic

Scenarios: This type of scenario tests the sensitivity of a climatic system by changing the key climatic variables based on expert judgment of their plausible changes envisaged in the future. In most cases, a combination of the key variables is used. An example scenario is considering an increase in temperature over a range of 1^{o}-$3^{o}C$ combined with an increase, decrease or no change in precipitation of 10%. These scenarios can be efficient in portraying a future consequence only if adopted variations in the key variables are based on an expert opinion of the most likely scenario derived either from climatologists or from climate models. b) Analogue scenarios: The past climate can be reconstructed from historical observed records or from measurements taken from ice cores (paleoclimate reconstruction). The observed records can give a good picture of the inter and intra decadal variations in climate and its regional distribution. However, this is dependent on quality of the observations and the number of observation stations covering a region. The paleoclimate reconstructions are on a larger time scale of hundreds to thousands of years ago and cover a more detailed variation in climate compared to the observed records. Therefore, future scenarios are developed based on the past behaviour of climate.

There are several GCMs that have been developed by different climate research institutions globally. Appendix A shows the CMIP5 GCMs as used in this study with their modeling centres and the institutions where they were developed.

2.1.2: General circulation models limitations

Global Climate Models are the best tools available for projecting changes in climate resulting from increases in greenhouse gas concentrations. There is a high level of confidence associated with GCM projections of increases in temperature, however the level of confidence about the nature and magnitude of projected changes decreases for other variables (rainfall, potential evapotranspiration and runoff), and at finer temporal and spatial scales (Potter *et al.,* 2016). There are a number of assumptions made throughout the modelling process which can generate significant uncertainties in the estimation of future impacts on the regional climate under increased greenhouse gas concentrations. The most significant sources of uncertainty in the preparation of global climate modelling results are:

• Uncertainty about how emissions may change into the future. These values depend on many socio-economic factors as well as the feedbacks in bio-physical systems;

• Uncertainty in the representation of climate processes in the GCMs. The GCMs are all considered plausible futures. Shortcomings in all models at finer temporal scales are outlined. A handful of GCMs perform poorly in some aspects of modelling at a regional scale, as listed in Grose *et al.* (2015) and Timbal *et al.* (2015);

• Uncertainty in the downscaling process. The GCMs operate at coarse spatial scales (typically in the order of 200 km x 200 km grid cells) and downscaling is required to represent these coarse scale climate changes locally. Many different downscaling methods exist with different capabilities of adding regional detail to the coarser resolution GCM output. Thus, different downscaling methods can result in differences in the magnitude of changes projected locally; and

• Uncertainty in the rainfall-runoff modelling process, including calibration uncertainty, the transposition of rainfall-runoff models to ungauged areas and the potential for bias in rainfall-runoff models when applied outside of their range of calibrated conditions.

However, Grose *et al.* (2015) and Timbal *et al.* (2015) assessed the level of confidence of a given modelled change in climate conditions from the global climate models. This level of confidence was based on the rating method used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, whereby confidence in a projected change is based on the type, amount, quality and consistency of different lines of evidence (which can be process understanding, theory, model output or expert judgment). The confidence ratings are described as being low, medium, high or very high.

2.2.3: Historical changes in global greenhouse gas concentrations and temperature

Global greenhouse gas concentrations have been trending upwards since the mid-19th century. Carbon dioxide concentrations, for example, increased approximately from 280 ppm to 400 ppm over this period, with a more rapid increase over the last few decades of the 20th century. The excess energy in the global climate system as a result of increased greenhouse gas concentrations is predominantly stored in the oceans, with only a small fraction resulting in increased air temperatures. The World Meteorological Organisation (WMO) (2016) states that 93% of this excess energy has been stored in the world's oceans, contributing directly to sea level rise (IPCC, 2014). Global air temperature has been trending upwards since the start of the 20th century, with 2015 being the hottest year on record (WMO, 2016). The IPCC fifth assessment report (IPCC, 2014) states that the globally averaged combined land and ocean surface temperature data, as calculated by a linear trend, show a warming of 0.85, (0.65 to 1.06) °C respectively over the period 1880 to 2012. Local temperature trends over a similar period, as presented in Grose *et al.* (2015) and Timbal *et al.* (2015) are of a similar magnitude to global trends. Most of this warming has occurred from 1970 onwards. Unlike the increases in greenhouse gas concentrations, temperature has exhibited discrete periods of rapid warming followed by periods of stable global temperatures. Findings by Meehl *et al.* (2011) suggest that the likely origin of this step-like behaviour lies in the interactions between the atmosphere and the oceans. Increased Deep Ocean mixing was observed during periods when global atmospheric temperatures remained static, suggesting increased heat transfer from the atmosphere to the oceans over these periods (Chu *et al.*, 2014).

2.2.4: Downscaling of general circulation models

Global Climate Models (GCMs) are the primary tools to simulate multi-decadal climate dynamics and to generate and understand global climate change projections under different future emission scenarios. However, these models have a coarse spatial resolution (typically a few hundred kilometres) and suffer from substantial systematic biases when compared with observations. Therefore, they are unable to provide actionable information at the regional and local spatial scales required in impact and adaptation studies (Grouillet *et al.,* 2016). Hence, higher resolution simulations and if possible bias corrected are required for the most relevant climate variables (Ayansina *et al.,* 2018).Downscaling attempts to resolve the scale discrepancy between climate change scenarios and the resolution required for impact assessment. Two main downscaling approaches have been developed since the early 1990s: Dynamical downscaling (based on Regional Climate Models, RCMs) and Statistical Downscaling Models (SDMs), which are nowadays recognized as complementary in many practical applications (Chen *et al.,* 2011).

2.2.4.1: Dynamical downscaling

The development and use of regional climate models (RCMs), also referred to as dynamical downscaling when applied to downscale global climate model (GCM) output originated in the late 1980s. Dynamical downscaling refers to the use of high-resolution regional simulations to dynamically extrapolate the effects of large-scale climate processes to regional or local scales of interest (Gebre and Ludwig, 2015). According to Trzaska and Schnarr (2014), the strength of dynamical downscaling applications is their reliance on explicit representations of physical principals (e.g., the laws of thermodynamics and fluid mechanics) that are expected to hold under climate change, but they can be sensitive to large-scale biases and are computationally expensive.

A number of RCM systems are available; these have evolved from mesoscale and weather forecast models or as regional configurations of global models. Many institutions worldwide use RCMs, which have proven to be flexible tools employed by a large and often diverse community for a wide variety of applications from regional process and sensitivity studies to paleoclimate and future climate simulations, essentially over all land regions of the world (Filippo and William, 2015). This flexibility has been important to many scientists, especially in developing regions, enabling them to engage in leading-edge research without requiring the large infrastructure typically needed to run a high-quality GCM. By contrast, the variety and breadth of RCM use require a good understanding of their advantages, limitations, performance, and technical issues (Farzan *et al.*, 2013). RCMs have been developed to study regional processes and to generate physically based high-resolution climate information at scales of relevance for vulnerability, impact, and adaptation (VIA) studies. Meriotti *et al.* (2014) reveal that the basic strategy for dynamical downscaling consists of first running GCMs to describe the effects of large-scale forcings and processes on the general circulation of the atmosphere, which in turn determines the sequence of weather events characterizing the climate of a region.

The most commonly used RCMs in climate change downscaling studies include the U.S. Regional Climate Model Version 3 (RegCM3); Canadian Regional Climate Model (CRCM); UK Met Office Hadley Centre’s Regional Climate Model Version 3 (HadRM3); German Regional Climate Model (REMO); Dutch Regional Atmospheric Climate Model (RACMO); and German HIRHAM, which combines the dynamics of the High Resolution Limited Area Model (HIRLAM) and European Centre-Hamburg (ECHAM) models. Although these models have been developed primarily over North America and Europe, they can be adapted to any region of the globe by incorporating appropriate information on terrain, land-cover, hydrology, and so on; hence, several RCMs can be used over a given region (Ekstrom *et al.*, 2015). Mizuta *et al.* (2014) asserted that dynamical downscaling has some distinctive advantages such as: (1.) accounts for sub- GCM grid scale forcing (e.g. topography); (2.) Information is derived from physically based models; (3.) Better representation of some weather extremes as compared to GCMs. However, the disadvantages include (1.) Expensive to run RCMs to statistical downscaling over a large region; (2.) Its dependence on GCM predictors; (3.) It is a spatially smoothed product compared to station scale.

2.2.4.2: Statistical downscaling

Statistical downscaling encompasses the use of various statistics-based techniques to determine relationships between large-scale climate patterns resolved by global climate models and observed local climate responses. These relationships are applied to GCM results to transform climate model outputs into statistically refined products, often considered to be more appropriate for use as input to regional or local climate impact studies (Dayon *et al.*, 2015). It is a two-step process consisting of (i) the development of statistical relationships between local climate variables (e.g., surface air temperature and precipitation) and large-scale predictors (e.g., pressure fields), and (ii) the application of such relationships to the output of global climate model experiments to simulate local climate characteristics in the future. Similarly, Vetter *et al.* (2016) asserted that statistical downscaling consists of a heterogeneous group of methods that vary in sophistication and applicability. They are all relatively simple to implement but require a sufficient amount of high-quality observational data. Methods can be classified into three main categories:

(a.) **Linear methods:** Establish linear relationships (i.e., some type of proportionality), between predictor(s) and predictand. Linear methods are very straightforward and widely used, and they can be applied to a single predictor-predictand pair or spatial fields of predictors-predictands. The greatest constraint is the requirement of a normal distribution of the predictor and the predictand values, which means that it cannot be used to predict the distribution of daily rainfall because it is typically non-normal (frequent small amounts of rainfall and a few heavy events generally make the distribution not symmetrical). These methods are primarily used for spatial downscaling.

(b.) **Weather classifications:** The local variable is predicted based on large-scale atmospheric "states." The states can be identifiable synoptic weather patterns or hidden, complex systems. The future atmospheric state, simulated by a GCM, is matched with its most similar historical atmospheric state. The selected historic atmospheric state then corresponds to a value or a class of values of the local variable, which are then replicated under the future atmospheric state. These methods are particularly well suited for downscaling non-normal distributions, such as daily rainfall. However, a large amount of observational daily data (e.g., 30 years of daily data for the region of interest) is required in order to evaluate all possible weather conditions (Endo *et al.*, 2012). In addition, these methods are more computationally demanding in comparison to linear ones, due to the large amount of daily data analyzed and generated.

(c.) **Weather generators:** These statistical methods are typically used in temporal downscaling. For example, they are used to generate daily sequences of weather variables (e.g., precipitation, maximum and minimum temperature, humidity, etc.) that correspond to monthly or annual averages or amounts. Temporal downscaling is necessary for some impact models that require local spatial

Table 2.5 identifies various statistical downscaling methods under the "linear," "weather classification," and "weather generator" categories, along with particular variable requirements, advantages, and disadvantages.

Table 2.4: Statistical Downscaling Categories and Methods

Category & Method		*Predictor and Predictand*	*Advantages*	*Disadvantages*
Linear Method spatial	Delta Method	Same type of variable (e.g., both monthly temperature, both monthly precipitation)	(i) Relatively straight-forward to apply (ii) Employs full range of available predictor variables	(i) Requires normality of data (e.g., monthly temperature, monthly precipitation, long-term average temperature) (ii) Cannot be applied to non-normal distributions (e.g., daily rainfall) (iii) Not suitable for extreme events
	Simple and multiple linear regression	Variables can be of the same type or different (e.g., both monthly temperature or one monthly wind and the other monthly precipitation)		
	CCA& SVD			
Weather Classification (Spatial and temporal)	Analog method	Variables can be of the same type or different (e.g., both monthly temperature, one large-scale atmospheric pressure field and the other daily rainfall)	(i) Yields physically interpret-able linkages to surface climate ii) Versatile, i.e., can be applied to both normally and non-normally distributed data	(i) Requires additional step of weather type classification ii) Requires large amount of data and some computational resources ii) Incapable of predicting new values that are outside the
	Cluster analysis			
	ANN			
	SOM			

				range of the historical data
Weather Generator (Spatial and temporal)	LARS-WG	Same type of variable, different temporal scales (e.g., predictor is monthly precipitation and predictand is daily precipitation)	Able to simulate length of wet and dry spells Produces large number of series, which is valuable for uncertainty analysis Production of novel scenarios	(i) Data-intensive ii) Sensitive to missing or erroneous data in the calibration set ii) Only some weathers generators can check for the coherency between multiple variables (e.g., high insolation should not be predicted on a rainy day) v) Requires generation of multiple time-series and statistical post-processing of results.
	MarkSim GCM			
	NHMM	Variables can be of the same type or different (e.g., both monthly temperature, one large-scale atmospheric pressure and the other daily rainfall).		

Source: Sunyer *et al.* (2013)

2.2.5: Historical development of IPCC global emissions scenarios

The Intergovernmental Panel on Climate Change (IPCC) is a scientific and intergovernmental body under the auspices of the United Nations, set up at the request of member governments, dedicated to the task of providing the world with an objective, scientific view of climate change and its political and economic impact (Weart, 2011). It was first established in 1988 by two United Nations organizations, the World

Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and later endorsed by the United Nations General Assembly (UNGA) through Resolution 43/53 (IPCC, 2013). The IPCC produces reports that support the United Nations Framework Convention on Climate Change (UNFCCC), which is the main international treaty on climate change.

According to UNFCC (2014), the ultimate objective of the UNFCCC is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (i.e., human-induced) interference with the climate system". IPCC reports cover "the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impact and options for adaptation and mitigation" (IPCC, 2013). Since the inception of IPCC, series of assessment reports has been issued up till the latest being the fifth which was completed in 2014. Each of these assessment reports was compiled under three working groups namely:

Working Group, I: Assesses scientific aspects of the climate system and climate change.

Working Group II: Assesses vulnerability of socio-economic and natural systems to climate change, consequences, and adaptation options.

Working Group III: Assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.

2.2.6: IPCC SA90 emission scenarios-FAR

According to IPCC (2013), first Assessment Report (FAR) was completed in 1990. During this time, many climate models used grid cells of about 500 km (311 miles) on side.SA90 emission scenarios and were the basis for climate change projection under the following assumptions:

- Scenario A (Business as usual)

- Coal intensive energy supply
- Deforestation continues
- Agricultural emissions are uncontrolled

▪ Scenario B

- Lower carbon fuels (e.g. natural gas)
- Increased efficiency
- Deforestation is reversed

▪ Scenario C

- A shift towards renewable and nuclear energy in second half of the next century
- Agricultural emissions limited.

▪ Scenario D

- A shift towards renewable and nuclear energy in first half of the next century
- Carbon dioxide emissions are reduced to 50% of 1985 levels by middle of next century

2.2.7: IPCC emission scenarios –SAR

According to IPCC (2013), second Assessment Report (SAR) was completed in 1995. During this time, horizontal resolution had improved by a factor of two, producing grid cells 250 km (155 miles) on a side. IS92 emission scenarios were the basis for climate change projection under the following assumptions:

Table 2.5: IS92 Emission Scenarios

Scenario	*Population*	*Economic Growth*	*Energy Supplies*
IS92a, b	World Bank 1991 11.3 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	12,000 EJ conventional oil 13,000 EJ natural gas Solar costs fall to $0.075/kWh 191 EJ of biofuels available at $70/barrel*

IS92c	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.0% 1990–2100: 1.2%	8,000 EJ conventional oil 7,300 EJ natural gas Nuclear costs decline by 0.4% annually
IS92d	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.7% 1990–2100: 2.0%	Oil and gas same as IS92c Solar costs fall to $0.065/kWh 272 EJ of biofuels available at $50/barrel
IS92e	World Bank 1991 11.3 billion by 2100	1990–2025: 3.5% 1990–2100: 3.0%	18,400 EJ conventional oil Gas same as IS92a,b Phase out nuclear by 2075
IS92f	UN Medium-High Case 17.6 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	Oil and gas same as IS92e Solar costs fall to $0.083/kWh Nuclear costs increase to $0.09/kWh

Source: IPCC, (2013) *Approximate conversion factor: 1 barrel = 6 GJ.

2.2.8: IPCC emission scenarios – TAR

According to IPCC (2013), third Assessment Report (TAR) was completed in 2001. During this time, model references generally had reduced the grid cells sizes to about 180 km (112 miles). Special Report on Emissions and Scenarios (SRES) was the basis for climate change projection under the following assumptions:

A1

- rapid economic growth
- low population growth
- rapid introduction of new and more efficient technologies

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2

- regional economic development
- high population growth
- slow technological change

B1

- rapid changes in economic structures
- low population growth
- introduction of clean and resource-efficient technologies

B2

- intermediate economic development
- moderate population growth
- less rapid and more diverse technological change than in the B1 and A1 storylines

2.2.9: IPCC special report on emission scenarios (SRES) - AR4

According to IPCC (2013), fourth Assessment Report (AR4) was completed in 2001. During this time, model references typically used a 110 km (68 miles) wide grid cells. Special Report on Emissions and Scenarios (SRES) as used in TAR was the basis for climate change projection under the following assumptions:

A1

- rapid economic growth
- low population growth
- rapid introduction of new and more efficient technologies

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2

- regional economic development
- high population growth
- slow technological change

B1

- rapid changes in economic structures
- low population growth
- introduction of clean and resource-efficient technologies

B2

- intermediate economic development
- moderate population growth
- less rapid and more diverse technological change than in the B1 and A1 storylines

2.2.10: IPCC representative concentration pathways (RCP) - AR5

According to IPCC (2014), fifth Assessment Report (AR5) was completed in 2014. During this time, model references generally had reduced the grid cells sizes to about 87.5 km. The four Representative Concentration Pathways (RCPs) consistent with certain socio-economic assumptions was the basis for climate change projection:

2.2.10.1: RCP 8.5 – High emissions

This RCP was consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterised by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time. This future is consistent with:

- Three times today's CO_2 emissions by 2100
- Rapid increase in methane emissions
- Increased use of croplands and grassland which is driven by an increase in population
- A world population of 12 billion by 2100
- Lower rate of technology development
- Heavy reliance on fossil fuels
- High energy intensity
- No implementation of climate policies

2.2.10.2: RCP 6.0 – Intermediate emissions

This RCP was developed by the National Institute for Environmental Studies in Japan. Radiative forcing is stabilised shortly after year 2100, which is consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions. This future is consistent with:

- Heavy reliance on fossil fuels
- Intermediate energy intensity
- Increasing use of croplands and declining use of grasslands
- Stable methane emissions
- CO_2 emissions peak in 2060 at 75 per cent above today's levels, then decline to 25 per cent above today

2.2.10.3: RCP 4.5 – Intermediate emissions

This RCP was developed by the Pacific Northwest National Laboratory in the US. Here radiative forcing is stabilised shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. This future is consistent with:

- Lower energy intensity
- Strong reforestation programmes
- Decreasing use of croplands and grasslands due to yield increases and dietary changes
- Stringent climate policies
- Stable methane emissions
- CO2 emissions increase only slightly before decline commences around 2040

2.2.10.4: RCP 2.6 – Low emissions

This RCP was developed by PBL Netherlands Environmental Assessment Agency. Here radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time. This future would require:

- Declining use of oil
- Low energy intensity
- A world population of 9 billion by year 2100
- Use of croplands increase due to bio-energy production
- More intensive animal husbandry
- Methane emissions reduced by 40 per cent
- CO2 emissions stay at today's level until 2020, then decline and become negative in 2100

- CO_2 concentrations peak around 2050, followed by a modest decline to around 400 ppm by 2100

2.3: Empirical Studies

Climate change is a burning issue of the 21st century and its attendant consequences on different environmental components cannot be underestimated. In this study particular emphasis is laid on its impact on water resources availability. Therefore, ranges of related literature will be reviewed to establish the findings of previous scholars on the subject matter. However, in an attempt to do a comprehensive review of literature on the topic of discourse, it will be classified into global, regional and national studies.

2.3.1: Global studies

Teng *et al.* (2012) estimated climate change impact on mean annual runoff across continental Australia. Budyko and Fu equations informed by projections from 15 global climate models and compared with the estimates from extensive hydrological modeling. The results show runoff decline in southeast and far southwest Australia, but elsewhere across the continent there is no clear agreement between the global climate models in the direction of future precipitation and runoff change. Averaged across large regions, the estimates from the Budyko and Fu equations ware reasonably similar to those from the hydrological models. The simplicity of the Budyko equation, the similarity in the results, and the large uncertainty in global climate model projections of future precipitation suggest that the Budyko equation is suitable for estimating climate change impact on mean annual runoff across large regions.

Florence *et al.* (2013) analyzed impact of climate change on the hydrogeology of two basins in northern France. Four sources of uncertainty: climate modelling, hydrological modelling, downscaling methods, and emission scenarios were integrated. The analysis focused on the evolution of the water budget and the river discharges. Seven hydrological models were used, from lumped rainfall-discharge to distributed hydro geological models, and led to quite different estimates of the water-balance components. One of the hydrological models, CLSM, was found to be unable to simulate the increased water stress and was, thus, considered as an outlier even though it gave fair results for the present day compared to observations. Although there were large differences in the results between the models, there was a marked tendency towards a decrease of the water resource in the rivers and aquifers (on average in 2050 about −14 % and −2.5 m, respectively), associated with global warming and a reduction in annual precipitation (on average in 2050 +2.1 K and −3 %, respectively). The uncertainty associated to climate models was shown to clearly dominate, while the three others were about the same order of magnitude and 3–4 times lower.

Simon and Nigel (2013) assessed the impact of climate change on water scarcity. Patterns of climate change from 21 GCMs under four SRES scenarios were applied to a global hydrological model to estimate water resources across 1339 watersheds. The Water Crowding Index (WCI) and the Water Stress Index (WSI) were used to calculate exposure to increases and decreases in global water scarcity due to climate change. 1.6 (WCI) and 2.4 (WSI) billion people are estimated to be currently living within watersheds exposed to water scarcity. Using the WCI, by 2050 under the A1 scenario, 0.5 to 3.1 billion people are exposed to an increase in water scarcity due to climate change. Sensitivity to the WCI and WSI thresholds that define water scarcity can be comparable to the sensitivity to climate change pattern. More of the world will see an increase in exposure to water scarcity than a decrease due to climate change but this is not consistent across all climate change patterns.

Kara (2014) investigated the impact of climate change on water resources through precipitation and discharge analyses in Omerli catchment Istanbul, Turkey. Precipitation and temperature data were obtained from GCM/RCM combinations based on A1B carbon scenario. The data were obtained at 25 km resolution on daily time scale for reference period between 1960 and 1990 and future period between 2071 and 2100. The HBV (Hydrologiska ByransVattenbalansavdel-ning) model was used to investigate discharge properties of the study area. Because RCM scale is comparatively coarse (25 km) for catchment scale, its results were downscaled to 1 km using the Geographically Weighted Regression (GWR) method. Depending on precipitation input from RCMs with and without GWR the HBV also shows significant underestimation in daily and extreme runoff but it provides better estimates with GWR input. The magnitude of extreme events increases in winter, spring, and summer but decreases in fall from reference to future period. Return periods of the extreme events increase in the future period and therefore, Omerli Basin is under water stress with changing climate.

Nyeko (2014) assessed the relative effects of climate change on regional and global exposure to water resources stress and river flooding. Projected future impact of climate change on exposure to water stress and river flooding is dominated by uncertainty in the projected spatial and seasonal patterns of change in climate. There was little clear difference in impact between RCP2.6, RCP4.5 and RCP6.0 in 2050 and between RCP4.5 and RCP6.0 in 2080. Impacts under RCP8.5 were greater than under the other RCPs in 2050 and 2080. For a given RCP, there was a difference in the absolute numbers of people exposed to increased water resources stress or increased river flood frequency. Climate change by 2050 would increase exposure to water resources stress for between approximately 920 and 3,400 million people under the highest RCP, and increase exposure to river flood risk for between 100 and 580 million people. Under RCP2.6, exposure to increased water scarcity would be reduced in 2050 by 22-24 %, compared to the impact under the RCP8.5, and exposure to increased flood frequency would be reduced by around 16 %.

Eylon *et al.* (2015) assessed climate change impact on water resources management in the upper Santa Cruz River, Arizona, USA. Precipitations for the upper Santa Cruz River from eight dynamically downscaled GCMs were projected. Analysis indicates an increase and decrease in the frequency of occurrence of dry and wet summers respectively. The winter rainfall projections indicate an increased frequency of both dry and wet winter seasons. The climate analysis results were also compared with resembled coarse GCMs and bias adjusted and statistically downscaled CMIP3 and CMIP5 projections readily available for the contiguous U.S. It was concluded that climatic change projections increase the uncertainty and further exacerbate the already complicated water resources management task. The ability to attain an annual water supply goal, the accrued annual water deficit and the potential for replenishment of the aquifer depend considerably on the selected management regime.

Ibrahim *et al.* (2015) used CMIP5 data under RCP 4.5 and 8.5 to simulate climate change impact on flow regime within the Lake Champlain Basin, USA. A subset of five climate models among the CMIP5 ensembles showed statistically significant trends in precipitation, but the magnitude of these trends was not adequately representative of those seen in observed annual precipitation. Adjusted precipitation forecasts project a streamflow regime described by an increase of about 30% in seven-day maximum flow, a four day increase in flooded days, a three order of magnitude increase in base flow index, and a 60% increase in runoff predictability (Colwell index).

Nezar *et al.* (2015) assessed the impact of climate change on water resources of Jordan. SWAT along with General Circulation Models (GCM) were used to assess the future impact of climate change on water resources in the study area. Based on the analysis of different GCM models, HadCM3 runs A2 and B2 were found to be the best fits for the climate conditions of Jordan. Using SWAT hydrological model, a decrease in the available monthly steam flow was noticed in the next 80 years in Jordan. The main rainy months in Jordan (Jan, Feb and Mar) will show a decrease in surface runoff amounts that may reach 40% as result of increasing temperature and decreasing precipitation. The results indicate that the current water strategy plans managed by Ministry of Water and Irrigation (MWI) should be revised to handle that additional stresses that resulted from the impact of climate change.

Pervez and Henebry (2015) evaluated sensitivities and patterns in freshwater availability due to projected climate and land use changes in the Brahmaputra basin, Bangladesh. The sensitivities and impact of projected climate and land use changes on basin hydrological components were simulated for the A1B and A2 scenarios and analyzed relative to a baseline scenario of 1988–2004. Basin average annual ET was found to be sensitive to changes in CO2 concentration and temperature, while total water yield, streamflow, and groundwater recharge were sensitive to changes in precipitation. The basin hydrological components were predicted to increase with seasonal variability in response to climate and land use change scenarios. Strong increasing trends were predicted for total water yield, streamflow, and groundwater recharge, indicating exacerbation of flooding potential during August–October, but strong decreasing trends were predicted, indicating exacerbation of drought potential during May–July of the 21st century.

Singh and Kumar (2015) analysed the vulnerability of water availability in India due to climate change. The study used a bottom-up probabilistic Budyko framework that estimates the vulnerability of available water to changing climate using three hydroclimatic variables: long-term precipitation, potential evapotranspiration, and actual evapotranspiration. These variables were assimilated within a probabilistic Budyko framework to derive estimates of water availability and associated uncertainty. Based on the exploratory analysis, it was found that southern India is most susceptible to changing climate with less than 10% decrease in precipitation causing a 25% decrease in water availability.

Lapidez (2016) assessed climate change impact on the water resources budget and hydrological regime of the Pampanga river basin in Philippines. The Coupled Model Intercomparison Project Phase 5 (CMIP5) tool under the Data Integration and Analysis System (DIAS) was used to generate data used in the analyses. The results show that the projected total annual water budget of the Pampanga river basin for the years 2046-2065 is larger than present. This increase will likely be concentrated to occur in the wet season (June-November). The models project a wetter wet season and a moderately drier dry season. Results also show that the number of extreme rainfall events is very likely to increase as well as the number of no-rain days. Adaptive measures and climate change policies can be planned and executed given the results of this study.

Oroud (2016) evaluated the composite risk of anthropogenic and climate change on the future water status in Jordan during the period 2030-2050. The projected water status was evaluated based on the more likely population growth and climate change scenarios. The most likely figure for the population of Jordan, excluding refugees from neighboring countries, in 2040 would be 15 million people. Given this likely projection, though conservative, annual water needs for the domestic sector alone are expected to be between 700 and 800 million m^3, with the current level of water consumption. A rise in near surface air temperature by 2 °C and a drop in total precipitation by 15%, as projected by most Global Circulation Models, would diminish renewable water resources in the mountainous region by 25-40%, being more severe as aridity increases.

Dehua *et al.* (2017) assessed the impact of climate change on Water Resources of the Xijiang Basin, South China. In this study, two hydrological models with different structures, a physically-based distributed model Liuxihe (LXH) and a lumped conceptual model Xinanjiang (XAJ) were employed to simulate the daily runoff in the Xijiang basin in South China, under historical (1964–2013) and future (2014–2099) climate conditions. The future climate series are downscaled from a global climate model (Beijing Climate Centre-Climate System Model, BCC-CSM version 1.1) by a high-resolution regional climate model under two representative concentration pathways—RCP4.5 and RCP8.5. The hydrological responses to climate change via the two rainfall–runoff models with different mathematical structures were compared, in relation to the uncertainties in hydrology and meteorology. It was found that the two rainfall–runoff models successfully simulate the historical runoff for the Xijiang basin, with a daily runoff Nash–Sutcliffe Efficiency of 0.80 for the LXH model and 0.89 for the XAJ model. It shows that the distributed model could produce more streamflow and peak flow than the lumped model under the climate change scenarios. Overall, the study reveals how uncertain it can be to quantify water resources with two different but well calibrated hydrological models.

Demircan *et al.* (2017) analyzed climate change projections for Turkey and surrounding region. Three GCMs under RCP4.5 and RCP8.5 scenarios outputs were used in the study. Temperature and precipitation covering the period between 2016 and 2099 were projected. According to the model's results, it was expected that there will be an increase between 1°C and 6°C in mean temperatures of Turkey. In general precipitation amount shows a decrease except in winter season. Although there was no regular decreasing or increasing trend throughout projection period, it attracts more attention due to irregularity of precipitation regime.

Deniz *et al.* (2017) examined climate change impact on hydro climatic regimes and extremes over Andean basins in central Chile. Daily precipitation and temperature data were based on observations to drive and validate the VIC macro-scale hydrological model in the region at a 0.25^{o} x 0.25^{o} resolution. Historical (1960-2005) and projected, following the RCP8.5 scenario (2006-2099), daily precipitation and temperatures from 26 CMIP5 climate models were bias corrected and used. The model simulations indicate decreases in annual runoff of about 40% by the end of the century, larger than the projected precipitation decreases (up to 30%). The projected hydroclimatic regime is also expected to increase the severity and frequency of extreme events. The probability of having extended droughts, such as the recently experienced mega-drought (2010-2015), increases to up to 5 events/100 years. On the other hand, probability density function of annual maximum daily runoff indicates an increase in the frequency of flood events.

De Sa *et al.* (2017) analyzed the likely changes in the water availability in the Rio Verde Grande basin, USA. This study performed the climate projections using the GCMs of the CMIP5, whereas the hydrological modelling was performed through WEAP. Based on the calculations of sustainability indexes, and comparing the current and future scenarios, it was observed that even with all the interventions proposed by the water resources plan of the Rio Verde Grande basin (WRPVG), there was a reduction in sustainability of water resources in some sub-basins due to climate change.

Edvinas *et al.* (2017) analyzed climate change impact on the Nemunas river basin, Europe. The monthly air temperature and precipitation projections for the 21st century were estimated using the CMIP 5 model outputs. According to RCP2.6 and RCP8.5 projections for the 21st century, annual precipitation and air temperature are both going to increase and the annual runoff is likely to decrease. The main distinction between the effects of climate change predicted by both scenarios was the difference in the cold-season hydrological regime, and especially the water supply during winter and spring. If greenhouse gas emissions follow a mostly conservative pathway, the temperature increase will lead to a decrease in snowfall and a reduction in the maximum snow water equivalent in the second half of the 21st century, while the most pessimistic pathway suggests the almost complete disappearance of snow from the Nemunas river basin.

Hashim and Ranjan (2017) evaluated the impact of future climate changes on the hydrological system of the Richmond river catchment, Australia. Daily observed rainfall, temperature and discharge and long-term monthly mean potential evapotranspiration from the hydro-meteorological stations within the catchment over the period 1972–2014 were used to run, calibrate and validate the HBV model before the simulation. Future climate signals were extracted from a multi-model ensemble of eight GCMs of the CMIP5 under three scenarios (RCP2.6, RCP4.5 and RCP8.5). The calibrated HBV model was forced with the downscaled rainfall and temperature to simulate future streamflow at catchment outlet for the near-future (2016–2035), mid (2046–2065) and late (2080–2099) 21st century. A baseline run, with baseline climate period 1971–2010, was used to represent current climate status. Almost all GCMs' scenarios predict slight increase in annual mean rainfall during the beginning of the century and decrease towards the mid and late century. Modelling results also show positive trends in annual mean streamflow during the near-future (13–23%), and negative trends in the mid (2–6%) and late century (6–16%), under all scenarios compared to the baseline-run.

Reiner *et al.* (2017) examined climate change projections of boreal summer precipitation over tropical America. Statistical downscaling was applied to outputs of 20 GCMs of CMIP5, for present climate (1970–2000), and for future (2071–2100) under the RCP2.6, RCP4.5 and RCP8.5 scenarios. For present climate, many SD GCMs faithfully reproduce the precipitation field in many regions of the study area. For future climate, as the radiative forcing increases, the projected changes intensify and the regions affected expand, with higher coherence between models. The zone between central and southeastern Brazil registered the most pronounced precipitation changes by a large number of SD models, even for the RCP2.6. In general, the changes in rainfall range from moderate (± 25%) to intense (from ±70% to ±100%) as the radiative forcing increases from the RCP2.6−RCP8.5.

Lei *et al.* (2017) studied the variations in climatic variables and their influence on runoff in the Manas river basin, China. Three global climate models (GCMs) from Coupled Model Inter-comparison Project Phase 5 (CMIP5) were bias-corrected using Equidistant Cumulative Distribution Functions (EDCDF) method to reveal the future climate change during the period from 2021 to 2060 compared with the baseline period of 1961–2000. The results showed that the runoff, precipitation, and mean, lowest and highest temperatures all presented an increasing trend in yearly scale during the period of 1961–2015, and their abrupt change points were at a similar time; the runoff series was more strongly related to temperature than to precipitation in the spring, autumn and yearly scales, and the opposite was true in winter. All GCMs projected precipitation and temperature, and the runoff simulated with these GCMs were predicted to increase in the period from 2021 to 2060 compared with the baseline period of 1961–2000.

Iulii *et al.* (2017) investigated the climate change impact on water resources in three representative Ukrainian catchments, focusing on three mesoscale river catchments (Teteriv, upper Western Bug, and Samara) characteristic for different geographical zones. Soil and Water Integrated Model (SWIM) was setup, calibrated, and validated for the three catchments under consideration. A set of seven GCM-RCM coupled climate scenarios corresponding to RCPs 4.5 and 8.5 were used to drive the hydrological catchment model. The climate projections, used in the study, were considered as three combinations of low, intermediate, and high end scenarios. Results indicate the shifts in the seasonal distribution of runoff in all three catchments. The spring high flow occurs earlier as a result of temperature increases and earlier snowmelt. The fairly robust trend is an increase in river discharge in the winter season, and most of the scenarios show a potential decrease in river discharge in the spring.

Mo *et al.* (2017) assessed impact of climate change on agricultural water resources and adaptation on the north China plain, China. Ensemble projection of CMIP5 with 20 GCMs, were used under scenarios of RCP2.6, RCP4.5, and RCP8.5. Potential evapotranspiration (ET) shows a decreasing trend under climate change, actual ET slightly increased with acceleration in hydrological cycling. GCM ensemble projections predict that by the 2050s, the increased crop water demand and intensified ET resulting from global warming will reduce water resources surplus (Precipitation-ET) about 4%-24% and increase significantly the irrigation water demand in crop growth periods. It is revealed that reducing the sowing area of winter wheat (3.0%-15.9%) in water-limited basins, together with improvement in crop water-use efficiency would effectively mitigate water shortages and intensify the resilience of agricultural systems to climate change.

Nahlah *et al.* (2017) assessed the impact of climate change on water resources in Greater Zab and Lesser Zab Basins, Iraq. To gain a better understanding of the effects of climate change on water resources of the study area in near future (2049-2069) as well as in distant future (2080-2099), Soil and Water Assessment Tool (SWAT) was applied. The model was first calibrated for the period from 1979 to 2004 to test its suitability in describing the hydrological processes in the basins. The calibrated model was then used to evaluate the impact of climate change on water resources. Six GCMs from CMIP5 under RCP 2.6, RCP 4.5, and RCP 8.5 for periods of 2049-2069 and 2080-2099 were used to project the climate change impact on these basins. The results demonstrated a significant decline in water resources availability in the future.

Sang *et al.* (2017) carried out a study on assessment of the impact of climate change on drought characteristics in the Hwanghae plain, North Korea. Multiple timescales of the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI) from 1981 to 2100 were used. The probability of non-exceedance for a one-month SPEI below −1.0 was only 1.1% in the spring season of 1995 but increased to 24.4% in 2085. The SPEI for a ten-year return period varied from −0.6 to −0.9 in 1995 and decreased to −1.18 in 2025. The results indicate that severe drought is more likely to occur in the future as a result of climate change. The seasonal drought conditions were also significantly influenced by climate change. The largest decrease in the SPEI occurred in late spring and early summer. Time series of SPIs and SPEIs found that the drought intensity identified by one-month SPEIs in 1995 was at a level of 1.21, which reached 1.39 in 2085, implying that climate change will intensify drought in the future.

Kang and Venkataramana (2018) assessed the climate change impact on future drought conditions and water resources of the Chesapeake Bay (CB) watershed, USA. Soil and Water Assessment Tool (SWAT) and the Variable Infiltration Capacity model were used to simulate a Modified Palmer Drought Severity Index (MPDSI), a Standardized Soil Moisture index (SSI), a Multivariate Standardized Drought Index (MSDI), along with Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models for both historical and future periods (f1: 2020-2049, f2: 2050-2079). The results of the SSI suggested that there was a general increase in agricultural droughts in the entire CB watershed because of increases in surface and groundwater flow and evapotranspiration. However, MPDSI and MSDI showed an overall decrease in projected drought occurrences due to the increases in precipitation in the future. The results of this study suggested that it is crucial to use multiple modeling approaches with specific drought indices that combine the effects of both precipitation and temperature changes.

According to Benjamin et *al.* (2019) in Australia, understanding the impact of climate change on water supply is essential for water planners and managers to ensure resources are best able to meet future demand for water. It provides an assessment of the likely projected impact of climate change on water resources for three regions: northern Australia, southern Australia and eastern Australia.

In northern Australia, climate projections for northern region show that natural climate variability, including distinct dry and wet seasons, is expected to remain the major driver of rainfall changes over the near future (2030). Long term (2090) projected changes are small compared to natural variability under low and medium emissions scenarios. Under a high emissions scenario both substantial increases and substantial decreases are possible with the projected change in summer rainfall ranging from -25 to +25 per cent by 2090. Further, it is expected that a larger proportion of rain will fall during extreme rainfall events, which are projected to become more intense. This has implications for aquifer recharge processes, particularly for aquifers that are recharged through seepage rather than filled through rivers and streams. Projections also show increases in evapotranspiration in all seasons.

In southern Australia, climate projections show a drying trend under all emissions scenarios with annual rainfall changes from -25 to +5% in 2090 under a high emissions scenario. Winter and spring rainfall was projected to decrease across southern Australia, with the exception of Tasmania where little change or an increase in winter rainfall is expected. The winter decline was particularly significant for southwest Australia, with projections showing a decline of up to 50% by 2090 under the highest emissions scenario.

Projections also show declines in runoff and soil moisture and increases in drought duration, strongly driven by the expected decline in annual rainfall along with increases in evapotranspiration. Further, it was expected that a larger proportion of rain will fall during extreme rainfall events, which were projected to become more intense.

In eastern Australia, climate projections of rainfall change in eastern Australia are the most uncertain of any broad region of Australia. Models show a range of projections for mean annual rainfall, from a substantial decrease to a substantial increase and a similar level of uncertainty for seasonal rainfall projections. There was medium agreement from climate models for substantial annual rainfall reductions by 2090 under a high emissions scenario, driven largely by rainfall declines in winter and spring. Changes in all seasons by 2030 are small relative to natural variability. Further, there was high confidence in projections of an increase in the intensity of extreme rainfall events, with a larger proportion of rainfall occurring during these extreme events

2.3.2: Regional studies

Monireh *et al.* (2013) analysed the impact of climate change on freshwater availability in Africa at the sub basin level for the period of 2020–2040. Future climate projections from five global GCMs under the four IPCC emission scenarios were fed into an existing SWAT hydrological model to project the impact on different components of water resources across the African continent. The GCMs were downscaled based on observed data of Climate Research Unit to represent local climate conditions at 0.5 grid spatial resolution. The results show that for Africa as a whole, the mean total quantity of water resources was likely to increase. For individual sub basins and countries, variations are substantial. It was found that in many regions/countries, most of the climate scenarios projected the same direction of changes in water resources, suggesting a relatively high confidence in the projections. The assessment of the number of dry days and the frequency of their occurrences suggest an increase in the drought events and their duration in the future. This poses additional challenge to agriculture in dry regions where water shortage was already severe while irrigation was expected to become more important to stabilize and increase food production.

Gebre *et al.* (2015) evaluated the potential impact of climate change on the hydrology and water resources availability of Didessa Catchment, Ethiopia. Future climate change scenarios of precipitation, temperature and potential evaporation were developed using output of dynamically downscaled data of ECHAM5 (GCM) 50 KMs resolution under A1B emission scenario for 2030's (2031-2040) and 2090's (2091-2100). The future projection of the GCM model of climate variables showed an increasing trend as compared to the base line period (1991-2000). At 2030`s and 2090`s average annual precipitation may increase by +33.22% and+8.40% respectively over the Didessa catchment. The impact of climate change on future runoff resulted in a positive magnitude change in average runoff flow at the outlet of the catchment. The increase in average runoff is associated with the increase in precipitation projection over the catchment. During the main rainy season of summer, at 2030`s and 2090`s average seasonal runoff percentage change may increase up to +157% and +136% respectively as compared to the base line period. Hence, more likely in the future the water resources availability may increase in the catchment.

Gebre and Ludwig (2015), assessed the hydrological response of climate change of four catchments (GilgelAbay, Gumer, Ribb, and Megech) of the upper Blue Nile River basin in Ethiopia using new emission scenarios based on IPCC fifth assessment report (AR5). Five biased corrected 50 KMs by 50 KMs resolution GCMs (Global Circulation Model) output of RCP 4.5 and RCP 8.5 emission scenarios were used. The future projection period was divided into two future horizons of 2030`s (2035-2064) and 2070`s (2071-

2100). All the five GCMs projection showed maximum and minimum temperature increases in all months and seasons in the upper Blue Nile basin. The change in magnitude in RCP 8.5 emission is more than RCP 4.5 scenario as expected. There is considerable average monthly and seasonal precipitation change variability in magnitude and direction. Runoff is expected to increase in the future, and 2030`s average annual runoff projection change may increase up to +55.7% for RCP 4.5 and up to +74.8% for RCP 8.5 scenarios. At 2070`s average annual runoff percentage change increase by +73.5% and by +127.4% for RCP 4.5 and RCP 8.5 emission scenarios, respectively.

Amir *et al.* (2016) assessed the impact of climate change on the stream flow in the Dinder River basin (DRB) and to infer its relative possible effects on the Dinder National Park (DNP) ecosystem habitats in Sudan. Four global circulation models (GCMs) from Coupled Model Intercomparison Project Phase 5 and two statistical downscaling approaches combined with a hydrological model (Soil and Water Assessment Tool) were used to project the climate change conditions over the study periods 2020s, 2050s, and 2080s. The results indicated that the climate over the DRB will become warmer and wetter under most scenarios. The projected stream flow is quite sensitive to rainfall and temperature variation, and will likely increase in this century. In contrast to drought periods during the 1960s, 1970s, and 1980s, the predicted climate change is likely to affect ecosystems in DNP positively and promote the ecological restoration for the habitats of flora and fauna.

Umesh and Pouyan (2016) examined impact of climate change on water resources in Malawi. Downscaled outputs from six general circulation models, for the most extreme Representative Concentration Pathway (RCP 8.5), were used as inputs to the soil and water assessment tool to assess the impact of climate change on evapotranspiration, surface runoff, water yield, and soil moisture content at the country, watershed, and sub-basin levels by the 2050s. At the country level, the results showed a –5.4% to +24.6% change in annual rainfall, a −5.0% to +3.1% change in annual evapotranspiration, from -7.5% to over +50% change in annual surface runoff and water yield, and up to an 11.5% increase in annual soil moisture. At the watershed level, results showed an increase in annual rainfall and evapotranspiration in the north and a gradual decline towards the south. Sub basin-level analysis showed a large probability of increase in the annual precipitation, surface runoff, water yield, and soil moisture, especially in the north. Overall, the northern region was found to be more prone to floods, while the southern region was found to be more prone to droughts. On a positive note, more precipitation in the north can provide more opportunity for agricultural production.

Ahmed *et al.* (2017) assessed climate change impact on surface water resources in the Rheraya catchment, Morocco. Two monthly water balance models, including a snow module, were considered to reproduce the monthly surface runoff for the period 1989–2009. Additionally, an ensemble of five regional climate models from the Med-CORDEX initiative was considered to evaluate future changes in precipitation and temperature, according to the two emissions scenarios RCP4.5 and RCP8.5. The future projections for the period 2049–2065 under the two scenarios indicate higher temperatures (+1.4°C to +2.6°C) and a decrease in total precipitation (−22% to −31%). The hydrological projections under these climate scenarios indicate a significant decrease in surface runoff (−19% to −63%, depending on the scenario and hydrological model) mainly caused by a significant decline in snow amounts, related to reduced precipitation and increased temperature.

Eric *et al.* (2017) examined future water resources availability under climate change scenarios in the Mekrou basin, Benin. Regional Climate Models (RCMs) were used as the input for four rainfall-runoff models which are ModHyPMA (Hydrological Model based on Least Action Principle), HBV (Hydrologiska ByransVattenbalansavdelning), AWBM (Australian Water Balance Model), and SimHyd (Simplified Hydrology). Then the mean values of the hydro-meteorological data of three different projected periods (2011–2040, 2041–2070 and 2071–2100) were compared to their values in the baseline period. The results of calibration and validation of these models show that the meteorological data from RCMs give performances that are as good as performances obtained with the observed meteorological data in the baseline period. The comparison of the mean values of the hydro-meteorological data of the baseline period to their values for the different projected periods indicates that for PET there is a significant increase until 2100 for both Representative Concentration Pathway 4.5 (RCP4.5) and RCP8.5 scenarios.

Gneneyougo *et al.* (2017) examined climate change and its impact on water resources in the Bandama Basin, Côte D'ivoire. Historical data from 14 meteorological and three hydrological stations were used. Simulation results for future climate from HadGEM2-ES model under representative concentration pathway (RCP) 4.5 and RCP 8.5 scenarios indicate that the annual temperature may increase from 1.2 ◦C to 3 ◦C. These increases will be greater in the north than in the south of the basin. The monthly rainfall may decrease from December to April in the future. During this period, it is projected to decrease by 3% to 42% at all horizons under RCP 4.5 and by 5% to 47% under RCP 8.5. These variations will cause an increase in surface and groundwater resources during the three periods (2006–2035; 2041–2060; 2066–2085) under the RCP 4.5 scenario. On the other side, these water resources may decrease for all horizons under RCP 8.5 in the Bandama basin.

Michael *et al.* (2017) analysed the separate and the combined impact of climate and land use changes on hydrology on the Bonsa catchment in Ghana. ACRU hydrological model and five RCP8.5 climate change scenarios (wet, 25th percentile, 75th percentile, dry and a multi-model median of nine GCMs) from the CMIP5 AR5 models for near (2020 – 2039) and far (2060 – 2079) future time slices were used. Change factors were used to downscale the GCM scenarios to the local scale, using observed climate data for the control period of 1990 to 2009. The land use of 1991 and 2011 were used as the baseline and current land use as well as three future land use scenarios (BAU, EG, EGR) for two time slices (2030 and 2070) were used. The study showed that under all separate climate change scenarios, overall flows reduced, but under combined climate and land use changes, stream flows increased. Under the combined scenarios, streamflow responses due to the different future land use scenarios were not substantially different. Also, land use is the dominant controlling factor in streamflow changes in the Bonsa catchment under a dry climate change, but under a wet climate change, climate controls streamflow changes. The spatial variability of catchment streamflow changes under combined land use and climate changes were greater than the spatial variability of streamflow changes under climate change.

Yared *et al.* (2018) evaluated the performance of six drought indices in characterising historical drought for the upper Blue Nile Basin, Ethiopia. The study compared six drought indices: Standardized Precipitation Index (SPI), Standardized Precipitation Evaporation Index (SPEI), Evapotranspiration Deficit Index (ETDI), Soil Moisture Deficit Index (SMDI), Aggregate Drought Index (ADI), and Standardized Runoff-discharge Index (SRI). The indices were calculated using monthly time series of observed precipitation, average temperature, river discharge, and modeled evapotranspiration and soil moisture from 1970 to 2010. The Pearson's correlation coefficients between the six drought indices were analysed. SPI and SPEI at 3-month aggregate period showed high correlation with ETDI and SMDI ($r > 0.62$), while SPI and SPEI at 12-month aggregate period correlate better with SRI. The performance of the six drought indices in identifying historic droughts: 1973–1974, 1983–1984, 1994–1995, and 2003–2004 was analysed using data obtained from Emergency Events Database (EM-DAT) and previous studies. None of the six drought indices could individually identified the onsets of all the selected historic drought events; however, they may identify the onsets when combined by considering several input variables at different aggregate periods.

2.3.3: National studies

Abaje *et al.* (2012) analysed recent trends and fluctuations of annual rainfall in the Sudano-Sahelian ecologicalzone of Nigeria: risks and opportunities. Rainfall data (1949-2008) for eight meteorological stations were used for this analysis. In order to identify trends, the rainfall series was sub-divided into 30-year overlapping sub-periods (1949-1978, 1959-1988, 1969-1998 and 1979-2008) and the Cramer's (tk) test was then used to compare the means of the sub-periods with the mean of the whole record period. The results of the test revealed that there was a change towards wetter conditions in the last 30-year period. The student's t-test was also used to examine the temporal changes in the rainfall series between the two non-overlapping sub-periods (1949-1978 and 1979-2008) and the result showed that Nguru and Katsina were significantly drier than the long-term mean. The 10-year running mean showed that annual rainfall for all the stations were below the long-term mean from the late 1960s to the early 1990s and above-average afterwards. The results of the linear trend lines revealed an increase in rainfall supply over the period of study. The study recommended that government policies related to agriculture and water resources development should take into account the risks and opportunities associated with increasing wet conditions in the Sudano-Sahelian ecological zone of Nigeria.

Abdullahi *et al.* (2014) evaluated the impact of climate change on water availability and investigated the sensitivity of the basin to climate change in Sokoto-Rima river basin, Nigeria using the Water Evaluation and Planning (WEAP) model. The calibration process of the model was done using the first twenty-two years' climatological records (1970-1992) and validated with the remaining data (1993-2013). Simulations were proposed for various climatic situations considering the global climatic models (GCM) predictions. Six (6) developed climate change scenarios of temperature increase (0, +0.5, +1°C) coupled with decrease or increase in precipitation (0, -10%, +10%) were combined and applied for the study area in the WEAP model for simulation. Results indicate that climate change will significantly reduce the runoff, and increase evapotranspiration and water demand in the basin, more especially the demand for irrigation. The results indicate an annual reduction in the total available water of about 1.70 billion cubic meters and monthly water demand of 17.11 Billion Cubic Meters for the month of April (which is the driest month in the basin) for the selected sites under 10% reduction in the actual rainfall within the basin and increase in evapotranspiration under 1°C increase in temperature. This indicates reduction of the surface water in the future for the basin.

Akinsanola and Ogunjobi (2014) investigated rainfall and temperature variability in Nigeria using observations of air temperature (^{o}C) and rainfall (mm) from 25 synoptic stations from 1971-2000(30years). The data were analyzed for the occurrences of abrupt changes in temperature and rainfall values over Nigeria while temporal and spatial trends were also investigated. Statistical approach was deployed to determine the confidence levels, coefficients of kurtosis, skewness and coefficient of variations. Analysis of air temperature indicated that in the first decade of 1971-1980 anomalies between -0.2 and -1.6 were predominant, in the second decade of 1981-1990,only five stations (Lokoja, Kaduna, Bida, Bauchi and Warri) showed positive anomaly while greater portion of the country were normal with evidence of warming in the third decade of 1991-2000.Results further indicated that there have been statistically significant increases in precipitation and air temperature in vast majority of the country. Analyses of long time trends and decadal trends in the time series further suggest a sequence of alternately decreasing and increasing trends in mean annual precipitation and air temperature in Nigeria during the study period.

Abdussalam (2015) investigated trends in extreme temperature and precipitation indices between 1971 and 2010 for six synoptic weather stations in northwest Nigeria. Results indicated that there have been statistically significant, spatially coherent trends in temperature indices that are related to temperature increases in the region. Significant, increasing trends were recorded in the annual minimum of daily maximum and minimum temperature, the annual maximum of daily maximum and minimum temperature, the number of summer nights, and the number of days where daily temperature has exceeded its 90th percentile. Significant negative trends were found in the number of days when daily temperature is below its 10th percentile and daily temperature range. Trends in precipitation indices, including the number of days with precipitation, the average precipitation intensity, and maximum daily precipitation events, were weak in general and do not show spatial coherence, with Kaduna showing decreasing trend.

Agumagu and Todd (2015) analysed the projected hydrological effects of climate change on the Niger Delta region, Nigeria. Runoff simulated represents the present and future flood risk for the catchment of the River Niger using Global Hydrological Models (GHMs). The simulated discharges were compared with the monthly gauge measurement along the River Niger from the Global Runoff Data Centre (GRDC). A period of (1970-2050) was chosen to understand the climatic variability across the Niger Delta region. The GHMs under Special Report on Emissions Scenarios (SRES) A2 scenario was used to provide future climate scenarios over the Niger River. The hydrological models from EU WATCH project were used to calculate flood extents for different model outputs. The simulation shows clears trends of increased in river discharge over the catchment although uncertainty cannot be over rule. Considering the future climate suggests that river flow from the basin could be substantially increased, especially in the long term when compare to the reference period. The rationale behind this work is the need to understand in clear terms the climate change threats on the Niger Delta region; this will form a practical basis for developing adaptation strategies to manage future climate risks

Ayeni *et al.* (2015) assessed the impact of global changes on the surface water resources of southwestern Nigeria. The study used long-term (1961– 2007) rainfall data to drive the Pitman monthly rainfall runoff model to assess changes to the water resources of three basins in Nigeria namely: Asa, Ogun and Owena. Three CGCMs—CSIRO Mark3.5, MIROC3.2-medres and UKMO-HadCM3—dynamically downscaled to a 60 km by 60 km grid using the Conformal-Cubic Atmospheric Model (C-CAM) were used to simulate impacts of future climate changes on water resources. The model results showed increases in the runoff coefficient with decreases in forest cover between 1981 and 2007, with average runoff coefficients of 5.3%, 12.0% and 6.4% for Asa, Ogun and Owena basins respectively. Based on annual reduction in rainfall trend projected by CSIRO, MIROC and UKMO, the future scenarios revealed a low runoff coefficient for the three basins such that Asa (CSIRO 6.0%, MIROC 6.0% and UKMO 5.9%), Ogun (CSIRO14.6%, MIROC 14.6% and UKMO 14.4%) and Owena (CSIRO 8.5%, MIROC 8.7% and UKMO 8.9%). In all scenarios, Asa basin had a lower runoff coefficient when compared to Ogun and Owena basins, indicating that future water stress in Asa basin would be much greater.

Salami *et al.* (2015) evaluated the impact of climate variability on water resources and yield capacity of selected reservoirs in the north central Nigeria. Trend analysis of mean temperature, runoff, rainfall and evapotranspiration was carried out using Mann Kendall and Sen's slope, while runoff was modeled as a function of temperature, rainfall and evapotranspiration using Artificial Neural Networks (ANN). Result demonstrated that rainfall and runoff exhibited positive trends at the two dam sites and their upstream while forecasted ten-year runoff displayed increasing positive trend which indicated high reservoir inflow. The reservoir yield capacity estimated with the ANN forecasted runoff was higher by about38% and 17% compared to that obtained with historical runoff at Asa and Kampe respectively. The study further revealed that this is an indication that there is tendency for water resources of the reservoir to increase and thus more water will be available for water supply and irrigation to ensure food security.

Adeoluwa *et al.* (2017) studied the geospatial analysis of extreme weather events in Nigeria (1985–2015). Four indices were used to characterize the intensity, frequency, and amount of rainfall over Nigeria. Self-organizing map was used to reduce the multiplicity of dimensions and produce four unique zones (clusters) characterizing extreme precipitation conditions in Nigeria. Spatial Trends revealed four regions with similar precipitation characteristics were evident varying from the south to the north through the middle belt of Nigeria. However, temporal trends revealed that there was a tendency for the maximum 1-day precipitation, maximum 5-day precipitation, and frequency of rainy days to increase with time in clusters 1, 2, and 4. In contrast, the maximum 1-day precipitation decreases with time in cluster 3. The intensity of rainfall was constant in cluster 1 throughout the period under study, while a decreasing trend was noticed in rainfall intensity and maximum 1-day precipitation in cluster 3. However, considering the results of the Mann-Kendall test, those trends were not significant. The only statistically significant upward trend was noticed in the frequency of rainy days in cluster 4. That this trend significantly increases the risk of flooding in Nigeria.

Imoleayo *et al.* (2018) examined the observed changes in climate extremes in Nigeria. Daily precipitation and temperature data over 24 stations, covering the three climatic zones (Guinea coast, Savannah and Sahel) of Nigeria for the period 1971–2013 were used. Results showed a significant increase in the frequencies of warm spell, warm days and nights and decreasing cold spell, cold days and nights over the three climatic zones. A significant increase in annual total precipitation was found in some stations across the Guinea coast and Sahel zones. Changes in consecutive dry days and consecutive wet days were non-significant in most stations. Also, a significant increase in extremely wet days was observed in a few stations across the three climatic zones. The study further stated that the implication of the observed warming could, however, result in thermal discomfort of lives in areas with significant positive trends. This could also exert pressure on the economy's power sector, as energy demand for cooling will increase. That the increase in total annual precipitation will potentially be favourable for hydropower generation and increase the availability of the potable water supply for both industrial and domestic uses in the country. However, the increase in consecutive dry days and the decrease in consecutive wet days are dangerous for agricultural practices and, hence, food security.

Gloria and Kingsley (2018) assessed the impact of climate change on the freshwater availability of Kaduna River basin, Nigeria. The study used statistical tools and participatory survey, trends in streamflow and their linkages with the climate indices to determine their amplifying impacts on water availability and impacts on livelihoods downstream the basin. Analysis indicated variable rainfall trend with significant wet and dry periods. Unlike rainfall, temperature showed annual and seasonal scale statistically increasing trend. Runoff exhibited increasing tendency but only statistically significant on annual scale as investigated with Mann–Kendall trend test. Sen's estimator values stood in agreement with Mann–Kendall test for all variables. Kendall tau and partial correlation results revealed the influence of climatic variables on runoff. Based on the survey, it was reported that some of the hydrological implications and current water stress conditions of these fluctuations for the downstream inhabitants were itemized. It was recommended that with increasing risk of climate change and demand for water, developing adaptive measures in seasonal regime of water availability and future work on modelling of the diverse hydrological characteristics of the entire basin was imminent.

Muhammad and Naim (2018) assessed the impacts of population growth and climate change on performance of water use systems and water allocation in Kano River Basin (KRB), Nigeria. The new and innovative Sufficiency (sustainable efficiency) framework, which incorporates quantity, quality, and beneficial aspects of water use in a comprehensive and systemic manner, was used. It was found that performance of the WUSs was sensitive to population growth and global warming under the scenarios considered. Kano River was relatively less sensitive to global warming impacts, while high population growth was dominant impact. Moreover, it was further revealed that their combined effect will result in a reduction of downstream water by 70%and potential demands will far exceed the available supply by 2050. It was recommended that efficient management of water regarding the qualitative as well as quantitative aspects is very critical in KRB.

Adeaga *et al.* (2019) examined water resources uncertainty in Yewa River Basin, Ogun state, South-West Nigeria. The study entails assessment of the effects of climate change and variability on water resources and its implication on both physical environment and hydrological regime using water evaluation and planning (WEAP) system model. Data used include water supply and demand for domestic, commercial, industrial and agriculture as well as climatic data (rainfall and temperature) and runoff. As revealed by the Scenario building, 45.24% of the annual water requirement within Yewa Basin was unmet with water potentials of annual mean discharge of 3682.46 m3/s (±830.1) and annual mean rainfall of 1106.26m (±475.25) with coefficient of variation of 40.88 and 73.73 respectively. The study concluded that the deficit observed called for an appropriate water resources management mechanism in Yewa Basin.

Adeyeri *et al.* (2019) investigated trends of climate extreme indices in the Komadugu-Yobe Basin (KYB) based on observed data of the period 1971–2017 as well as regional climate model (RCM) simulations for the historical period(1979–2005), the near future (2020–2050), and the far future (2060–2090). The Adapted Caussinus Mestre Algorithm for homogenizing Networks of Temperature series homogeneity test was used. The magnitude of the linear trends was estimated using the Sen's slope estimator and Mann-Kendall's test performed to check the statistical significance of the trends. Future trends were assessed using the ensemble mean of eight regional climate model data under two emission scenarios, provided by the Coordinated Regional Climate Downscaling Experiment (CORDEX). In the observations, warm spell duration, warm day-, and warm night frequencies exhibited statistically significant positive trends. Although there was a positive trend in the annual total rainfall, the number of consecutive wet (dry) days decreases (increases). The future climate also showed a continuing positive trend in the temperature extreme indices as well as more frequent extreme rainfall events. The study concluded that it is pertinent for decision-makers to develop suitable adaptation and mitigating measures to combat climate change in the Basin.

Ibrahim *et al.* (2020) examined potential impacts of climate change on extreme weather events in the Niger Delta part of Nigeria. Four CMIP5 GCMs under RCP4.5 and RCP8.5 emission scenarios were used for climate change predictions. Standardized precipitation indices (SPI) of 1-month and 12-month time steps were used for extreme event assessment. Results from the climate change scenarios predict an increase in rainfall across all future periods and under both emission scenarios, with the highest projected increase during the last three decades of the century. Under the RCP8.5 emission scenario, the rainfall at Port Harcourt and Yenagoa stations were predicted to increase by about 2.47% and 2.62% while the rainfall at Warri station was predicted to increase by about 1.39% toward the end of the century. The 12-month SPI under RCP4.5 and RCP8.5emission scenarios predict an exceedance in the extreme wet threshold (i.e., SPI > 2) during all future periods and across all study locations. These findings suggest an increasing risk of flooding within the projected periods and can be useful to policymakers for the formulation and planning of flood mitigation and adaptation measures.

2.3.4: Appraisal of reviewed literature

The general inferences drawn from this review is that GCMs have an edge over the use of hypothetical scenarios in climate change impact studies. It has been recognised as highly versatile and most suitable in modeling future climate globally. Flato *et al.* (2013) infer that it is the primary tools available for investigating the response of the climate system to various forcings, for making climate predictions on seasonal to decadal time scales and for making projections of future climate over the coming century and beyond. Currently, there are many climate models used in predicting important climatic variables. There are over 40 different Global Climate Models (GCMs) from Couple Model Intercomparison project Phase 5 (CMIP5) dataset. While most of these models simulations give a fairly representation of temperature when compared with observation data, the reverse is the case for precipitation. Some models simulations either under estimate or overestimate precipitation when compared with observation data; this can be address using statistical multi-criteria approach. According to Farzan *et al.* (2013) statistical multi-criteria approach include univariate and multivariate techniques, for selecting suitable GCMs to be used for climate change impact analysis in any location of interest globally.

Similarly, the main rationale for using scenarios is that climate change is a slow process where decisions today can have irreversible consequences for some years or even centuries (Vetter *et al.,* 2016). Special Report on Emissions and Scenarios (SRES) and Representative Concentration Pathways (RCPs) are the two emission scenarios commonly used in recent times for climate change impact studies. While the former involve storylines that embrace generic notions of sustainability and environmental protection, the scenarios do not envision explicit attempts to stabilize CO_2 concentrations at any particular level. The later was developed and referred to as pathways to emphasize that they are not definitive, but are instead internally consistent time-dependent forcing projections that could potentially be realized with multiple socioeconomic scenarios. In particular, they can take into account climate change mitigation policies to limit emissions.

The projection of future water availability is usually done by following a complex modelling chain, often starting with assumptions regarding future radiative forcing (e.g. representative concentration pathways, RCPs) and climate projections by general circulation models (GCMs) to regional climate models (RCMs), or statistical downscaling methods, to bias correction of climate data, and finally through hydrological impact models to obtaining final results (Toreti *et al.,* 2013, Krysanova *et al.,* 2016 cited in Valentina *et al.,* 2018). Different types of hydrological models (HMs) are used for water availability assessment namely Water Evaluation and Planning Model (WEAP), Soil and Water Assessment Tool Model (SWAT), Agricultural Catchment Research Unit Model (ACRU), Variable Infiltration Capacity Model, Soil and Water Integrated Model (SWIM) and Budyko equation only to mention but few.

Common features of these models are their complexity, expertise, cost, applicability and data availability. However, the Budyko equation is straightforward, easy to use, and the data needed is readily available. The result of the Budyko equation with aforementioned hydrological models suggest that it is suitable for estimating climate change impact on water availability (Tang *et al.*, 2012; Xu *et al.*, 2013; Berghuijs *et al.*, 2014; Singh and Kumar 2015; Greve *et al.*, 2016; Anastasia *et al.*, 2018).

Impacts of climate change on the occurrence of future droughts can be evaluated based on precipitation and temperature projections, simulated hydrometeorological variables, and various drought indices (Kang and Venkataramana, 2018). There are quite numbers of drought indices such as Standardized Precipitation Index (SPI), Standardized Precipitation Evaporation Index (SPEI), Evapotranspiration Deficit Index (ETDI), Soil Moisture Deficit Index (SMDI), Aggregate Drought Index (ADI), and Standardized Runoff-discharge Index (SRI) (Yared *et al.*, 2018). The Standardized Precipitation Index (SPI) is one of the most prevalent indices for evaluating drought (Thilakarathne and Sridhar, 2017 cited in Yared *et al.*, 2018), and it is based on long-term precipitation observations. With the same framework of SPI computation, the Standardized Soil Moisture Index (SSI) is applied to quantify agricultural drought using soil moisture as an input. Oftentimes the mean value of the precipitation is set to zero, and values above zero indicate wet conditions, while values below zero indicate dry conditions. Similarly, the Palmer Drought Severity Index (PDSI) is widely used but has several issues that have been largely reported (Janssen *et al.*, 2014). Despite multiple drought indices the challenge in evaluating drought still remains for establishing a single meteorological or hydrologic variable (Yared *et al.*, 2018).

Water stress has become a major constraint to socio-economic development and a threat to livelihood in different parts of the world (Liu *et al.*, 2017). There are numbers of different methods used in measuring water stress ranging from simple to highly complex methods with different data requirements. Mekonnen and Hoekstra (2016) reveal that among these methods are Falkenmark indicator' or 'water stress index', water use to availability ratio or criticality ratio, physical and economic water scarcity, water poverty index, and water crowding index. One of the most commonly used measures of water stress is the 'Falkenmark indicator' or 'water stress index'. This method defines water stress in terms of the total water resources that are available to the population of a region; measuring scarcity as the amount of renewable freshwater that is available for each person each year. However, the indicator overlooks temporal variability and the important drivers of demand, related to economic growth, lifestyle, and technological developments. Despite the availability of numerous indicators for estimating water stress, the 'Falkenmark indicator' or water stress index is commonly used because it is straightforward, easy to use, and the data needed is readily available. On the other hand, the availability ratio, or criticality ratio, is another widely used indicator to assess water scarcity. The advantage of this ratio is that it measures the amount of water used, and relates it to the available renewable water resources, while it disadvantage is that the ratio of consumption to average available renewable water resources usually indicates an unrealistically low level of water stress.

Similarly, physical and economic water scarcity is another indicator, yet it has not been used as much as other indicators to assess water stress. One reason for this is that it is considerably more complex than many other indices and thus more time-consuming to compute. Another is perhaps that its interpretation is less intuitive than other indices and therefore less attractive for presentation to the public and/or a policy audience (Rijsberman, 2006 cited in Liu *et al.,* 2017). Lastly, the water poverty index (WPI) proposes a relationship between the physical extent of water availability, its ease of abstraction, and the level of community welfare. This indicator has the advantage of comprehensiveness, however, its application is hampered by its complexity and lack of information for some of the factors required for building the indicator on large scale (Rijsberman, 2006 cited in Liu *et al.,* 2017).

In light of the forgoing, it is evident that each model and emission scenario has its strengths and weaknesses. To maximize on the weakness and strength of these models and scenarios, this study will adapt the multi-models ensemble mean and scenario which has been used in similar studies (Greve *et al.,* 2016; Ahmed *et al.,* 2017; and Yared *et al.,* 2018). This can be used in climate change impact study of northern Nigeria. More so, various methods have been identified from the reviewed literature for each of the four objectives of this study. Thus, it is pertinent to mention that based on the complexity, popularity, applicability, expertise, performance and most importantly data availability for each of the method; the following will be used to achieve the stated objectives of the study. They are Percentage Impact Analysis (PI), Budyko equation, extreme rainfall indices and Water Stress Index (WSI) for objectives: 1, 2, 3 and 4 respectively.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1: Types and Sources of Data

3.1.1: Types of data used

The data used in this study included:

i. Temperature data for the period of 60 years (1959-2018) for the Kainji Lake Basin (KLB), Sokoto-Rima Basin (SRB) and Komadugu-Yobe Basin (KYB) as representative of the Guinea and Sudano-Sahelian ecological zones of Nigeria;
ii. Rainfall over the period of 60 years (1959-2018) for KLB, SRB and KYB;
iii. Evapotranspiration over the period of 60 years (1959-2018) for KLB, SRB and KYB;
iv. Extreme rainfall indices (Rx5day, R10mm, CWD and CDD) over the periods of 60 years (1959-2018) for KLB, SRB and KYB;
v. Baseline population of KLB, SRB and KYB in year 2006;
vi. Projected temperature over the period of 3 time slices (2019-2048), (2049-2078), (2079-2100) for KLB, SRB and KYB;
vii. Projected rainfall over the period of 3 time slices (2019-2048), (2049-2078), (2079-2100) for KLB, SRB and KYB;
viii. Projected extreme rainfall indices (Rx5day, R10mm, CWD and CDD) over the period of 3 time slices (2019-2048), (2049-2078), (2079-2100) for KLB, SRB and KYB;
ix. Projected population over the period of 3 time slices (2019-2048), (2049-2078), (2079-2100) for KLB, SRB and KYB.

3.1.2: Sources of data used

The daily evapotranspiration, temperature and precipitation data used were from the archive of the Royal Netherlands Meteorological Institute Known as KNMI Climate Explorer (https://climexp.knmi.nl). Many climate change studies have been undertaken using data from this source (Nurmohamed and Donk 2017; Jacquelyn *et al.,* 2018 and Mitchell *et al.,* 2019). In addition, the data also include extreme rainfall indices. It comprises of observed and simulated evapotranspiration, temperature, rainfall and extreme rainfall indices data. The observed data are that of Climate Research Unit (CRU TS 4.2) and the simulated data are that of CMIP5 both found in the KNMI database. The respective coordinates of each basin was used to derive the observed and simulated evapotranspiration, temperature and rainfall time series (Table 3.1). However, the population data were derived from Nigeria 2006 population census.

Table 3.1: Location and size of the study area

Ecological Zones	**River Basin**	**Latitude (^{o}N)**	**Longitude (^{o}E)**	**Area (KM^2)**	**Elevation (m a.s.l.)**
Guinea savanna	Kainji Lake Basin (KLB)	9^o 51' - 10^o 11'	4^o 34' - 4^o 36'	1,300	142
Sudan savanna	Sokoto-Rima Basin (SRB)	10^o 12' - 12^o 25'	3^o 44' - 8^o 14'	135,000	300
Sahel savanna	Komadugu-Yobe Basin (KYB)	12^o 88' - 13^o 31'	7^o 90' 11^o 56'	84,138	294

Source: (Abdullah *et al*, 2014; Abdussalam, 2017; Babagana, 2017)

3.2: Models in Climate Change Projections

Global climate models (GCMs) were used to project anticipated changes in climate based on greenhouse gas emission scenarios. The IPCC Fifth Assessment Report provides four of these plausible greenhouse gas emissions scenarios. The scenarios considered in this study were low, medium and highest concentration of greenhouse gases known as (RCP2.6, RCP4.5 and RCP8.5) adopted in line with the recent historical trajectory of greenhouse gas concentrations, as well as because these scenarios can be expected to provide both wettest and driest projections. Overall, the outputs from the multi-model ensemble mean of the whole GCMs that participated in CMIP5 were used for this study (Appendix A). This is because individual climate models simulation could either underestimate or overestimate the nature of climate in an area. Often, the use of multi-model mean is advocated so as to avoid the likely bias that may ensue (Liu *et al.*, 2017 and Hamid *et al.*, 2019).

3.3: Methods of Data Analyses

To assess the relative performance of the simulation data against observation data, the root mean square error (RMSE), mean absolute error (MAE) and Nash-Sutcliffe coefficient of efficiency (NSE) were computed (Chaiand Draxler 2014; Shrestha and Htut, 2016; Khan *et al.*,2018 and Amid *et al.*, 2019).

They are derived as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{n}} \qquad 3.1$$

$$MAE = \frac{\sum_{i=1}^{n}|(SIM_i - OBS_i)|}{n} \qquad 3.2$$

$$NSE = 1- \frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{\sum_{i=1}^{n}(OBS_i - \overline{OBS_i})^2} \qquad 3.3$$

Where

SIM and OBS refer to 'simulated or predicted data'

n is the total number of pairs of simulated and observed data,

i is the ith value of the simulated and observed data and

$\overline{OBS}$ is the mean value of the observed data.

RMSE evaluates the average error magnitude between simulated and observed data. MAE measures the average magnitude of errors in a set of predictions but less sensitive to extreme values than RMSE. NSE was used to quantify how well the plot of observed versus simulated data fits the 1:1 line. For a perfect model, NSE is 1.

3.3.1: Sensitivity of the study area to climate change

The sensitivity of each basin based on changes in rainfall mm/day and temperature in degree Celsius were then studied and compared. Annual and seasonal changes of the dry season (November, December, January, February, March and April) denotes as NDJFMA, and wet season (May, June, July, August, September and October) denotes as MJJASO were computed and compared for each of the three IPCC scenarios (RCP 2.6, 4.5 and 8.5). The projections were divided into three climatic periods namely: near term (2019-2048), mid-term (2049-2078), and long term (2079-2100) with reference to (1959-1988) and (1989-2018) baseline periods. Thereafter, percentage impact (PI) was computed for temperature given as (PI_1) and rainfall (PI_2) (Zobel *et al.*, 2018). The PI_1 is computed from the equation:

$$PI_1 = \left(\frac{t_n}{t_0}\right) 100 \qquad 3.4$$

Where PI_1 = percentage impact for temperature

t_n = temperature under a given scenario

t_0 = temperature of the reference period

100 =percentage

PI_2 is computed from the equation:

$$PI_2 = \left(\frac{p_n}{p_o}\right) 100 \qquad 3.5$$

Where PI_2 = percentage impact for rainfall

p_n = precipitation under a given scenario

p_o = precipitation from the referenced period

100 = percentage

To achieve part of objective one, Mann-Kendall test was applied to detect the monotonic trends in projected temperature and rainfall time series. The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series (Abdussalam 2015; Scherrer *et al.*, 2016; Zobel *et al.*, 2018).This is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \text{sign}\left(x_j - x_k\right) \qquad 3.6$$

$$VAR(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad 3.7$$

Where:

n = the number of data points

t_i = the number of ties for the i value and

m = the number of tied values (a tied group is a set of sample data having the same value)

$$Z_s = \begin{Bmatrix} \frac{S-1}{\sqrt{VAR(S)}} \; if S > 0 \\ 0 \qquad if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \; if S < 0 \end{Bmatrix} \qquad 3.8$$

A positive value of Z_s indicates increasing trends while negative Z_s value reflects decreasing trends, while 0 values indicate no trends. Testing trends was done at specific α significant level. When $|Z_s| > Z_{1}\text{-}^{\alpha}/_{2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1}\text{-}^{\alpha}/_{2}$ is obtained from the standard normal distribution table. In this study, significance levels of α=0.05 was used. Oguntunde *et al.*, 2012and Daramola *et al.*, 2017 confirm that at the 5% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 1.96$ and conclude that there is significant trend in the time series.

Regional Mann-Kendall (RMK) Test

In order to assess trends at a regional scale, the regional MK test was employed as used by (Karl, and Anders, 2010; Erum and Ishitaq 2018), to quantitatively combine results of the MK test for individual locations and to evaluate the regional trends. In the regional MK test, the S_r of regional data is calculated as:

$$S_r = \sum_{i=1}^{n} S_i \qquad 3.9$$

Where

S_r is Kendall's S for the "ith" location in a region with m locations within the region. If S_r is estimated using independent identical distributed data, S_r is approximately normally distributed for large m with mean equal to 0 and the variance as noted below.

$$Var(S_r) = \sum_{i=1}^{n} Var = \sigma^2 \qquad 3.10$$

$$Z_r = \begin{cases} \frac{S_r - 1}{\sigma} for S_r > 0 \\ 0 \qquad for S_r = 0 \\ \frac{S_r + 1}{\sigma} for S_r < 0 \end{cases} \qquad 3.11$$

To determine whether to reject or not the null hypothesis of no trend, the test statistics Z_r is assessed against the critical value Zcrit corresponding to the specific significance level α of the test. For the two-tailed test, the critical value is defined as $\Phi^{-1}(1 - \alpha/2)$, where Φ is cumulative distribution function of standard normal distribution (Helsel and Hirsch 2002; cited in Erum and Ishitaq 2018). The null hypothesis is rejected and the trend is considered significant statistically if the value of $|Z_r| \geq$ Zcrit.

3.2.2: Determination of the potential impact of climate change on water resources availability in the study area.

Firstly, water yield (annual differences between rainfall and potential evapotranspiration) was generated using a web based application known as KNMI climate explorer. The coordinates of each of the three basins was used to derive the average water yield. The water yield scenario projections were generated for three future periods namely near term (2019-2048), mid-term (2049-2078) and long term (2079-2100) using the multi-model ensemble mean of CMIP5 GCMs under three CO_2 emission trajectories (RCPs 2.6, 4.5 and 8.5) with reference to the 1959-1988 and 1989-2018 baseline condition.

Furthermore, the whole process was done for annual (January-December), dry season (November-April) denoted as NDJFMA, and the wet season (May-October) denoted as MJJASO. Berghuijs and Greve (2015) computed these based on the water balance and the energy balance equations:

$$\frac{\Delta s}{dt} = P - E - Q \qquad 3.12$$

$$R_n = p\lambda E + H + G \qquad 3.13$$

Where S is the water storage, P the precipitation, E = actual evaporation,

Q the catchment runoff, Rn = the net radiation, λ = the latent heat of vaporization, H = the sensible heat flux, G = the ground heat flux.

By dividing equation (12) by equation (13);

The runoff, Q, can be estimated as $(Q = P - E)$. 3.14

Similarly, Decadal percentage departure was calculated

It enables the determination of water yield that are higher than the long-term average which are designated by positive values and water yield lower than the long-term average, designated by negative values. The decadal variability of water yield was obtained by using the deviation of the decadal mean (ten years mean) of the water yield (differences between rainfall and evapotranspiration) from the 2030-2100of the water yield. It is worthy to mention that decade 2030 represent the mean of (2021-2030) while decade 2100 signify the mean of (2091-2100). For each decade, the mean values symbolise the average annual for each ten years. This can be computed as presented in equation 3.15;

$$Dd = \frac{\mu 10 - \mu t}{\mu t} X\ 100 \qquad 3.15$$

Where:

Dd : Decadal departure

$\mu 10$: Decadal mean

μt : Long term mean

3.2.3: Identification of the occurrence of extreme rainfall events under future climatic conditions in the study area.

The Expert Team on Climate Change Detection and Indices (ETCCDI) identified twenty seven (27) indices of temperature and precipitation extremes (Nakaegawa *et al.*, 2014; Abdussalam, 2015; Chanapathi *et al.*, 2018). However, this study used a set of four extreme rainfall indices that are directly related to water resources. The data and computation were done using web application software known as KNMI Climate Explorer developed by Sillmann *et al.* (2013).Projections were produced for three future periods namely near term (2019-2048), mid-term (2049-2078) and long term (2079-2100) using the multi-model ensemble mean of CMIP5 GCMs under RCP2.6, RCP4.5 and RCP8.5 with reference to 1959-1988 and 1989-2018 baselines.

Furthermore, climate change indices regarding occurrence of extreme rainfall trend using equation 3.8 and 3.11 were evaluated in order to determine the future trend at individual and regional locations. The extremes used in the trend analysis $(Rx5day, R10mm, CWD\ and\ CDD)$ Chanapathi *et al.*, 2018 are as follow:

$$Rx5day_j = \max(RR_{ij}) \quad 3.16$$

$$R10mm_j = dayswhenRR_{ij} \geq 10\text{ mm}$$

$$CWD_j = Maximumlengthofwetspell \quad 3.18$$
$$whereRR_{ij} \geq 1\text{mm}$$

$$CDD_j = Maximumlengthofdryspell \quad 3.19$$
$$whereRR_{ij} < 1\text{mm}$$

Where,

$Rx5day$ is the annual maximum consecutive 5-day rainfall,

$R10mm$is the annual count of days when rainfall is more than 10 mm,

CWD is the maximum length of wet spell where daily rainfall is more than 1 mm,

CDD is the maximum length of dry spell where daily rainfall is less than 1 mm

RR_{ij} is the daily rainfall on day i in period j,

$RR5_{ij}$ is the consecutive 5 day rainfall on day i in period j

In addition, decadal percentage departure was calculated for each of the four rainfall indices namely: $Rx5day$, $R10mm$, CWD and CDD using equation 3.15

3.2.4: Estimation of water stress resulting from the impact of climate change and population growth in the study area.

Water stress analysis was carried out in three steps. Firstly, water yield (annual differences between rainfall and potential evapotranspiration) was generated using a web based application known as KNMI climate explorer. The coordinates of each of the three basins was used to derive the average water yield. The water yield scenario projections were generated for three future periods namely near term (2019-2048), mid-term (2049-2078) and long term (2079-2100) using the multi-model ensemble mean of CMIP5 GCMs under three CO_2 emission trajectories (RCPs 2.6, 4.5 and 8.5) with reference to the 1959-1988 baseline condition. In the second step, population of each of the basin was projected for three future periods namely near-term (2019-2048), mid-term (2049-2078) and long-term (2079-2100) using the Nigeria average population growth rate of 2.6% as declared in 2006 population census.

In the third step, the information generated from step one and two above were used to analyse the per capita water in each of the three basins based on the most commonly used indicator of water stress known as the Falkenmark indicator' or 'water stress index' (table 3.5) (Vorosmarty *et al.*, 2005; Schewe *et al.*, 2013; Wada *et al.*, 2014; and Simon and Richard 2017). This method defines water scarcity in terms of the total water resources that are available to the population of an area; measuring scarcity as the amount of renewable freshwater that is available for each person each year. This was done in three ways namely: water stress condition under climate change at constant population, water stress condition under population growth at constant climate, and water stress condition under the combined influence of climate change and population growth. This is computed as:

$$WSI = \frac{AWY \times TLA}{TP} \tag{3.20}$$

Where WSI: Water Stress Index

AWY: Annual water yield

TLA: Total land area

TP: Total population

However, population projection can be computed as follows:

$$P_T = P_O e^{k\Delta t} \tag{3.21}$$

Where:

P_T: Population at time T

P_O: Population at time zero or initial population

k : Growth rate

Δt: Elapsed time in years from time zero

In addition, decadal percentage departure was calculated for per capita water under:

- Climate change at constant population,
- Population growth at constant climate and
- Combined impacts of climate change and population growth
- each of the four rainfall indices namely:

These were computed using equation 3.15

Table 3.5: Classification of Water Stress Level

WSI (CM/capita/year)	Stress Level

> 1,700	No Stress
1,000 - 1,700	Stress
500 - 1,000	Scarcity
< 500	Absolute Scarcity

Source: Falkenmark (1989) cited in Stella *et al*, (2019)

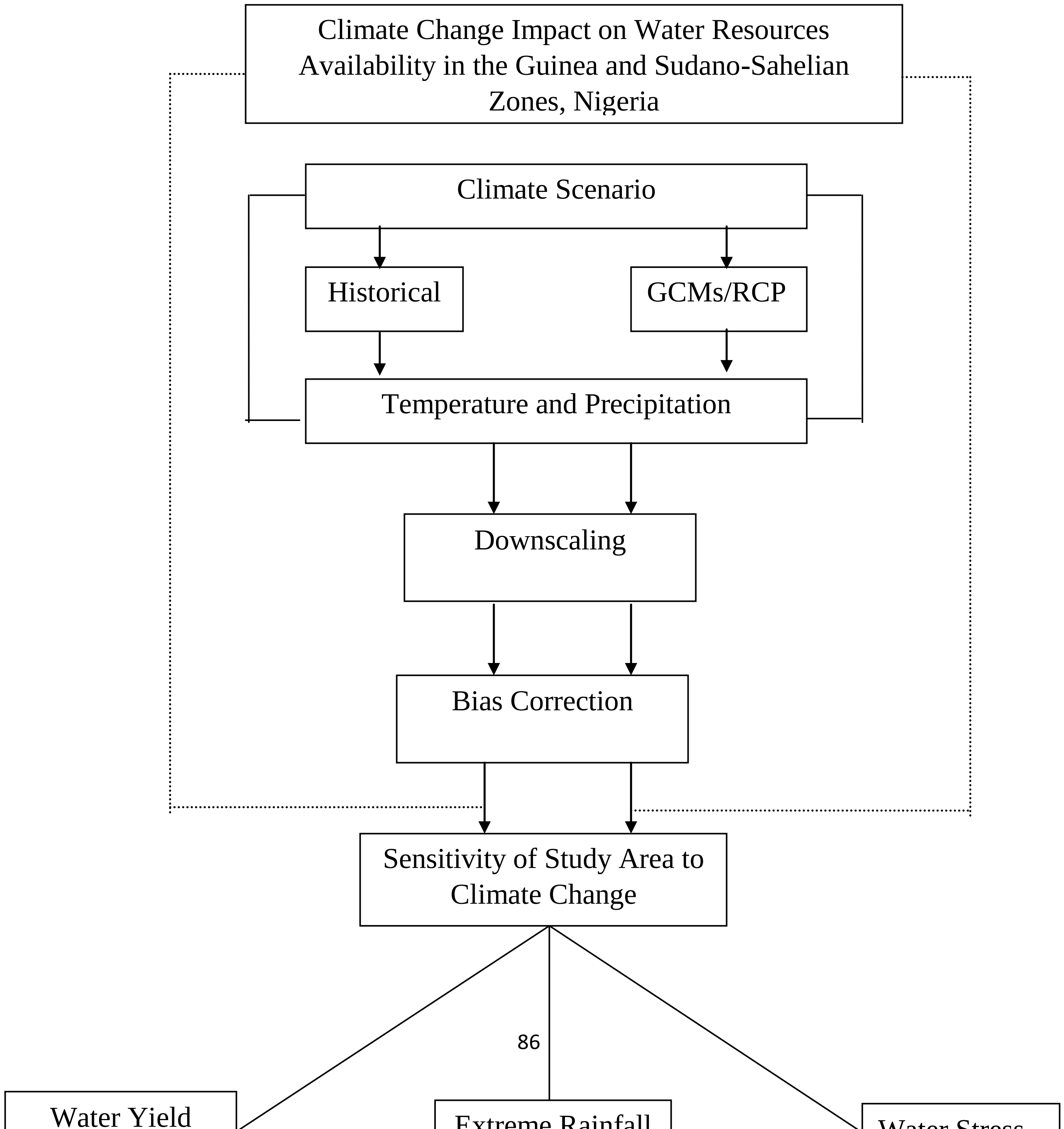


Figure 3.1: Flow Chart of the Methodology

Source: Author's computation, (2018)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents and discusses results for the objectives/research questions based on the various methods of data analysis as discussed in methodology section in chapter three.

4.1: Sensitivity of the Guinea and Sudano-Sahelian Ecological Zones of Nigeria to Climate Change

4.1.1: Evaluation of models performance for temperature and rainfall

The veracity of the CMIP5 multi-model ensemble mean simulation compared with observed rainfall and temperature in the Guinea and Sudano-Sahelian ecological zones of Nigeria was evaluated using statistical matrices. The matrices are root mean square error (RMSE), Mean Absolute Error (MAE) and Nash-Sutcliffe Efficiency (NSE) (Table 4.1). These statistical tests have been frequently used to quantify the significant differences between the observed and simulated hydro-meteorological time series (Chai *et al.*, 2014; Vette r*et al.,* 2016).

The results indicate that Sokoto – Rima Basin (SRB) has the highest error between the simulated and observed dry season temperatures given as RMSE (1.55) and MAE (1.45) while Kainji Lake Basin (KLB) has the least error given as RMSE (1.14) and MAE (1.05). As for NSE, KLB has the highest value (0.94) followed by Komadugu – Yobe Basin (KYB) (0.89) and then SRB (0.86). This implies that the CMIP5 multi-model ensemble mean is better able to reproduce the dry season temperature in KLB than in the KYB and SRB. Wet season temperature in KYB has the highest error between the simulated and observed given as RMSE (0.65) and MAE (0.55) while SRB has the least error given as RMSE (0.57) and MAE (0.55). As for NSE, all the three basins have the same value given as (0.98).

Table 4.1: Evaluation matrices between observed and simulated temperature and rainfall

	KAINJI-LAKE BASIN (KLB)			**SOKOTO-RIMA BASIN (SRB)**			**KOMADUGU-YOBE BASIN (KYB)**		
TEMPERATURE	RMSE	MAE	NSE	RMSE	MAE	NSE	RMSE	MAE	NSE
Seasonal Dry	1.14	1.05	0.94	1.55	1.45	0.86	1.14	1.10	0.89
Seasonal Wet	0.60	0.55	0.98	0.57	0.55	0.98	0.65	0.55	0.98
Annual	0.86	0.70	0.97	0.72	0.60	0.98	0.72	0.60	0.98
RAINFALL									
Seasonal Dry	0.32	0.30	0.99	0.17	0.16	0.99	0.13	0.12	1
Seasonal Wet	1.29	1.05	0.94	0.78	0.60	0.98	0.96	0.95	0.96
Annual	0.49	0.35	0.99	0.50	0.40	0.98	0.50	0.50	0.98

This implies that the CMIP5 multi-model ensemble mean reproduce the same wet season temperature across the three basins. There is also variation in the ability of the

CMIP5 multi-model ensemble mean to reproduce the annual tempearture across the three basins. KLB has the highest error between the simulated and observed annual temperature given as RMSE (0.86)and MAE (0.70) while KYB and SRB have the same least error given as RMSE (0.72) and MAE (0.60). NSE, KYB and SRB have the same value (0.98) and the least is KLB (0.97). This entails that the CMIP5 multi-model ensemble mean is better able to reproduce the annual temperature in KYB and SRB compared to KLB.

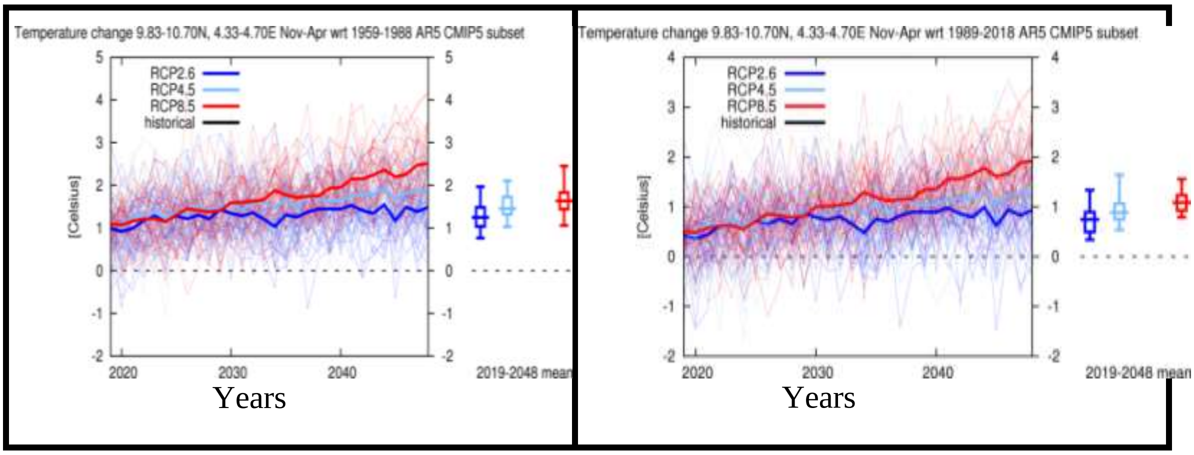
Dry season rainfall in KLB has the highest error between the simulated and observed given as RMSE (0.32) and MAE (0.30) while KYB has the least error given as RMSE (0.13) and MAE (0.12). As for NSE, KYB has the highest value (1.0) denoting perfect replication of dry season rainfall in the basin. KLB and SRB have the least NSE value (0.99). This confirms that the CMIP5 multi-model ensemble mean is better able to reproduce the dry season rainfall in KYB than in KLB and SRB. Furthermore, wet season rainfall across these basins reveal that KLB has the highest error between the simulated and observed given as RMSE (1.29) and MAE (1.05) while SRB has the least error given as RMSE (0.78) and MAE (0.60). As for NSE, SRB has the highest value (0.98) followed by KYB (0.96). This implies that the CMIP5 multi-model ensemble mean is better able to reproduce the wet season rainfall in SRB than in the KYB and KLB. Moreso, there is variation in the ability of the CMIP5 multi-model ensemble mean to reproduce the annual rainfall across the three basins. SRB and KYB have the highest error between the simulated and observed as obtainable fromRMSE (0.50) and MAE (0.40) while KLB has the least error given as RMSE (0.49) and MAE (0.35). This means that the CMIP5 multi-model ensemble mean is better able to replicate the annual rainfall in KLB than in KYB and SRB.

On a general note, despite the variations in the ability of the CMIP5 multi-model ensemble mean to reproduce dry and wet season temperatures and rainfall across the three basins, the errors between the observed and simulated are within the acceptable threshold. The error margins for temperature (0.57 - 1.55) and rainfall (0.13 - 1.29) are in tandem with (1.78 - 2.10) reported by Vera and Diaz (2015) for South America and also consistent with those found in most regions of the world (Kumar *et al.*, 2013). NSE of (0.8) threshold is in the range of 'very good values' as recommended by Moriasi *et al.* (2007) cited in (Miguel *et al.*, 2018) for general performance ratings. Thus, we can conclude that these CMIP5 multi-model mean is good at simulating the rainfall and temperature in the Guinea and the Sudano-Sahelian ecological zones of Nigeria.

4.1.2: Projected changes in dry season temperature

The projected changes in dry season temperature comprising the months of November to April **(**NDJFMA**)** over KLB, SRB and KYB are shown in Figures (4.1, 4.2 and 4.3) respectively.

1959 – 1988 Baseline **1989 – 2018 Baseline**



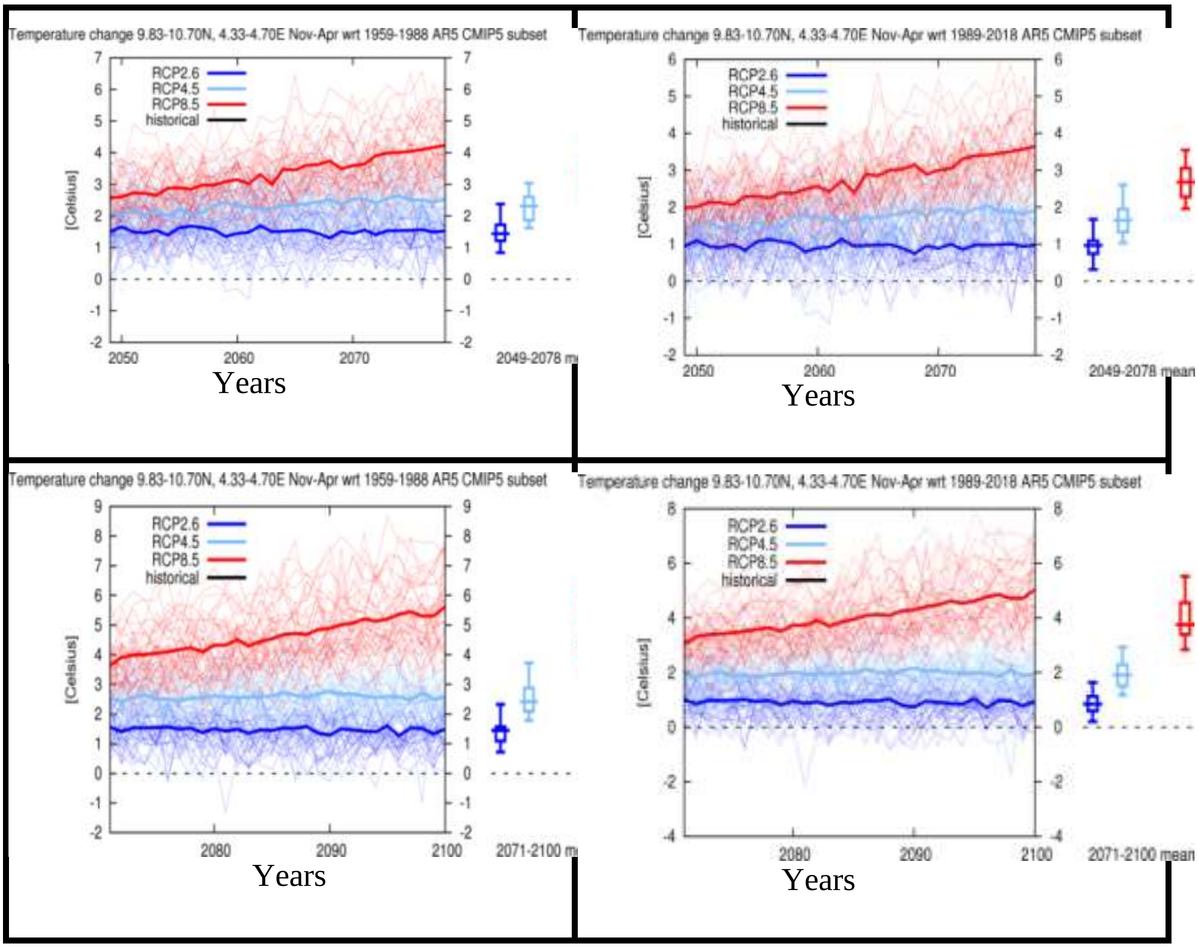
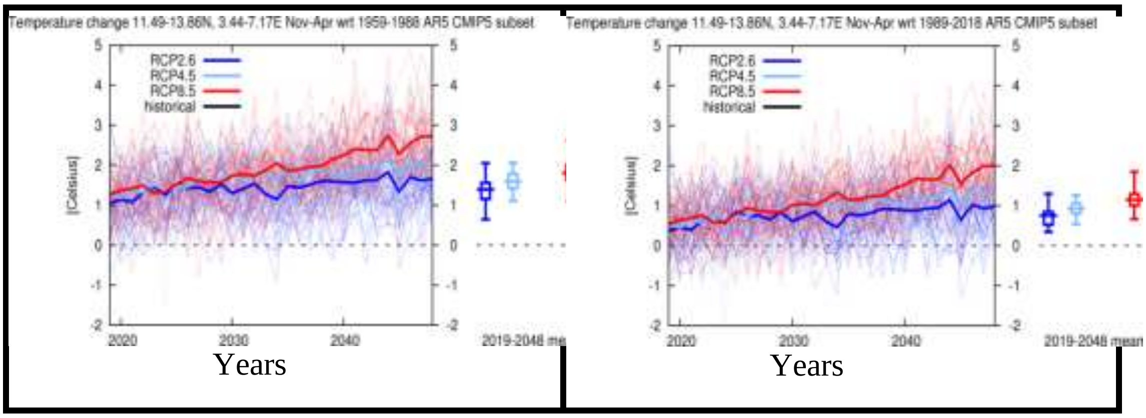


Figure 4.1: Projected changes in dry season temperature over KLB

1959 – 1988 Baseline **1989 – 2018 Baseline**



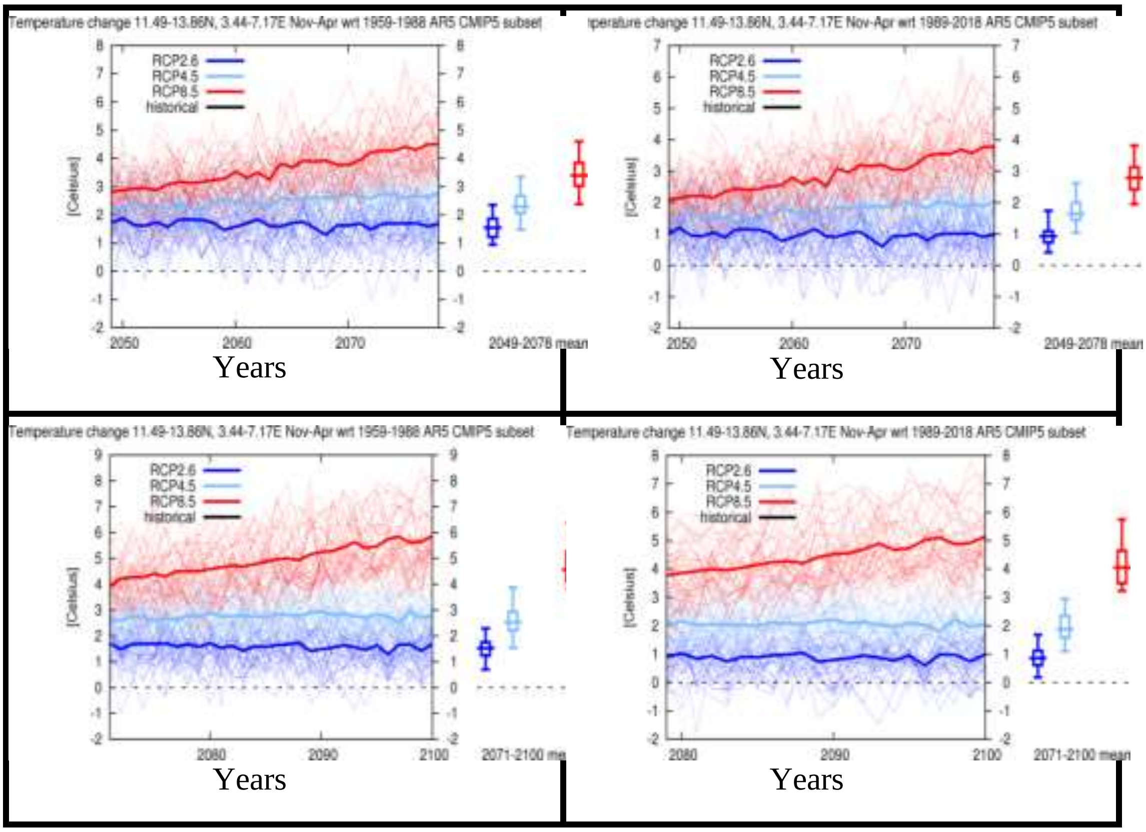


Figure 4.2: Projected changes in dry season temperature over SRB

The first column is the projection for the first baseline period (1959-1988) while the second column is the projection for the second baseline period (1989-2018). The first, second and third rows are for near-term (2019-2048), mid-term (2049-2078), and long-terms (2079-2100) projection periods respectively. It is observed that dry season temperature will increase from the near-term through mid-term to the long-term projected periods with reference to the first and second baselines of (1959-1988) and (1989-2018) respectively in the KLB, SRB and KYB. Looking at the differences between first climatic period (2019-2048) and third climatic period (2079-2100) it shows that based on (1959-1988) baseline, dry season temperature in KLB will increase for RCP8.5 from (1^{o}C to 5.8^{o}C), RCP4.5 from (1^{o}C to 2.5^{o}C) and RCP2.6 from (1^{o}C to 1.5^{o}C).The respective values of these for (1989-2018) baseline are RCP8.5 from (0.4^{o}C to 5^{o}C), RCP4.5

1959 – 1988 Baseline **1989 – 2018 Baseline**

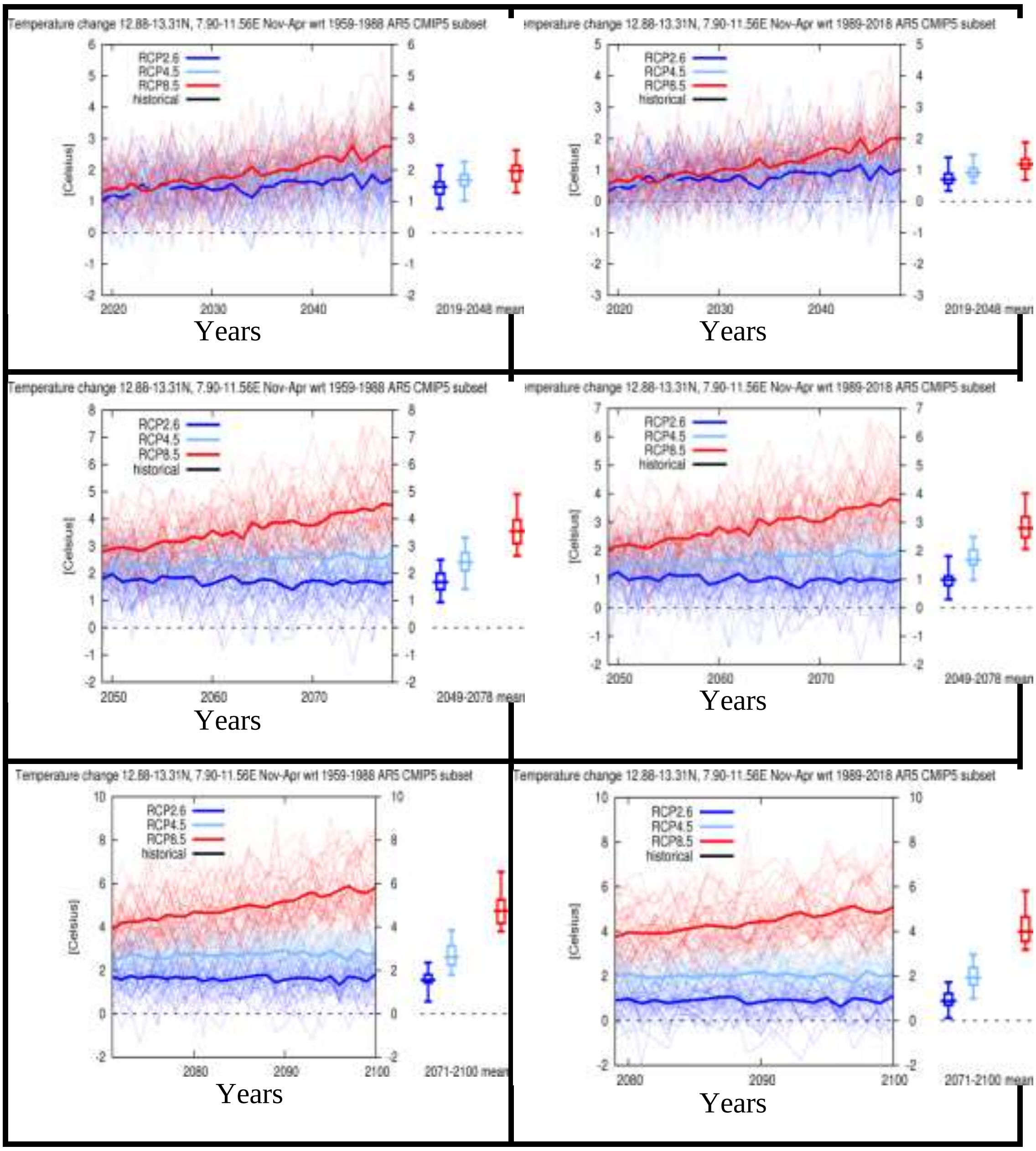


Figure 4.3: Projected changes in dry season temperature over KYB

Table 4.2: Mann–Kendall trend analysis of projected dry, wet and average annual temperature

Climatic Period	Alpha	Dry Season	Wet Season	Annual
		KLB		
	1959 – 1988 baseline average			
2019 – 2048	**0.05**	**2.142***	**2.151***	**2.386***
2049 – 2078	**0.05**	**1.987***	**2.142***	**2.447***
2079 – 2100	**0.05**	**0.955**	**2.136***	**2.278***
	1989 – 2018 baseline average			
2019 – 2048	**0.05**	**2.012***	**2.341***	**2.437***
2049 – 2078	**0.05**	**2.663***	**1.982***	**2.481***
2079 – 2100	**0.05**	**2.481***	**2.142***	**2.033***
		SRB		
	1959 – 1988 baseline average			
2019 – 2048	0.05	2.210*	2.606*	2.447*
2049 – 2078	0.05	1.122	2.210*	1.598
2079 – 2100	0.05	2.444*	2.744*	1.984*
	1989 – 2018 baseline average			
2019 – 2048	0.05	2.108*	2.176*	2.074*
2048 – 2078	0.05	2.176*	2.695*	2.244*
2079 – 2100	0.05	0.952	1.994*	1.986*
		KYB		
	1959 – 1988 baseline average			
2019 – 2048	0.05	1.685	2.012*	1.985*
2049 – 2078	0.05	2.481*	2.603*	2.663*
2079 – 2100	0.05	2.210*	2.356*	2.032*
	1989 – 2018 baseline average			
2019 – 2048	0.05	1.802	1.509	2.563*
2049 – 2078	0.05	2.142*	2.621*	2.190*
2079 – 2100	0.05	2.481*	2.603*	2.438*
		Regional Trend		
2019 – 2048	0.05	2.322*	1.980*	2.439*
2049 – 2078	0.05	2.093*	2.185*	2.261*
2079 – 2100	0.05	2.154*	2.091*	2.384*

**=* *Statistically significant trends at the 0.05 significance level.*

from (0.5^{o}C to 2^{o}C) and RCP2.6 remain as (0.5^{o}C). As for the SRB it reveals that based on (1959-1988) baseline, dry season temperature will increase for RCP8.5 from (1.2^{o}C to 5.9^{o}C), RCP4.5 from (1^{o}C to 2.9^{o}C) and RCP2.6 from (1^{o}C to 1.8^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 from (0.4^{o}C to 5.1^{o}C), RCP4.5 from (0.4^{o}C to 2^{o}C) and RCP2.6 from (0.4^{o}C to 1^{o}C). Similarly, those for KYB show that based on (1959-1988) baseline, dry season temperature will increase for RCP8.5

from (1.2^{o}C to 5.9^{o}C), RCP4.5 from (1.2^{o}C to 2.8^{o}C) and RCP2.6 from (1.2^{o}C to 1.9^{o}C) in the KYB. The respective values of these for (1989-2018) baseline are RCP8.5 from (0.5^{o}C to 5^{o}C), RCP4.5 from (0.5^{o}C to 2^{o}C) and RCP2.6 from (0.5^{o}C to 1^{o}C). These findings are in agreement with the work of Adefisan (2018) who observed that throughout the entire West Arica, there is a general temperature increase. That at the scenario A1B, the minimum temperature over Southern part of West Africa located at 10°N has (18°C) in the present (2000-2029) but will increase to (22°C) in the future (2070-2099). That the respective values of these for A2 are (18°C to 30°C) while those of B1 are (24°C to 26°C).

Trend analysis of dry season temperature reveals that in KLB, there is a significant positive trend under the three climatic periods with reference to the two baselines. The only exception is third climatic period with reference to the first baseline where it is observed that though there is a positive trend, it is not significant at 0.05 significance levels (Table 4.2). In SRB and KYB, similar observations are made regarding the trend (Table 4.2). It is pertinent to mention that all the climatic periods with reference to the two baselines across the KLB, SRB and KYB do or did not record any negative trend (Table 4.2).Furthermore, regional trend analysis of the three basins tested at the 0.05 degree of alpha confirm significant positive trends for (2019-2048), (2049-2078), and (2079-2100) with respect to highest emission trajectories. These are indications that obviously the Guinea and the Sudano-Sahelian ecological zones of Nigeria will witness continuous warming till the end of the 21st century.

4.1.3: Projected changes in wet season temperature

Distribution of wet season temperature comprising the months of May to October (MJJASO) over KLB, SRB and KYB are shown in Figure (4.4, 4.5 and 4.6) respectively. The first, second and third rows are respectively for (2019-2048), (2049-

2078), and (2079-2100) projection periods respectively. Looking at the differences between (2019-2048) and (2079-2100) periods based on(1959-1988) baseline, wet season temperature in KLB will increase for RCP8.5 from (0.8^{o}C to 5.1^{o}C), RCP4.5 from (0.8^{o}C to 2.5^{o}C) and RCP2.6 from (0.8^{o}C to 1.2^{o}C).

1959 – 1988 Baseline **1989 – 2018 Baseline**

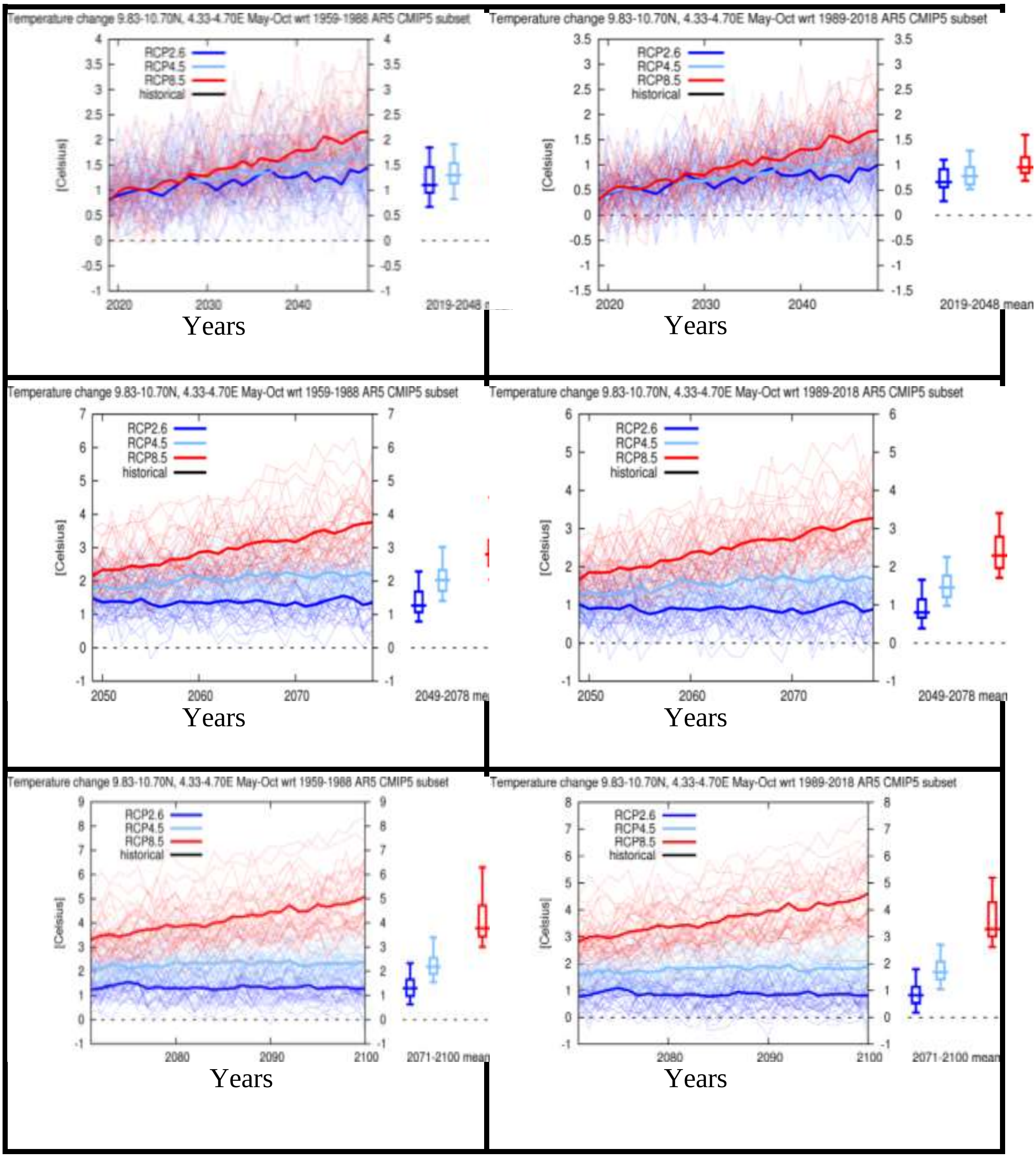


Figure 4.4: Projected changes in wet season temperature over KLB

1959 – 1988 Baseline **1989 – 2018 Baseline**

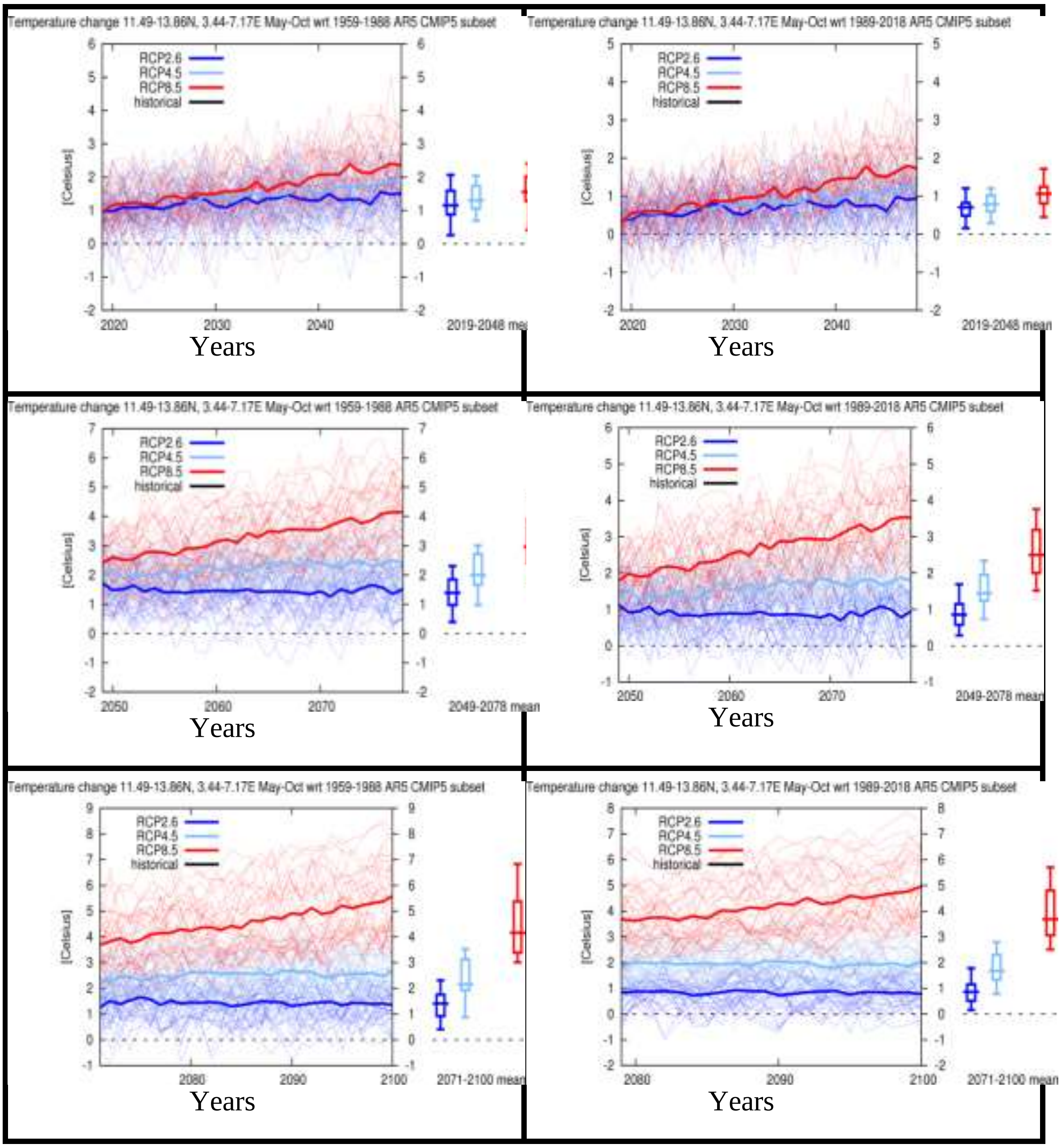


Figure 4.5: Projected changes in wet season temperature over SRB

The respective values of these for (1989-2018) baseline are RCP8.5 from (0.4^{o}C to 4.6^{o}C), RCP4.5 from (0.5^{o}C to 1.9^{o}C) and RCP2.6 from (0.5^{o}C to 0.9^{o}C). As for the SRB it reveals that based on (1959-1988) baseline, wet season temperature will increase for RCP8.5 from (1^{o}C to 5.7^{o}C), RCP4.5 from (1^{o}C to 2.8^{o}C) and RCP2.6 from (1^{o}C to 1.2^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 from (0.2^{o}C to 5^{o}C), RCP4.5 from (0.2^{o}C to 2^{o}C) and

1959 – 1988 Baseline **1989 – 2018 Baseline**

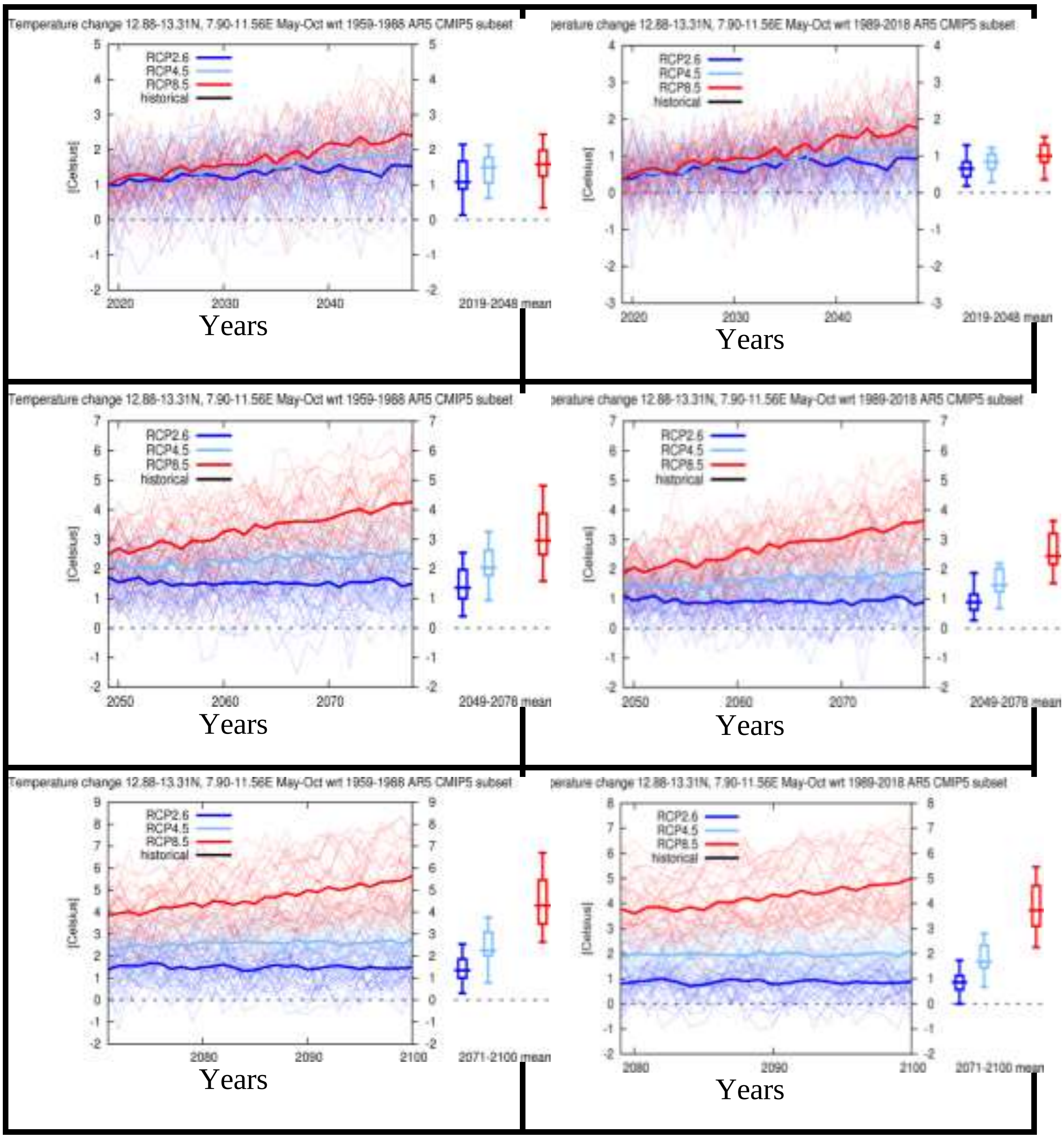


Figure 4.6: Projected changes in wet season temperature over KYB

RCP2.6 from (0.2°C to 1.9°C).Similarly, those for KYB show that based on (1959-1988) baseline, wet season temperature will increase for RCP8.5 from (1°C to 5.8°C), RCP4.5 from (1°C to 2.9°C) and RCP2.6 from (1°C to 1.5°C). The respective values of these for (1989-2018) baseline are RCP8.5 from (0.4°C to 5°C), RCP4.5 from (0.4°C to 2°C) and RCP2.6 from (0.4°C to 1°C). This finding is in tandem with the work of Demircan *et al.* (2017) that between (2016 and 2099) it was expected that there will be an increase of between 1°C and 6°C in the wet season temperature of Turkey. This is also consistent with that observed by Navneet *et al.*(2017) in India where wet season temperature compared to baseline for 2020s will be between 1.4 and 2.0°C, for 2050s it will range between 2.8 and 3.6°C and for 2080s it will be 4.0 and 6.7°C.

Regional trend analysis of wet season temperature entails that in KLB, SRB and KYB there are significant positive trends. However, there is exception in KYB where it is found that in the third climatic period (2071 - 2100) with reference to the second baseline (1989 - 2018) it does not show any significant positive trend at the 0.05 significance levels (Table 4.2). Consequently, it can be deduced that the warming trends observed in the Guinea and Sudano-Sahelian ecological zones of Nigeria through projection periods of (2019-2048), (2049-2078), and (2079-2100) communicate the sensitive nature of these zones to climate change (Table 4.2). More so, it is imperative to mention that despite the increasing trends of the dry and the wet season temperature in the projections, the increase is slightly more in dry than wet season.

4.1.4: Projected changes in average annual temperature

Average annual temperature over KLB is shown in Figure (4.7). It is observed that the average annual temperature will increase from the near projection to the long-term projection period with reference to the first and second baselines of (1959-1988) and (1989-2018) respectively. At the near term projection (2019-2048) it shows that based on (1959-1988) baseline, average annual temperature will increase for RCP8.5 by (2.4^{o}C), RCP4.5 (1.8^{o}C) and RCP2.6 (1.5^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 (1.8^{o}C), RCP4.5 (1.3^{o}C) and RCP2.6 (1^{o}C). As for the mid-term projection (2049-2078) it reveals that based on (1959-1988) baseline, temperature will increase for RCP8.5 by (4^{o}C), RCP4.5 (2.2^{o}C) and RCP2.6 (1.4^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (3.5^{o}C), RCP4.5 (1.9^{o}C) and RCP2.6 (0.9^{o}C). Similarly, those for long-term projection (2079-2100) show that based on (1959-1988) baseline, annual temperature will increase for RCP8.5 by (5.4°C), RCP4.5 (2.5°C)

1959 – 1988 Baseline **1989 – 2018 Baseline**

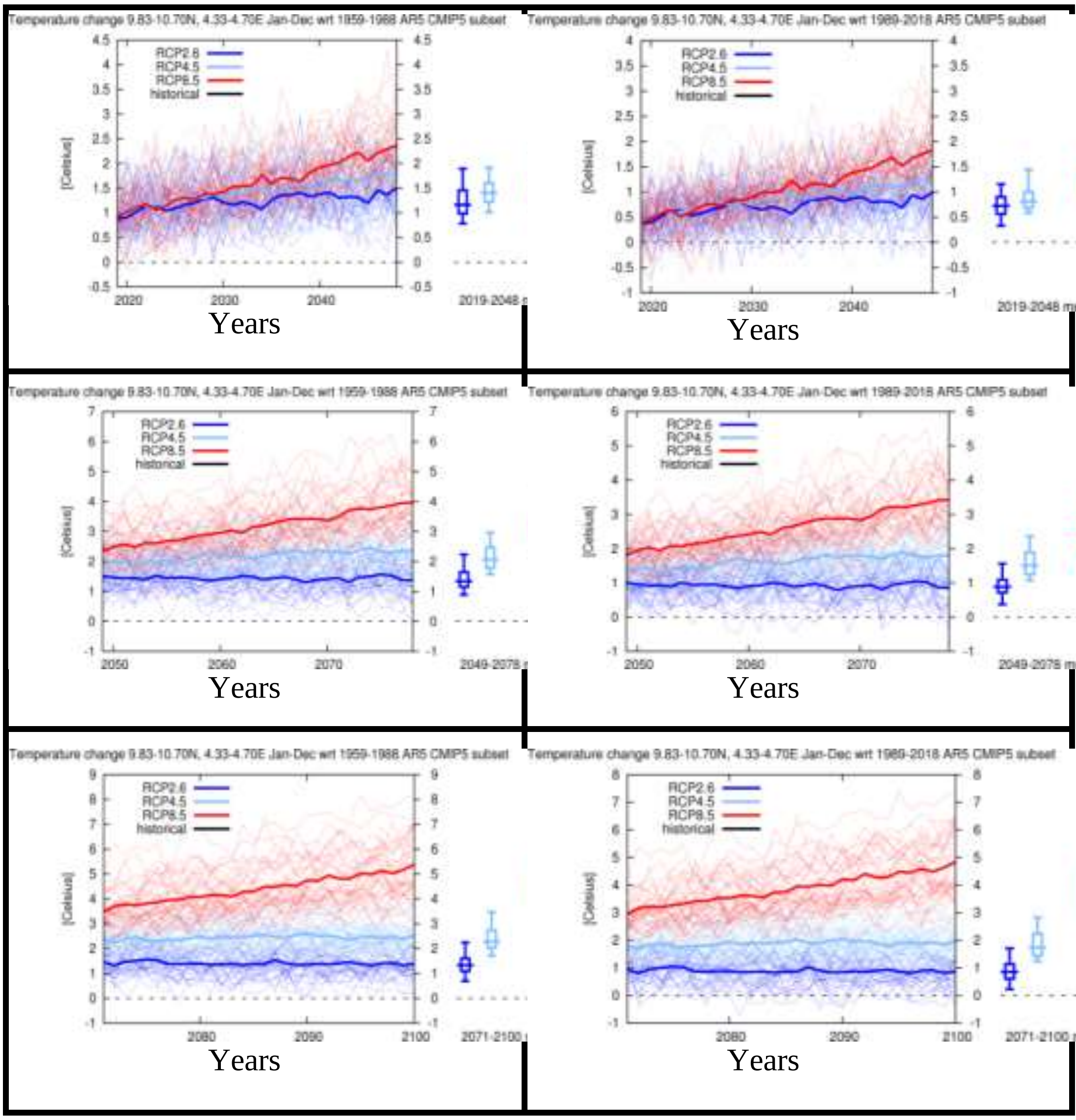


Figure 4.7: Projected changes in average annual temperature over KLB

and RCP2.6 (1.4°C).The respective values of these for (1989-2018) baseline are RCP8.5 by (4.9°C), RCP4.5 (2°C) and RCP2.6 (0.9°C). This shows that climate change during the projected periods of (2019-2048), (2049-2078), and (2079-2100) in the KLB is real. It is obvious there is a general increase in the average annual temperature over this area. This agrees with Pancheewan and Jessada (2016) where for Chao Phraya River basin in

Thailand changes of 4.7°C and 3.7°C, according to A2 and B2 scenarios respectively were observed. The average annual temperature will increase slightly, and this trend will continue further in the future (2090-2099).

In SRB, it is observed that average annual temperature will increase from the near-term to long term projection periods (Figure 4.8). The near-term projection (2019-2048) shows that based on (1959-1988) baseline, annual temperature will increase for RCP8.5 by (2.8°C), RCP4.5 (2°C) and RCP2.6 (1.8°C).

1959 – 1988 Baseline **1989 – 2018 Baseline**

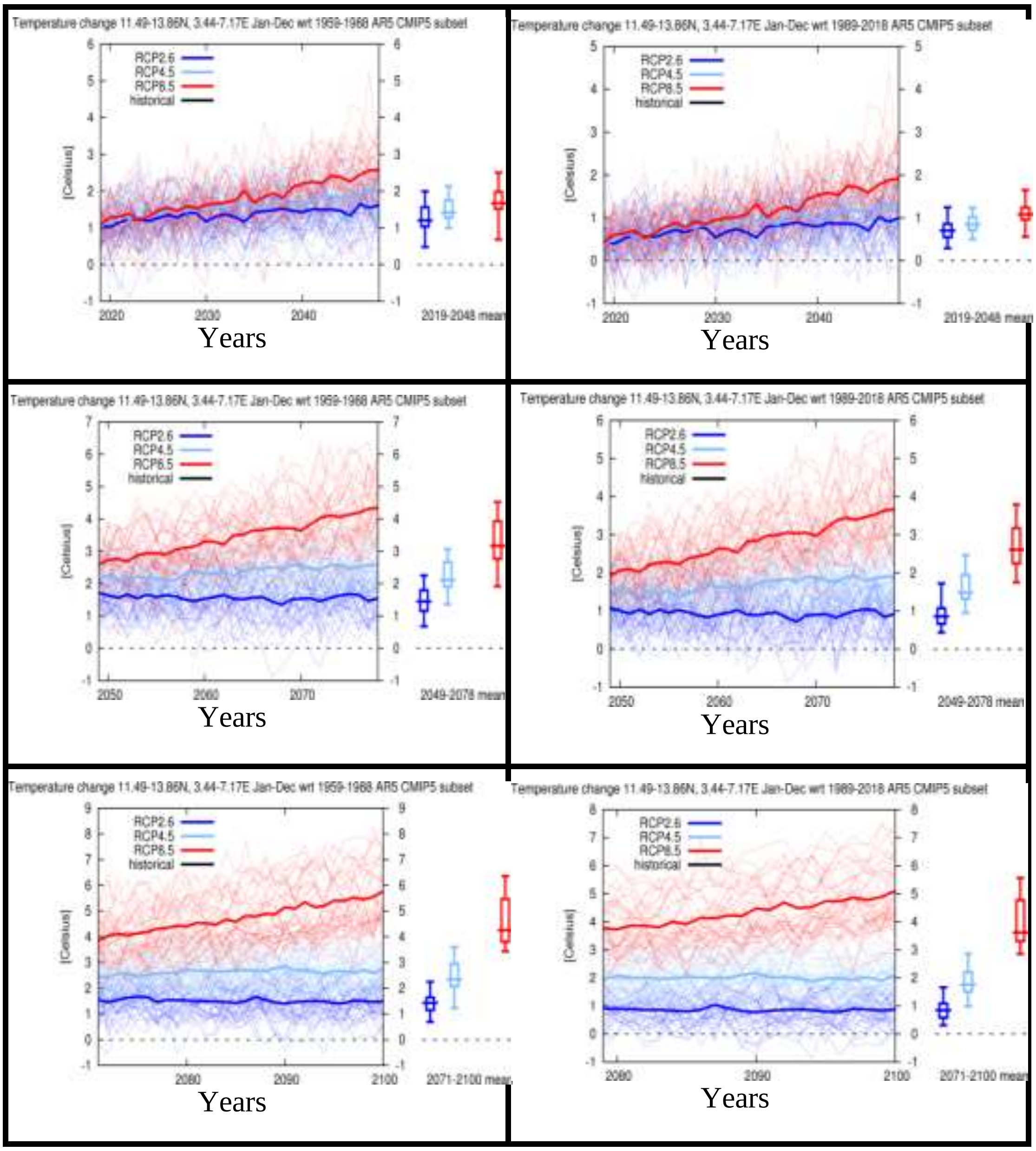


Figure 4.8: Projected changes in average annual temperature over SRB

The respective values of these for (1989-2018) baseline are RCP8.5 by (1.9^{o}C), RCP4.5 (1.2^{o}C) and RCP2.6 (1^{o}C). As for the mid-term (2049-2078) it reveals that based on (1959-1988) baseline, annual temperature will increase for RCP8.5 by (4.2^{o}C), RCP4.5 (2.7^{o}C) and RCP2.6 (1.7^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (3.8^{o}C), RCP4.5 (1.9^{o}C) and RCP2.6 (0.9^{o}C). Likewise, those for long term projection (2079-2100) show that based on (1959-1988) baseline, it will increase for RCP8.5 by (5.8^{o}C), RCP4.5 (2.9^{o}C) and RCP2.6 (1.5^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (5.1^{o}C), RCP4.5 (2^{o}C) and RCP2.6 (0.9^{o}C). This shows that increase in average annual temperature over this area is indicative of climate change.

Figure (4.9) shows the average annual temperature change in KYB. A look at the near-term projection (2019-2048) reveals that based on (1959-1988) baseline, annual temperature will increase for RCP8.5 by (2.7^{o}C), RCP4.5 (2^{o}C) and RCP2.6 (1.8^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (1.9^{o}C), RCP4.5 (1.3^{o}C) and RCP2.6 (1^{o}C). As for the mid-term (2049-2078) it is observed that based on (1959-1988) baseline, it will increase for RCP8.5 by (4.4^{o}C), RCP4.5 (2.7^{o}C) and RCP2.6 (1.7^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (3.8^{o}C), RCP4.5 (2^{o}C) and RCP2.6 (0.9^{o}C). In the same way, those for long-term projection period (2079-2100) confirms that based on (1959-1988) baseline, annual temperature will increase for RCP8.5 by (5.9^{o}C), RCP4.5 (2.9^{o}C) and RCP2.6 (1.8^{o}C). The respective values of these for (1989-2018) baseline are RCP8.5 by (5.1^{o}C), RCP4.5 (2^{o}C) and RCP2.6 (0.9^{o}C).

Moreover, average annual trends of temperature obtained by Mann-Kendall test is given in (Table 4.2). According to the result, the significant increasing trend in average annual temperature series is detected under the three projected periods with respect to the two baselines of (1959 - 1988) and (1989-2018). The significant positive trends are observed in all the three basins namely KLB, SRB and KYB at the 0.05 significance levels (table 4.2). Mihretab *et al.* (2016) reported similar situation in Eastern Africa, including Ethiopia, Somalia, Djibouti, Eritrea, and parts of Kenya, Uganda, Tanzania, and Sudan where statistically the trend of the mean annual temperature increased over the years.

1959 – 1988 Baseline **1989 – 2018 Baseline**

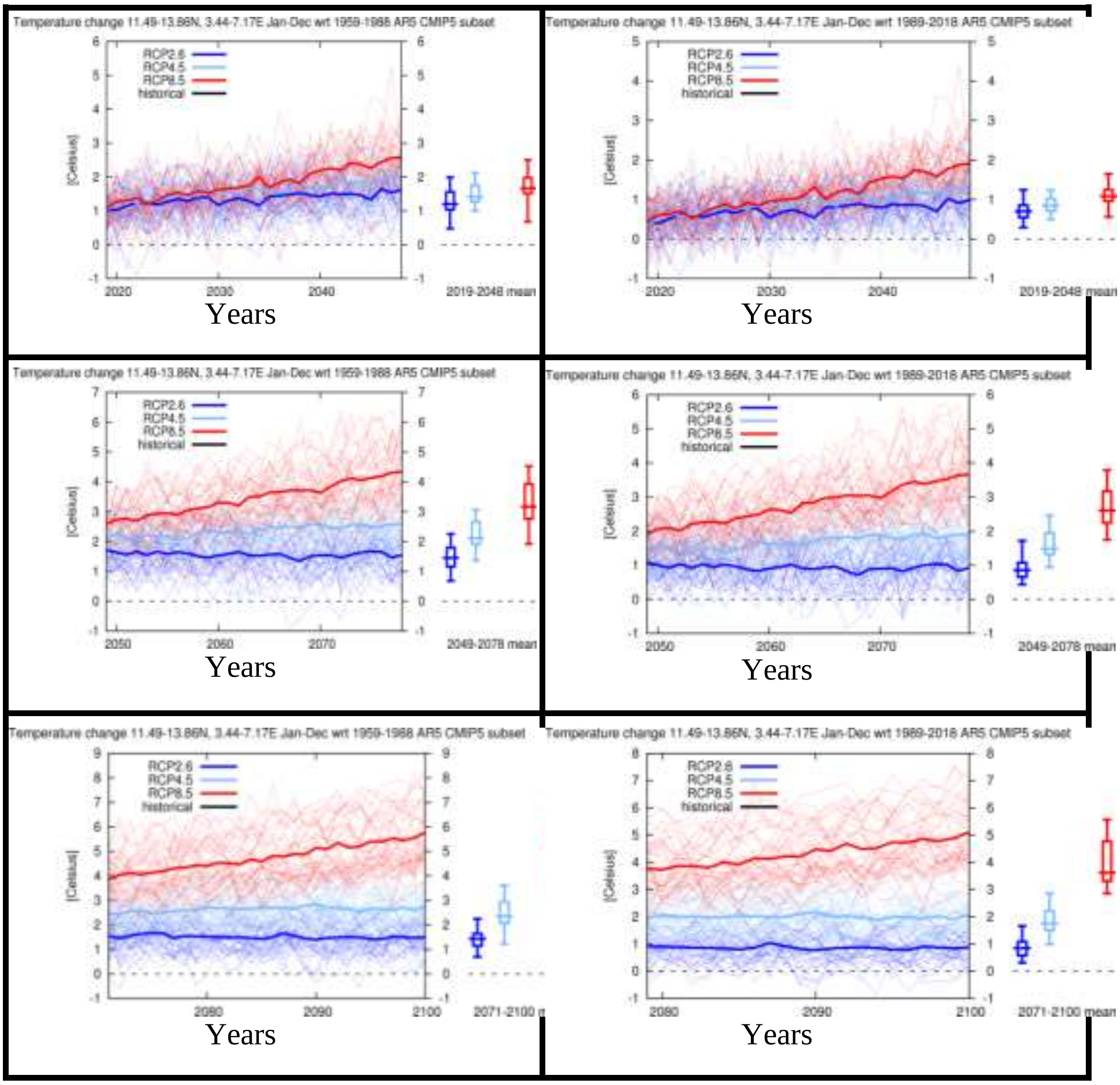


Figure 4.9: Projected changes in average annual temperature over KYB

In addition, the observed regional warming trends of (0.9^{o}C - 6.2^{o}C) from near- term (2019-2048) to the long-term projection period (2071-2100) in the Guinea and Sudano-Sahelian ecological zones had been confirmed by Ojoye *et al.* (2016) that revealed for the base period (1960-2013) there was a significant upward trend in almost all the stations considered, with a very high value (0.83^{o}C) in Maiduguri which reveals that the stations had been warming from 1960 to 2013. The upward warming trend is an indication that the average annual temperature by the end of 21st century will be as high as (50^{o}C - 52^{o}C) for RCP8.5, (45^{o}C - 46^{o}C) for RCP4.5 and between (42^{o}C - 43^{o}C) for RCP2.6. Moss *et al*, (2010) and Vuuren *et al.* (2011) affirmed that RCP8.5 condition is obtainable if there are three times the present CO_2 emissions by 2100, no implementation of climate policies and heavy reliance on fossil fuels. As for RCP4.5 condition, it is obtainable if there is consistent stringent climate policy, CO_2 emissions increases only slightly and strong reforestation programmes. While RCP2.6 condition is obtainable when there is decline use of oil, CO_2 emissions stays at present level until year 2020 and low energy intensity.

4.1.5: Projected changes in dry season rainfall

Dry season rainfall projections comprising months of November to April (NDJFMA) over KLB, SRB and KYB are considered (Table 4.3). Differences between and among the near-term projection (2019-2048), mid-term (2049-2078) and long-term (2079-2100) periods relative to (1959-1988) and (1989-2018) baselines are found in the rainfall amounts (mm/day). Positive changes that signify increase in rainfall amount is mostly observed over the three basins. This means that dry season rainfall amount will increase in the future. As observed in the three terms projections, the increase will be highest for the near-term projection such that RCP8.5 (+0.7mm/day), RCP4.5 (+0.4mm/day) and RCP2.6 (+0.6mm/day) while the mid-term projection will be the least found as RCP8.5 (+0.5mm/day), RCP4.5 (+0.2mm/day) and RCP2.6 (+0.3mm/day).Furthermore, the differences with respect to the two baselines of (1959-1988) and (1989-2018) periods show that the dry season rainfall will be higher with reference to (1989-2018) baseline when compared to (1959-1988) baseline. The (1989-2018) baseline found RCP8.5 (0.7 mm/day), RCP4.5 (0.7 mm/day) and RCP2.6 (0.6 mm/day) compared to RCP8.5 (0.6 mm/day), RCP4.5 (0.5 mm/day) and RCP2.6 (0.1 mm/day) for the (1959-1988) baseline.

Table 4.3: Projected changes in dry season rainfall

Scenario	**RCP2.6**			**RCP4.5**			**RCP8.5**		
Basin	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**
	1959 – 1988 baseline average (mm/day)								
2019-2048	+0.6	+0.5	-0.2	+0.4	+0.4	+0.4	+0.7	+0.5	+0.2
2049-2078	+0.5	+0.6	-0.2	+0.6	+0.5	+0.2	+0.7	+0.6	+0.4
2079-2100	+0.6	+0.1	+0.2	+1.4	+0.5	-0.2	+0.9	+0.7	+0.4
	1989 – 2018 baseline average (mm/day)								
2019-2048	+0.7	+0.4	+0.4	+0.3	+0.3	+0.1	+0.6	+0.5	-0.2
2049-2078	+1.2	+0.6	+0.4	+0.8	+0.7	+0.2	+0.8	+0.5	+0.6
2079-2100	+0.4	+0.5	+0.3	+1.5	+0.7	+0.2	+0.6	+0.6	+0.4

Across the three basins, dry season rainfall will be highest in the KLB given as RCP8.5 (0.8 mm/day), RCP4.5 (1.5 mm/day) and RCP2.6 (1.2 mm/day) followed by SRB given as RCP8.5 (0.7 mm/day), RCP4.5 (0.7 mm/day) and RCP2.6 (0.6 mm/day). The least increase is in KYB given as RCP8.5 (0.6 mm/day), RCP4.5 (0.4 mm/day) and RCP2.6 (0.3 mm/day). Trend analysis of dry season rainfall reveals a contrasting pattern as compared to dry season temperature. The result of the Mann-Kendall trend analysis proves that though positive trend exists in all the three projection periods with reference to first and second baselines in KLB, most are not significant at the 0.05 significance levels. The only significant positive trends are observed in mid-term and long-term projection periods with reference to second baseline (Table 4.4).

Table 4.4: Mann–Kendall trend analysis of projected dry, wet and average annual rainfall

	KLB			
	1959 – 1988 baseline average			
Climatic Period	**Alpha**	**Dry Season**	**Wet Season**	**Annual**
2019 – 2048	**0.05**	**1.142**	**2.510***	**1.360**
2049 – 2078	**0.05**	**1.576**	**2.214***	**2.044***
2079 – 2100	**0.05**	**0.045**	**2.540***	**2.252***
	1989 – 2018 baseline average			
2019 – 2048	**0.05**	**1.012**	**2.312***	**2.437***
2049 – 2078	**0.05**	**2.346***	**1.974***	**2.481***
2079 – 2100	**0.05**	**2.118***	**2.142***	**2.033***
	SRB			
	1959 – 1988 baseline average			
2019 – 2048	0.05	1.210	0.406	0.774
2049 – 2078	0.05	1.122	2.051*	1.872
2079 – 2100	0.05	1.444	1.748	1.403
	1989 – 2018 baseline average			
2019 – 2048	0.05	0.508	1.521	1.034
2048 – 2078	0.05	1.136	2.904*	1.472
2079 – 2100	0.05	0.512	1.970*	1.326
	KYB			
	1959 – 1988 baseline average			
2019 – 2048	0.05	-1.858	2.401*	1.915
2049 – 2078	0.05	-0.481	2.027*	1.936
2079 – 2100	0.05	1.095	2.657*	0.032
	1989 – 2018 baseline average			
2019 – 2048	0.05	-1.026	1.279	0.563
2049 – 2078	0.05	0.142	1.961*	1.199
2079 – 2100	0.05	1.339	2.038*	1.438
	Regional Trend			
2019 – 2048	0.05	0.322	1.067*	0.391
2049 – 2078	0.05	1.093	2.336*	1.217
2079 – 2100	0.05	2.115	2.148*	1.853

**= Statistically significant trends at the 0.05 significance level.*

In SRB, though positive trends are observed with regard to projected periods and baselines, none is significant at 0.05 significant levels. While in KYB, the situation is similar to trends pattern observed in SRB but also recorded the occurrence of negative trends that are even significant at 0.05 significant levels (Table 4.4). In addition, regional Kendal test (Table 4.4) at the 0.05 degree of alpha indicates that there are no significant positive trends in dry season rainfall for the whole of the Guinea and Sudano-Sahalian ecological zones of Nigeria in near-term, mid-term and long-term projections.

4.1.6: Projected changes in wet season rainfall

Wet season rainfall projections comprising months of May to October (MJJASO) over KLB, SRB and KYB are considered (Table 4.5). Just like dry season rainfall over these basins, the wet season rainfall exhibit similar pattern of increasing rainfall up till the end of 21^{st}century. However, the rate of increase in the wet season rainfall is higher than during the dry season period. Not only that, there were increasing number of occurrences of significant positive trends in wet season rainfall as compared with dry season rainfall (Table 4.4). The differences in the range of dry and wet season rainfall for the first climatic period show that for the dry season rainfall is given as (+0.7mm/day),(+0.4mm/day) and (+0.6mm/day) for RCP8.5, RCP4.5 and RCP2.6 respectively. While the respective values for wet season rainfall is found as (+3mm/day), (+2mm/day) and (+1.5mm/day) for RCP8.5, RCP4.5 and RCP2.6 in their respective order.

More so, it is observed that both the dry and wet season rainfall recorded the highest rainfall amount in the second climatic period of (2049-2078). With respect to the baseline, the highest rainfall amount for the dry season occur under the (1959-1988) baseline, while the highest amount of rainfall for the wet season is found under the (1989-2018) baseline period. It is also worthy of note that the increasing pattern of rainfall amount for both dry and wet season follow a sequential order such that the dry and wet season rainfall amount is highest in the KLB and least for the KYB.

Table 4.5 Projected changes in wet season rainfall

Scenario	RCP2.6			RCP4.5			RCP8.5		
Basin	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**
				1959 – 1988 baseline average (mm/day)					
2019-2048	+3	-1.2	-0.8	+2	+0.2	+1.4	+1.5	+0.8	+1.5
2049-2078	+2.8	-0.8	-1	+3	+0.6	+1.2	+2	+1.2	+1.8
2079-2100	+1.2	+0.2	+1.2	+0.5	+0.4	+1	+4	+0.8	+2
				1989 – 2018 baseline average (mm/day)					
2019-2048	+3.8	-1	+2.2	+2.1	+0.5	+2	+1.5	+0.8	+1.5
2049-2078	+1.4	-0.8	+0.8	+2.5	+2	+2	+2.1	+1.2	+1.8
2079-2100	+0.4	-1	+2	+1.2	+0.7	+2.5	+2.7	+1	+1.5

The values for the KLB are found as (0.8mm/day), (0.8mm/day) and (1.2mm/day) for RCP8.5, RCP4.5 and RCP2.6 respectively during the dry season, while (2.1mm/day), (2.5mm/day) and (1.4mm/day) for RCP8.5, RCP4.5 and RCP2.6 respectively for the wet season. The respective values for KYB are found as (0.6mm/day), (0.2mm/day) and (0.4mm/day) for RCP8.5, RCP4.5 and RCP2.6 respectively during dry season, while (1.8mm/day), (2mm/day) and (0.8mm/day) for RCP8.5, RCP4.5 and RCP2.6 respectively throughout the wet season.

4.1.7: Projected changes in average annual rainfall

Average annual rainfall over KLB is shown on (Table 4.6). It is observed that average annual rainfall will increase from the near term projection to the long term projection period with reference to the first and second baselines of (1959-1988) and (1989-2018) respectively.

Table 4.6: Projected changes in average annual rainfall

Scenario	RCP2.6			RCP4.5			RCP8.5		
Basin	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**
			1959 – 1988 baseline average (mm/day)						
2019-2048	+0.6	+0.2	+0.2	+0.5	+0.4	+0.4	+0.8	+0.4	+0.2
2049-2078	+0.7	+0.4	+02	+0.4	+0.2	+0.2	+1.3	+0.7	+0.4
2079-2100	+0.8	+0.6	+0.2	+1.4	+1.2	+1.5	+1	+0.3	+0.4
			1989 – 2018 baseline average (mm/day)						
2019-2048	+1.4	+1	+0.6	+2.2	+1.9	+0.6	+1.2	+0.6	+0.4
2049-2078	+1.2	+0.6	+0.5	+2	+1.7	+0.8	+1.4	+0.8	+0.5
2079-2100	+0.6	+0.4	+0.8	+1.2	+0.2	+0.8	+1.5	+0.9	+0.6

At the near-term projection (2019-2048) it shows that based on (1959-1988) baseline, average annual rainfall will increase for RCP8.5 by (0.8mm/day), RCP4.5 by (0.5mm/day) and RCP2.6 by (0.6mm/day). The respective values of these for (1989-2018) baseline are RCP8.5 by (1.2mm/day), RCP4.5 by (2.2mm/day) and RCP2.6 by (1.4mm/day). As for the mid-term projection (2049-2078) it reveals that based on (1959-1988) baseline, average annual rainfall will increase for RCP8.5 by (1.3mm/day), RCP4.5 by (0.4mm/day) and RCP2.6 by (0.7mm/day) in the KLB. The respective values of these for (1989-2018) baseline are RCP8.5 by (1.4mm/day), RCP4.5 by (2mm/day) and RCP2.6 by (1·2mm/day).Also, those for long term (2079-2100) show that based on (1959-1988) baseline; average annual rainfall will increase for RCP8.5 by

(1mm/day), RCP4.5by (1.4mm/day) and RCP2.6 by (0.8mm/day) in the KLB. The respective values of these for (1989-2018) baseline are RCP8.5 by (1.5mm/day), RCP4.5 by (1.2mm/day) and RCP2.6 by (0.6mm/day). Navneet *et al.*(2017) reported a similar trend in India where rainfall projection in comparison to the baseline period, show a clear increase of 127mm (11.4%) for the 2020s, an increase of 80mm (7.2%) for the 2050s and an increase of 227mm (20.5%) for the 2080s. This shows that changes observed in average annual rainfall during these periods (2019-2048), (2049-2078), and (2071-2100) are indicative of climate change in KLB.

In SRB (Table 4.4), the near-term projection (2019-2048) shows that based on (1959-1988) baseline, average annual rainfall will increase for RCP8.5 by (0.4mm/day), RCP4.5 by (0.4mm/day) and RCP2.6 by (0.2mm/day). The respective values of these for (1989-2018) baseline are RCP8.5 by (0.6mm/day), RCP4.5 by (1.9mm/day) and RCP2.6 by (1mm/day). As for the mid-term period (2049-2078) it reveals that based on (1959-1988) baseline, it will increase for RCP8.5 by (0.7mm/day), RCP4.5 by (0.2mm/day) and RCP2.6 by (0.4mm/day). The respective values of these for (1989-2018) baseline are RCP8.5 by (0.8mm/day), RCP4.5 by (1.7mm/day) and RCP2.6 by (0.6mm/day). Likewise, those for long-term projection (2079-2100) show that based on (1959-1988) baseline, average annual rainfall will increase for RCP8.5 by (0.3mm/day), RCP4.5 by (1.2mm/day) and RCP2.6 by (0.6mm/day) in the SRB. The respective values of these for (1989-2018) baseline are RCP8.5 by (0.9mm/day), RCP4.5 by (0.2mm/day) and RCP2.6 by (0.4mm/day). This shows that climate change during projected periods of (2019-2048), (2049-2078), and (2079-2100) is imminent, as it is found that there is a general increase in average annual rainfall but lower than that which is obtainable in KLB. This has been corroborated with finding of Edvinas*etal.* (2017) that according to

RCP2.6andRCP8.5, average annual precipitationisgoingtoincreaseforthe21st century in Nemuna river basin in Europe.

The average annual rainfall change in KYB is shown in (Table 4.4). Looking at the near-term projection (2019-2048) it shows that based on (1959-1988) baseline, average annual rainfall will increase for RCP8.5 by (0.2mm/day), RCP4.5 from (0.4mm/day) and RCP2.6 from (0.2mm/day). The respective values of these for (1989-2018) baseline are RCP8.5 by (0.4mm/day), RCP4.5 by (0.6mm/day) and RCP2.6 by (0.6mm/day).As for the mid-term (2049-2078) it reveals that based on (1959-1988) baseline, it will increase for RCP8.5 by (0.4mm/day), RCP4.5 by (0.2mm/day) and RCP2.6 by (0.2mm/day) in the KYB. The respective values of these for (1989-2018) baseline are RCP8.5 by (0.5mm/day), RCP4.5 by (0.8mm/day) and RCP2.6 by (0.5mm/day). Finally, those for long term projection (2079-2100) show that based on (1959-1988) baseline; average annual rainfall will increase for RCP8.5 by (0.4mm/day), RCP4.5 by (1.2mm/day) and RCP2.6 by (0.2mm/day). The respective values of these for (1989-2018) baseline are RCP8.5 by (0.6mm/day), RCP4.5 by (0.8mm/day) and RCP2.6 by (0.8mm/day). Despite the increasing pattern of average annual rainfall, most of these increases are not significant at 0.05 significant levels. It is only in KLB that significant increasing trends of rainfall was observed while non-significant but positive trends were recorded in SRB and KYB (Table 4.4). It is imperative to mention that the increasing average annual rainfall amount is higher than dry season rainfall over all the three basins under study but lower than the wet season rainfall.Regional trend analysis of average annual rainfall over the Guinea and Sudano-Sahelian ecological zones of Nigeria reveal that there is no significant positive trends at 0.05 degree of alpha for near, mid and long term projections. This is with respect to highest CO_2 emission pathways.

The projected changes in rainfall and temperature have significant implications on water resources of the Guinea and Sudano-Sahelian ecological zones of Nigeria. For example, significant increasing rainfall expected during the wet season by near, mid and long-term projection could directly impact availability of water resources for domestic, agricultural and industrial uses. Other major changes in the seasonal and spatial distribution of rainfall can have significant economic impacts. Moreover, the projected average temperature rise of (0.9^{o}C - 6.2^{o}C) throughout the study area can adversely impact the availability of surface water resources due to the high rate of evaporation associated with increasing temperature. Not only has that, increasing water consumption has been attributed to rise in temperature especially during the dry season (Emeribe *et al.,* 2016). Varieties of crops currently grown in the Guinea and Sudano-Sahelian ecological zones have specific requirement that cannot tolerate warmer temperatures. Further, increasing temperatures with corresponding decreases rainfall in the dry season can cause droughts and negatively impact the irrigation potentials in SRB and KYB.

4.2: Changes in Water Yield

4.2.1: Projected changes in dry season water yield

The near-term (2019-2048) projection shows that dry season water yield will decrease across the KLB, SRB and KYB with reference to the two baselines of 1959-1988 and 1989-2018 as well as under the RCPs 2.6, 4.5 and 8.5 (Figure 4.10a -c). Condition observed in KLB indicate that water yield will decrease within the range of (-0.02 to -0.2 mm/day) for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018).RCP8.5 accounts for the highest decrease of (-0.2 mm/day) and lowest being RCP2.6 with (-0.02 mm/day) under the 1959-1988 baseline, while a contrasting pattern of increase is observed under 1989-2018 baseline for RCPs 2.6 and 4.5 which ranges from (+0.02 to +0.25 mm/day) but decreases by (-0.08 mm/day) for RCP8.5. Table (4.7) trend analysis of dry season water yield confirms no significant decreasing

1959 – 1988 Baseline **1989 – 2018 Baseline**

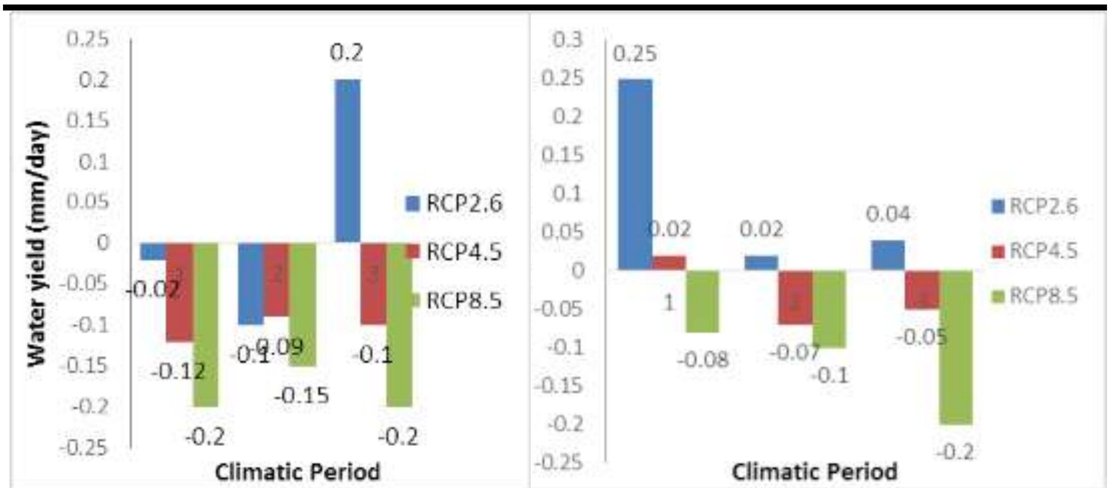


Figure 4.10a: Projected changes in dry season water yield for the KLB

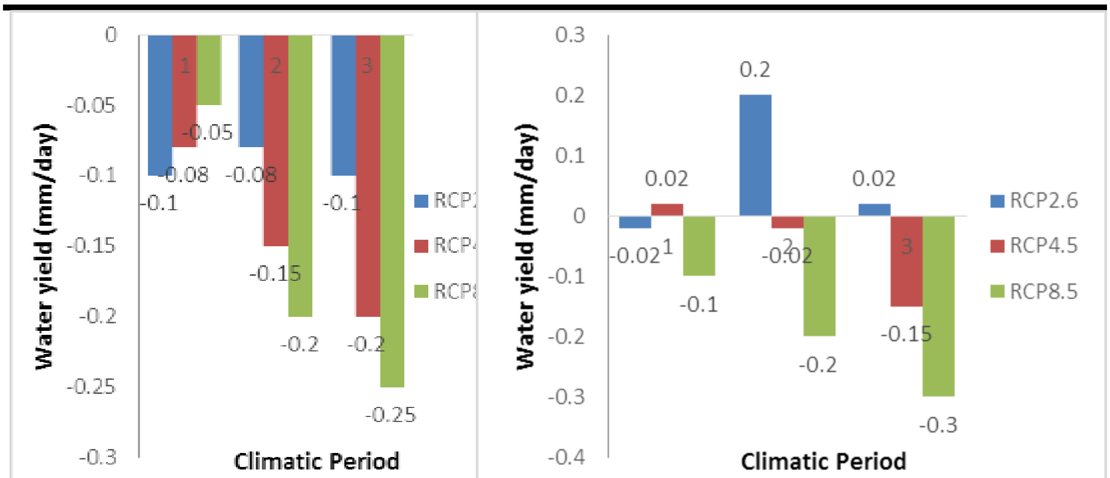


Figure 4.10b: Projected changes in dry season water yield for the SRB

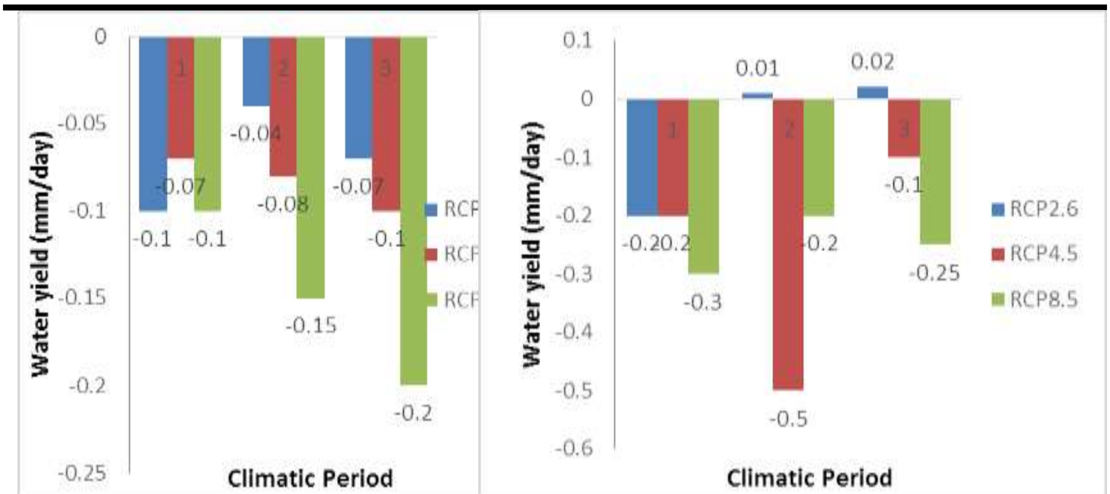


Figure 4.10c: Projected changes in dry season water yield for the KYB

trend at the 0.05 significance levels.However, water yield during dry season over SRB reveals decreasing range of (-0.05 to -0.1 mm/day) with reference to the two baselines of 1959-1988 and 1989-2018 but not significant at the 0.05 significance levels for low and highest emission trajectories (Table 4.7). Similarly, KYB dry season water yield shows a decrease of (-0.07 to -0.3 mm/day) such that RCP4.5 and RCP8.5 responsible for the lowest and highest decreases respectively. Mann Kendal trend analysis at 0.05 significant levels reveal no significant trend for RCPs 2.6 and 4.5 but significant for RCP8.5 (Table 4.7).

Table 4.7: Mann–Kendall trend analysis of projected water yield for KLB, SRB and KYB

Climatic Period	**Water Yield**											
	Dry			**Wet**			**Annual**			**Regional Trend**		
RCP8.5												
	KLB	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**Dry**	**Wet**	**Annual**
2019-2048	**-1.8**	**-1.3**	**-2.8***	**1.6**	**2.4***	**0.4**	**0.2**	**1.7**	**1.1**	**-1.3**	**-2.1**	**1.5**
2049-2078	**-1.4**	**-2.9***	**-1.1**	**2.9***	**2.5***	**2.6***	**0.9**	**1.4**	**0.9**	**-2.1**	**2.7***	**1.54**
2079-2100	**-2.6***	**-2.3***	**-2.8***	**2.6***	**2.8***	**2.7***	**1.4**	**1.9**	**1.9**	**-2.8***	**2.4***	**0.4**
RCP4.5												
	KLB	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**Dry**	**Wet**	**Annual**
2019-2048	**-0.7**	**-1.6**	**-1.4**	**1.3**	**1.5**	**1.4**	**1.8**	**1.4**	**0.3**	**-1.4**	**2.4***	**1.9**
2049-2078	**-1.1**	**-1.3**	**-2.7***	**0.9**	**2.4***	**1.7**	**0.2**	**0.6**	**1.5**	**-0.1**	**1.8**	**0.3**
2079-2100	**-0.8**	**-2.6***	**-1.9**	**2.6***	**2.1***	**1.6**	**0.3**	**1.2**	**1.5**	**-1.8**	**2.3***	**1.38**
RCP2.6												
	KLB	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**KLB**	**SRB**	**KYB**	**Dry**	**Wet**	**Annual**
2019-2048	**-1.1**	**-1.6**	**-0.9**	**0.9**	**1.9***	**2.0***	**1.4**	**1.9**	**1.4**	**-1.7**	**2.4***	**1.2**
2049-2078	**-0.7**	**-0.6**	**-1.5**	**0.7**	**0.8**	**0.6**	**0.9**	**1.4**	**1.4**	**-1.6**	**0.9**	**1.3**
2079-2100	**1.2**	**-0.4**	**-1.4**	**2.4***	**2.7***	**1.6**	**0.3**	**1.4**	**0.9**	**-0.3**	**2.6***	**1.7**

(*) = Statistically significant trends at the 0.05 significance level.

(+) = positive trend in water yield (-) = negative trend in water yield

At mid-term projection (2049-2078), KLB dry season water yield decreases with a lower magnitude compared to near-term projection. It ranges between (-0.09 to -0.15 mm/day) for all the three RCPs. Under 1959-1988 baseline, RCP4.5 accounts for the lowest decrease but highest decrease for RCP8.5 while under 1989-2018 baseline, RCP2.6 experience a slight increase of (+0.02 mm/day) but decreases within the range of (-0.07 to 0.1 mm/day) for RCPs 4.5 and 8.5 (Figure 4.10a). Statistical trend analysis indicates non-significant neither negative nor positive trend at the 0.05 significance levels. In SRB, there is existence of increase of dry season water yield to a magnitude of (+0.2 mm/day) for RCP2.6 under 1989-2018 baseline but decreases for other RCPs under both 1959-1988 and 1989-2018 baselines with a range of (-0.02 to 0.2 mm/day). The decreasing trends were tested at 0.05 alpha levels and were found only for RCP8.5 but not for lower emission pathways (table 4.7). Furthermore, KYB dry season water yield confirms similar pattern of decrease as observed over KLB and SRB with a range of (-0.04 to -0.5 mm/day) for all the three CO_2 emission trajectories. RCP4.5 shows the highest magnitude of decrease specifically under 1989-2018 baseline period. This singular decrease is the highest for the whole three basins put together. Table (4.7) trend analysis of dry season water yield over KYB reveals significant decreasing trend at 0.05 significant levels for medium emission pathway but not for low and high emission trajectories.

During the long term projections (2079-2100), dry season water yield over KLB experience positive trend for RCP2.6 up to (+0.2 mm/day) but not significant. However, RCPs 4.5 and RCP8.5 continue with a decreasing trend under the two baselines with a range of (-0.05 to 0.2 mm/day) which were found significant for RCP8.5 but not for RCP4.5. In SRB the dry season water yield experiences decreasing pattern for all the three RCPs except RCP2.6 with slight increase of just (+0.02 mm/day). However, the range of decrease is within the range of (-0.1 to -0.3 mm/day) for RCPs 4.5 and 8.5. The (-0.3 mm/day) decreasing pattern is the highest observed for RCP8.5 in the whole basins such that Mann Kendal trend analysis confirms significance at the 0.05 significance levels. As for KYB, decreasing trend is also noticed for the three RCPs but only significant for highest emission pathways. Regional trend analysis of the three basins as a whole confirms that the Guinea and Sudano-Sahelian ecological zones of Nigeria will experience decreasing dry season water yield from the near term (2019-2048), mid-term (2049-2078) and long term (2079-2100) with reference to 1959-1988 and 1989-2018 baselines. In table (4.7) it is observed that the decreasing dry season water yield were only significant for RCP8.5 but not under middle and low emission trajectories.

4.2.2: Projected changes in wet season water yield

Wet season water yield over the KLB, SRB and KYB that collectively refer to the Guinea and Sudano-Sahelian ecological zones are shown in figure (4.11a-c). Wet season water yield were projected for near, mid and long term with reference to 1959-1988 and 1989-2018 baselines. Near term projection (2019-2048) period at KLB, wet season water yield will increase within the range of (+0.1 to +0.2 mm/day) for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018). RCP2.6 accounts for the highest increase of (+0.15 mm/day) and lowest being RCP4.5 and RCP8.5 with (+0.1 mm/day) under the 1959-1988 baseline, while a contrasting pattern of increase is observed under 1989-2018 baseline where RCPs 2.6 and 8.5 account for the highest with (+0.2 mm/day) and lowest been RCP4.5 (Figure 4.11a). Trend analysis of wet season water yield within the 2019-2048 periods over KLB indicates that it is not significant at 0.05 significant levels for all the three RCPs (Table 4.7). SRB wet season water yield reveals that the range of increase is between (+0.1mm to +0.3 mm/day) for all the three RCPs under 1959-1988 and 1989-2018 baselines. RCP8.5 accounts for the highest under the two baselines with (+0.3 mm/day) each,

1959 – 1988 Baseline **1989 – 2018 Baseline**

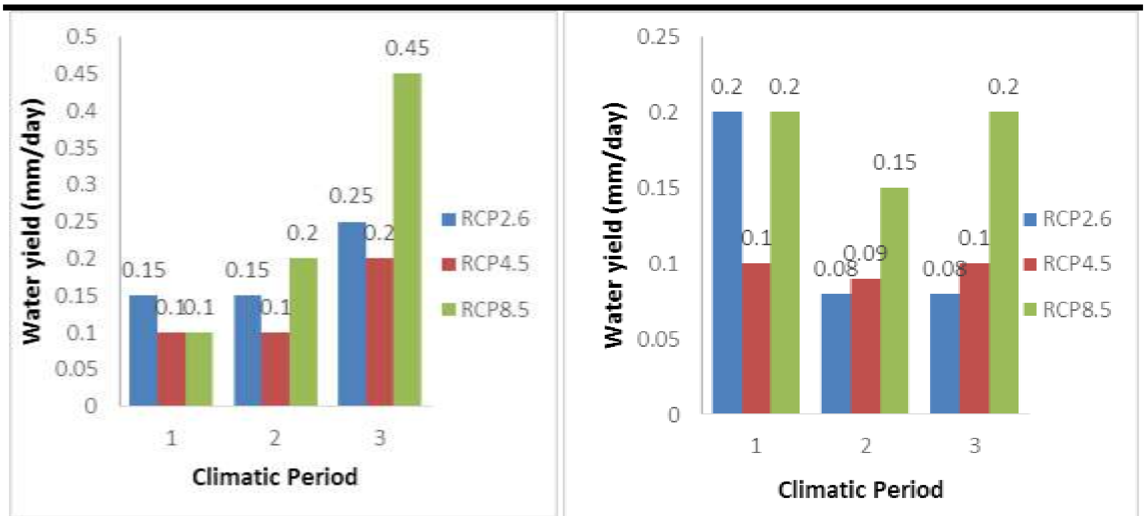


Figure 4.11a: Projected changes in wet season water yield for KLB

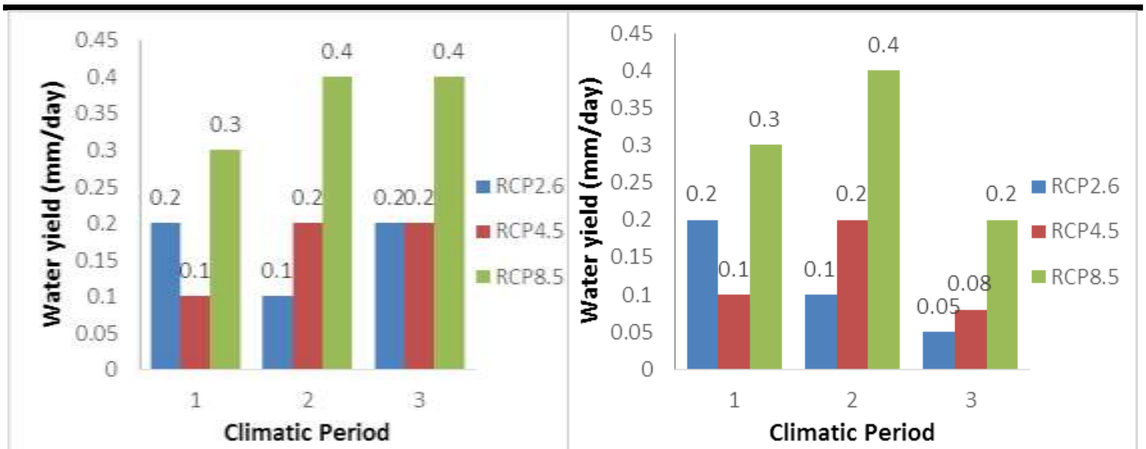


Figure 4.11b: Projected changes in wet season water yield for SRB

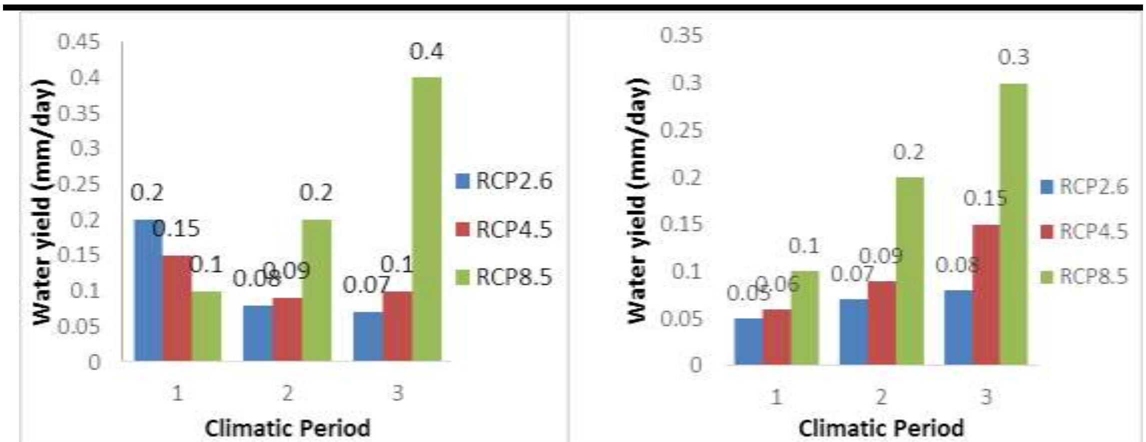


Figure 4.11c: Projected changes in wet season water yield for KYB

while RCP4.5 accounts for the lowest (Figure 4.11b). Trend analysis of wet season water yield in SRB under the 2019-2048 periods shows significant trend at 0.05 significant levels for scenarios (RCP2.6 and RCP8.5) but non-significant for medium emission scenario (RCP4.5) see (Table 4.7). Similarly, condition over KYB reveals lower magnitude of increase compared to SRB at this period. Figure (4.11c) shows (+0.1 to +0.2 mm/day) range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of (+0.05 to +0.1 mm/day) under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6.It is important to point out that the range of increase under 1989-2018 baseline is the same for KLB and KYB but differ greatly with SRB. However, the trend analysis of wet season water yield over KYB under the (2019-2048) period shows that there is significant trend for RCP2.6 under 1959-1988 baseline but not under 1989-2018 baseline as well as for other two RCPs.

By 2049-2078 projected period, wet season water yield in KLB will increase steadily to a range of (+0.1 to +0.2 mm/day) under 1959-1988 baseline such that RCP8.5 accounts for highest and lowest been RCP4.5. While under 1989-2018 baseline, it varies between (+0.08 to +0.15 mm/day) with RCP8.5 the highest and lowest will be RCP2.6. SRB projected wet season water yield indicates the same magnitude of increase under both baselines just between (+0.1 to 0.4 mm/day) for all the RCPs. RCP8.5 having highest value and lowest being RCP2.6 (Figure 4.11b). At the same time for the KYB, projected wet season water yield ranges between (+0.08 to +0.2 mm/day) under 1959-1988 baseline with a wide margin between RCP8.5 and RCP2.6 but ranges between (+0.07 to 0.2 mm/day) under 1989-2018 baseline (Figure 4.11c). The trend analysis (Table 4.7) shows that there is significant increasing trend at 0.05 significant levels for highest emission of CO_2 but not for middle and low CO_2 emission pathways.

In (2079-2100) period, anticipated condition in KLB mirror a similar pattern as obtained in the two preceding periods where there is a consistent increase in the wet season water yield. That is to say water yield increases from first projected period of 2019-2048 through 2049-2078 to third projected period of 2079-2100 in KLB (Figure 4.11a). Trend analysis of (2079-2100) period in KLB reveals that there is significant trend at 0.05 significant levels (Table 4.7). SRB pattern of wet season water yield under (2079-2100) period is comparable with that observed over KLB such that the range of (+0.2 to 0.4 mm/day) in SRB is bit smaller (Figure 4.11b). Thus, trend analysis of (2079-2100) period over SRB shows a significant increasing trend at 0.05 significant levels for all the three RCPs. (Table 4.7). The situation over KYB in this period reveals the projected pattern in the range of (+0.07 to 0.4 mm/day) for all the three RCPs such that RCP8.5 accounts for the highest and the lowest among the three been RCP2. Therefore, trend analysis of (2079-2100) period (Table 4.7) over KYB reveals significant increasing trend at 0.05 significant levels for highest CO_2 emission pathways but not for the middle and low emission trajectories.

Regional trend analysis of wet season water yields over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that under 2019-2048 period there is no significant increasing trends at 0.05 significant levels. This is with respect to high emission scenario (RCP8.5) but significant in low and middle emission scenarios (RCPs 2.6 and 4.5) (Table 4.7). By (2049-2078) through (2079-2100) period, there is significant increasing trends in the whole Guinea and Sudano-Sahelian ecological zone as a region in wet season water yield for RCP8.5 except RCPs 2.6 and 4.5 under mid-term projection (Table 4.7).

4.2.3: Projected changes in average annual water yield

Average annual water yield over the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100 are shown in Figure (4. 12a-c). Average annual water yield within the 2019-2048 periods over the KLB indicates that thereis no significant

1959 – 1988 Baseline **1989 – 2018 Baseline**

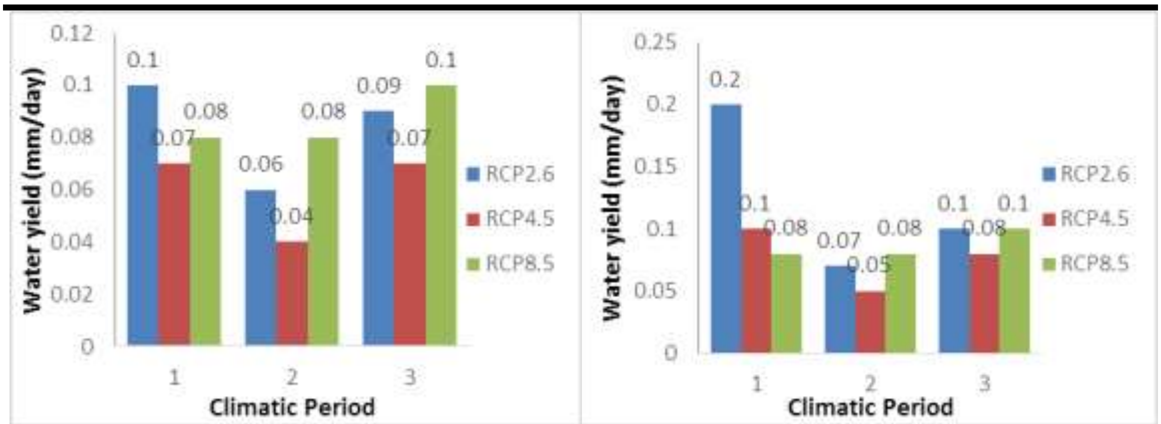


Figure 4.12a: Projected changes in average annual water yield for KLB

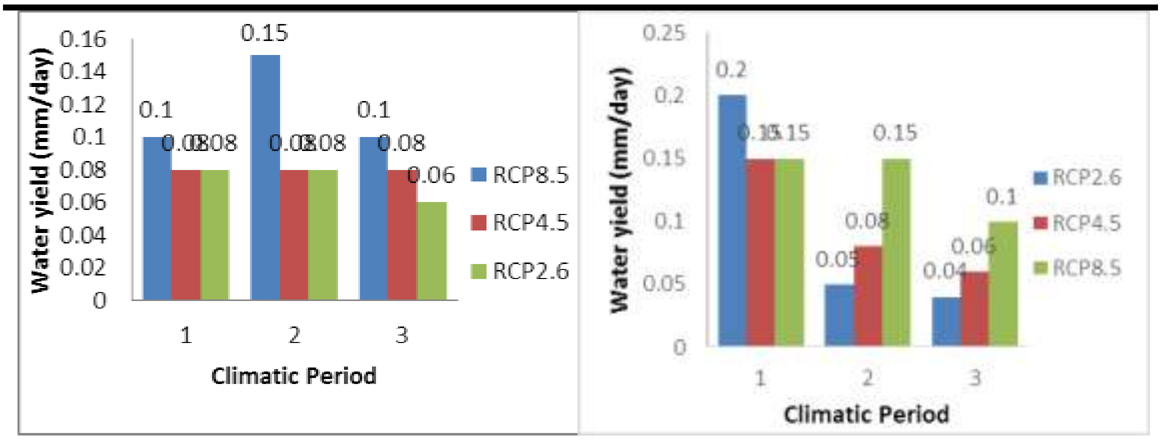


Figure 4.12b: Projected changes in average annual water yield for SRB

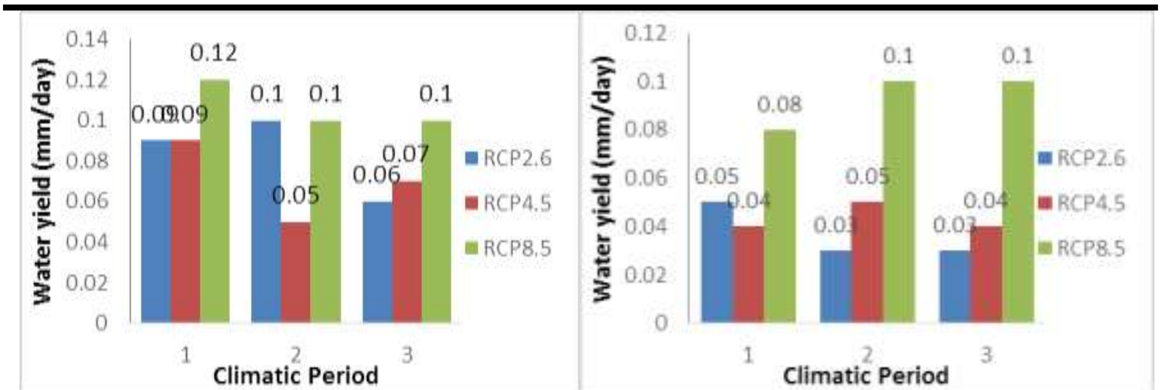


Figure 4.12c: Projected changes in average annual water yield for KYB

increasing trends at 0.05 significant levels for RCP2.6 and RCP8.5 but significant for RCP4.5 (Table 4.7). Situation over SRB reveals that the range of increase is between (+0.08 to 0.1 mm/day) for all the RCPs under 1959-1988 baseline but amplify to the range of (+0.15 to 0.2 mm/day) under the 1989-2018 baseline. RCP2.6 accounts for the highest under the two baselines while RCPs 4.5 and 8.5 responsible for the lowest (Figure 4.12b). Trend analysis in SRB under the 2019-2048 periods (Table 4.7) shows no significant increasing trends at 0.05 significant levels for all the three emission trajectories. Likewise, in KYB average annual water yield reveals (+0.09 to 0.12 mm/day) range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of (+0.05 to +0.08 mm/day) under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6. However, the trend analysis over KYB under the (2019-2048) period shows that there are no significant increasing trends for all the three RCPs at 0.05 significant levels.

By (2049-2078) mid-term projected period, KLB average annual water yield increases within the range (+0.04 to +0.08 mm/day) this is slightly lower than that obtainable in near-term projection. RCP8.5 sustains the lead under the two baselines while RCP4.5 is the lowest for the two baselines. Trend analysis result indicates no significant increasing trends exist under the low, middle and high emission pathways at 0.05 significant levels (Table 4.7). SRB projected average annual water yield signify an increase of just between (+0.08 to +0.15 mm/day) for all the three RCPs under the two baselines are visible. The projected increase is statistically not significant at 0.05 significant levels for all the three RCPs. On the other hand, the KYB projected average annual water yield ranges between (+0.05 to +0.1 mm/day) under 1959-1988 baseline with just a little margin between RCP8.5 and RCP2.6 but ranges between (+0.03 to +0.1 mm/day) under 1989-2018 baseline (Figure 4.12c). The trend analysis shows that there is no significant increasing for all the three CO_2 emission pathways. During (2079-2100) period, estimated provision in KLB reflects a consistent variability of increase in average annual water yield to the range (+0.07 to +0.1 mm/day) for all the three RCPs under the two baselines such that RCP8.5 accountable for the highest increases but lowest for RCP4.5 (Figure 4.12a). Trend analysis of (2079-2100) period in KLB (Table 4.7) discloses that there are no significant increasing trends at the 0.05 significance levels for RCP2.6 and RCP4.5 and RCP8.5. Similar patterns of increasing trends are noticeable in SRB and KYB but Mann Kendal trend analysis at the 0.05 degree of alpha confirms no significant trends for the two basins for low, middle and high emission trajectories.

Regional trend analysis of average annual water yields over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that there are no significant trends for RCPs 2.6, 4.5 and 8.5 with respect to the three projected periods under consideration. This is to say that despite the projected increasing pattern of average annual water yield observed over the Guinea and the Sudano-Sahelian ecological zones, incidences of water crisis cannot be ruled out because the anticipated increase is not statistically significant at the 0.05 degree of alpha. This finding is in tandem with that reported by Ndhlovu and Woyessa (2020) in Zambezi river basinwhere annual statistics under RCP8.5 show a significant increase of 40 % in water yield while under RCP4.5 there is an increase in water yield of 5 % but not significant.This is also corroborated with work of Gabriela *et al.* (2019) in southeastern Brazil. However, Anastasia *et al.* (2018) stated that climate change will alter the hydrological regimes of rivers in Europe. Furthermore, it will create additional challenges for water resourcesand aquatic ecosystems which are already stressed due to extensive anthropogenic activities. Therefore, the impacts of the projectedclimate change have to be understood and incorporated into the regional water management strategies to ensure sustainable approach in governing the water systems (Olkeba*et al.*, 2016).

4.2.4: Decadal changes in dry season water yield from 2030-2100 average

With regard to water yield, decadal changes from the average water yield of 2030 – 2100 in dry seasons shows evidence of variability between positive and negative changes (Table 4.8).

Table 4.8: Decadal departures of dry season water yield from 2020-2100 average

Decades	KLB		SRB		KYB	
	Mean	% Change	Mean	% Change	Mean	% Change
2030	-0.05	26.3	-0.1	23.4	-0.3	-30.4
2040	-0.07	21.7	-0.2	-5.26	-0.1	26.5
2050	-0.06	25.0	-0.09	26.6	-0.3	-30.4
2060	-0.1	16.7	-0.3	-24.9	-0.2	13.0
2070	-0.1	16.7	-0.2	-5.26	-0.2	13.0
2080	-0.08	33.3	-0.2	-5.26	-0.3	-30.4
2090	-0.2	-36.6	-0.3	-23.9	-0.25	-8.79
2100	-0.2	-36.6	-0.1	27.4	-0.2	13.0

In KLB, it is apparent that positive change in water yield during the dry season will occur in all the decades but two, namely 2090 and 2100 with (-33.6%) each. However, the range of positive change is from (+16.6% to 33.3%) with highest in 2080 and lowest occurring in 2060 and 2070. Situation over SRB shows that all decades will witness negative departure but three, that is 2030, 2050 and 2100 with positive departure rates of (+23.4%), (+26.6%) and (+27.4%) respectively. The magnitude of change in negative departure ranges from (-5.26% to -23.9%) (Table 4.8). Similarly, KYB dry season water yield departure indicates visible sign of positive changes in four decades as well as negative change in other four decades. The decades with positive changes are 2040, 2060, 2070 and 2100 with a range of (+13% to 26.5%) while negative changes are confirm in 2030, 2050, 2080 and 2090 in a range of (-8.79% to -30.4%). It is important to mention that except 2090, the magnitude of negative change is the same in other three decades (Table 4.8). Comparison of all the three basins together reveal that the worst negative changes in water yield will occur in KYB while best positive change is likely in KLB.

4.2.5: Decadal changes in wet season water yield from 2030-2100 average

Wet season decadal changes in water yield over KLB, SRB and KYB is presented in Table 4.9.

Table 4.9: Decadal departures of wet season water yield from 2020-2100 average

Decades	KLB		SRB		KYB	
	Mean	% Change	Mean	% Change	Mean	% Change
2030	0.2	43.2	0.3	-3.45	0.1	11.5
2040	0.1	23.1	0.3	-3.45	0.3	-30.4
2050	0.3	17.3	0.1	15.5	0.1	23.5
2060	0.15	42.7	0.4	-37.9	0.2	13.0
2070	0.1	32.1	0.2	31.0	0.2	13.0
2080	0.2	28.2	0.5	-12.4	0.3	-30.4
2090	0.2	28.2	0.2	31.0	0.3	-30.4
2100	0.2	28.2	0.3	-3.45	0.3	-30.4

The table shows that over KLB, there is occurrence of positive changes in decadal water yield in all the decades between 2030-2100. The positive change ranges from (+17.3% to +43.2%) such that 2030 accounts for the highest and the lowest is in 2050. This result is a clear indication that water yield will increase over this basin up till the end of 21 century but with high variability. At SRB, changes in water yield confirm that there will be positive changes in 2050, 2070 and 2090 within the range of (+15.5% to 31%) such that the least positive change happening in 2050. Aside these three decades, all the remaining decades are likely to witness negative changes in average water yield within the range of (-3.45% to -37.9%). The worst negative change is in 2060 while the least negative spread over 2030, 2040 and 2100 (Table 4.9). In KYB, changes in average water yield informs that there will be four decades of negative changes in average water yield which are 2040, 2080, 2090 and 2100 with (-30.4%) negative change each while 2030, 2050, 2060 and 2070 will experience positive changes within the range of (+11% to +23.5%). Decade 2050 accounts for the highest and lowest in 2030

4.2.6: Decadal departures of annual water yield from 2030-2100 average

Decadal changes of annual water yield from the average of 2030 – 2100 shows evidence of variability between positive and negative changes (Table 4.10).

Table 4.10: Decadal departures of annual water yield from 2030-2100 average

Decades	**KLB**			**SRB**			**KYB**	
	Mean		% Change	Mean		% Change	Mean	% Change
2030	0.08	25		0.15	-7.14	0.08	27.3	
2040	0.06	31.5	0.15	-7.14	0.1	9.09		
2050	0.08	25		0.1	28.6	0.1	9.09	
2060	0.08	25		0.15	-7.14	0.11	0.14	
2070	0.08	25		0.17	-21.4	0.2	-18.8	
2080	0.1	37.5	0.12	14.3	0.08	27.3		
2090	0.07	23.3	0.1	28.6	0.1	9.09		
2100	0.1	37.5	0.15	-7.14	0.1	9.09		

In KLB, it is evident that positive change in annual water yield will occur in all the decades. That is to say all decadal water yields over KLB will witness above average water yield indicatives of relative water surplus. However, the range of positive change is from (+25% to 37.5%) with highest in 2080 and 2100 while lowest occurring in 2030, 2050, 2060 and 2070. Situation over SRB shows that all decades will witness negative departure but three, that is 2050, 2080 and 2090 with positive departure rates of (+28.6%), (+14.3%) and (+28.6%) respectively. The magnitude of change in negative departure ranges from (-7.14% to -21.4%) (Table 4.10). Similarly, KYB annual water yield departure indicates visible sign of positive changes in all but two decades. The decades with positive changes range from (+9.09% to 27.3%) while negative change in 2070 is (-18.8%). It is important to mention that 2060 witness (0%) change, meaning the water yield during this decade is the same with long term average (Table 4.10). Comparison of all the three basins together reveal that the worst annual negative changes in water yield will occur in SRB while best positive change is likely in KLB.

4.3: Trends of Extreme Rainfall Indices

4.3.1: Changes in maximum 5-day rainfall

The maximum 5-day rainfall is projected to change differentially in space and time over the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100 (Figure 4.13a-c). The (2019-2048) period shows that the maximum 5-day rainfall will increase within the range of 5–10mm for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018) over the KLB. RCP8.5 accounts for the highest increase of 10mm and lowest being RCP4.5 with 5mm under the 1959-1988 baseline, while a contrasting pattern of increase is observed under 1989-2018 baseline where RCP2.6 accounts for the highest with 10mm and lowest being RCP8.5 (Figure 4.13a). Trend analysis of maximum 5-day rainfall within the 2019-2048 periods over KLB indicates that it is not significant at 0.05 significant levels for all the three RCPs (Table 4.11). SRB maximum 5-day rainfall reveals that the range of increase is between 12mm-16mm for all the RCPs under 1959-1988 baseline but decreases to the range of

7mm-10mm under the 1989-2018 baseline. RCP8.5 accounts for the highest with 16mm under 1959-1988 baseline but lowest with 8mm under 1989-2018 baseline. While

1959 – 1988 Baseline **1989 – 2018 Baseline**

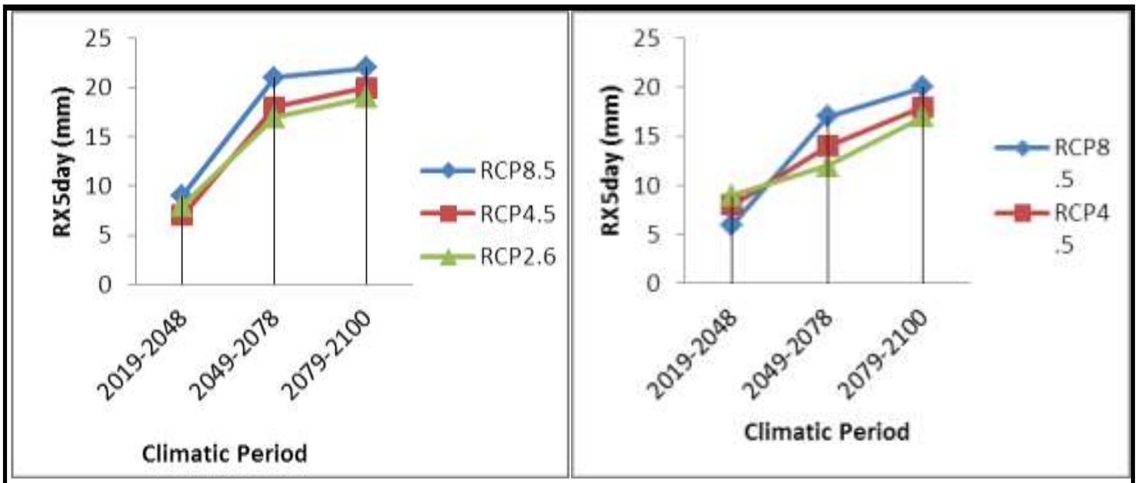


Figure 4.13a: Projected maximum 5-day rainfall for KLB

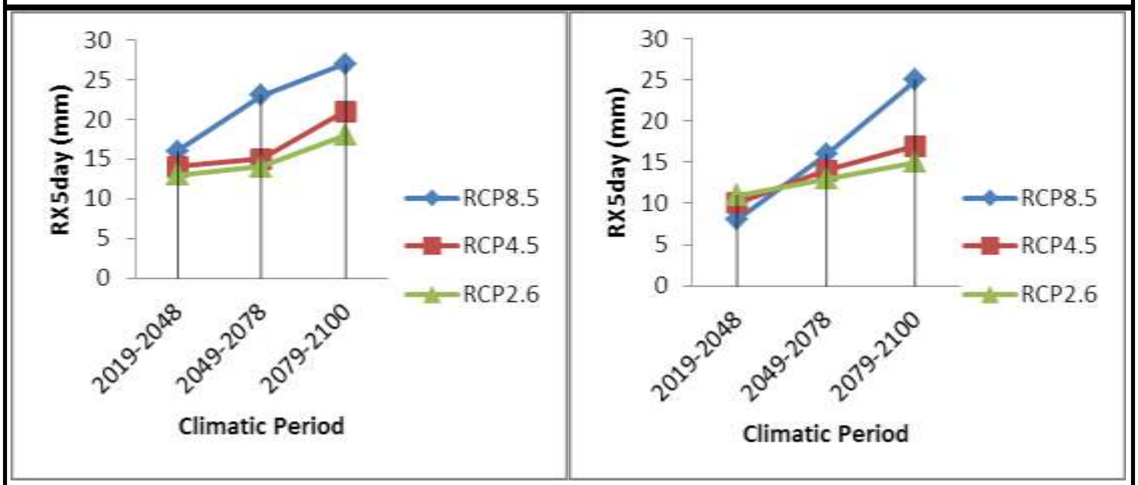


Figure 4.13b: Projected maximum 5-day rainfall for SRB

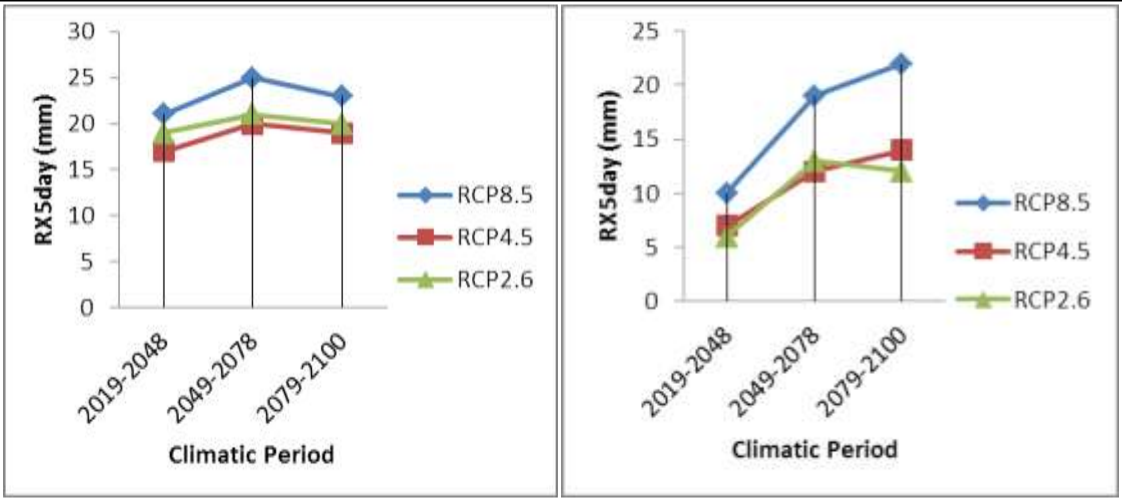


Figure 4.13c: Projected maximum 5-day rainfall for KYB

Table 4.11: Mann–Kendall trend analysis of extreme rainfall indices for KLB, SRB and KYB

Climatic Period	Extreme Rainfall Indices											
	rcp2.6			rcp4.5			rcp8.5			Regional Trend		
	Maximum 5-day rainfall (Rx5day)											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.7	1.6	2.4*	1.3	1.5	2.4*	1.8	2.4*	2.3*	1.4	1.4	2.9*
2049-2078	2.1*	1.3	2.7*	1.9*	1.4	1.9*	2.2*	2.6*	2.5*	2.1*	1.9*	2.3*
2079-2100	1.9*	0.6	2.8*	2.6*	2.1*	2.6*	2.3*	2.4*	2.5*	1.9*	2.3*	2.4*
	Heavy rainfall days (R10mm)											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	1.7	1.7	2.4*	0.3	1.1	2.2*	1.4	2.6*	2.0*	1.4	0.2	1.9*
2049-2078	2.6*	1.5	2.1*	2.3*	0.6	2.3*	2.4*	2.6*	2.5*	2.1*	1.9	2.6*
2079-2100	2.9*	0.2	1.9*	2.6*	2.1*	2.6*	2.3*	2.4*	2.5*	1.9*	2.2*	2.2*
	Consecutive wet days (CWD)											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.7	-1.6	-1.6	-1.3	-1.8	-1.5	-1.8	-0.9	-0.3	-1.9	2.6	2.8*
2049-2078	1.6	-1.3	-1.6	-0.8	-2.9	-1.7	-1.9	-0.6	-1.5	-0.5	1.7	0.3
2079-2100	-0.8	-2.6*	-1.8	-1.6	-2.5*	-1.6	-2.3*	-2.4*	-2.5*	-1.8	2.3	2.8*
	Consecutive dry days (CDD)											

	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	**1.7**	**1.1**	**2.2***	**1.1**	**1.5**	**2.1***	**1.8**	**2.4***	**2.3***	**1.4**	**1.4**	**2.4***
2049-2078	**2.5***	**1.4**	**2.6***	**1.4***	**1.4**	**1.8***	**2.4***	**2.6***	**2.5***	**2.1***	**0.9**	**2.2***
2079-2100	**1.5***	**0.8**	**2.9***	**2.7***	**2.1***	**2.0***	**2.2***	**2.4***	**2.5***	**2.9***	**2.3***	**2.1***

(*) = Statistically significant trends at the 0.05 significance level.

(+) = increasing extreme rainfall indices *(-) = decreasing extreme rainfall indices*

RCP2.6 accounts for the lowest with 12mm under 1959-1988 baseline but highest with 10mm under 1989-2018 baseline (Figure 4.13b).Trend analysis of maximum 5-day rainfall in SRB under the 2019-2048 periods shows no significant trend at 0.05 significant levels for lower emission scenarios (RCP2.6 and RCP4.5) but significant for higher emission scenario (RCP8.5) see (Table 4.11). Similarly, maximum 5-day rainfall in KYB reveals 16-21mm range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of 5mm-10mm under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6. It is important to point out that the range of increase under 1989-2018 baseline is the same for KLB and KYB but differ greatly with SRB.

However, the trend analysis of maximum 5-day rainfall over KYB under the (2019-2048) period shows that there is significant trend for all the three RCPs at 0.05 significant levels. Therefore, maximum 5-day rainfall will be mostly felt in KYB than the other two basins. By 2049-2078 projected period, maximum 5-day rainfall in KLB will increase steadily to a range of 16-21mm under 1959-1988 baseline such that RCP8.5 accounts for highest and lowest being RCP2.6 with values of 20mm and 15mm respectively. Under 1989-2018 baseline, it varies between 12mm-17mm with RCP8.5 being the highest and lowest will be RCP2.6. This is not surprising considering the fact that at this period, the increases in CO2 emission supposed to stabilize and start declining with respect to lowest emission scenario (RCP2.6). SRB projected maximum

5-day rainfall indicates a slightly increase of just between 12-22mm for all the RCPs under 1959-1988 baseline with RCP8.5 having highest value and lowest being RCP2.6 (Figure 4.10b). While under 1989-2018 baseline, the range of 11mm-17mm is imminent which is similar to that obtained under the same baseline in KLB. As for the KYB, projected maximum 5-day rainfall ranges between 19mm-24mm under 1959-1988 baseline with just a little margin between RCP8.5 and RCP2.6 but ranges between 10mm-20mm under 1989-2018 baseline which has the widest margin between RCP8.5 and RCP2.6 (Figure 4.10c). The trend analysis shows that there is significant trend at the 0.05 significance levels for all the RCPs (Table 4.11).

In (2079-2100) period, anticipated condition in KLB mirror a similar pattern as obtained in the two preceding periods where there is a consistent increase in maximum 5-day rainfall. That is to say maximum 5-day rainfall increases from first projected period of 2019-2048 through 2049-2078 to third projected period of 2079-2100 in KLB (Figure 4.13a). Trend analysis of (2079-2100) period in KLB reveals that there is significant trend at 0.05 significant levels (Table 4.11). SRB pattern of maximum 5-day rainfall under (2079-2100) period is in contrast with that observed over KLB such that the range of 17mm – 25mm of maximum 5-day rainfall in SRB is far wider with a difference of 5mm (Figure 4.13b). Thus, trend analysis of (2079-2100) period over SRB shows a significant upward trend at 0.05 significant levels (Table 4.11). The situation over KYB in (2079-2100) period is similitude of the projected pattern in KLB. This is because the range of 19mm-23mm for all the RCPs over KYB is the lowest among the three periods. Therefore, trend analysis of (2079-2100) period over KYB reveals significant upward trend at the 0.05 significance levels. Regional trend analysis of maximum 5-day rainfall over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that under 2019-2048 period there is no significant trend at the 0.05 significance levels. This is with respect to lower emission scenarios (RCP2.6 and RCP4.5) but significant in higher emission scenario (RCP8.5) (table 4.11). By (2049-2078) through (2079-2100) period, there is significant upward trend in the whole Guinea and Sudano-Sahelian ecological zone as a region for maximum 5-day rainfall time series with respect to all the RCPs. This is in tandem with Abdullah (2015) that reveals in Turkey statistically significant trends of maximum 5-day rainfall. Furthermore, Libanda and Chilekana (2018) contend that extreme precipitation exerts damaging impacts on both society and ecosystems over Zambia. That understanding projections of extreme precipitation is part of a resilient response to its impacts.

4.3.2: Changes in number of heavy rainfall days

Total number of days in a year with rainfall >10mm (heavy rainfall days) in the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100 are shown (Figure 4. 14a-c). The (2019-2048) period shows that the heavy rainfall days will increase within the range of 7–10 days and 3-8 days for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018) respectively over the KLB. RCP8.5 accounts for the highest increase, while RCP2.6 accounts for the lowest under the two baselines (Figure 4.14a). Trend analysis of heavy rainfall days within the 2019-2048 periods over KLB indicates that it is not significant at 0.05 significant levels for RCP2.6 and RCP4.5 but significant upward trend is observed in number of days with rainfall>10mm with respect to RCP8.5 (Table 4.11). SRB heavy rainfall days reveals that the range of increase is between 6-10 days for all the RCPs under 1959-1988 baseline but decreases to the range of 5-8 days under the 1989-2018 baseline. RCP8.5 accounts for the highest under the two baselines. While the RCP2.6 accounts for the lowest number of heavy rainfall days (Figure 4.14b).Trend analysis of heavy rainfall days in the SRB under the 2019-2048 periods shows no significant trend at 0.05

significant levels for all the three emission trajectories (Table 4.11). Likewise, the number of days with rainfall >10mm in KYB reveals 5-9 days range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of 3-7 days under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6.

However, the trend analysis of heavy rainfall days over KYB under the (2019-2048) period shows that there is significant trend for all the three RCPs at 0.05 significant levels. By 2049-2078 projected period, heavy rainfall days in KLB maintains a stable condition for RCP2.6 under 1959-1988 baseline but variable under 1989-2018 baseline.

1959 – 1988 Baseline **1989 – 2018 Baseline**

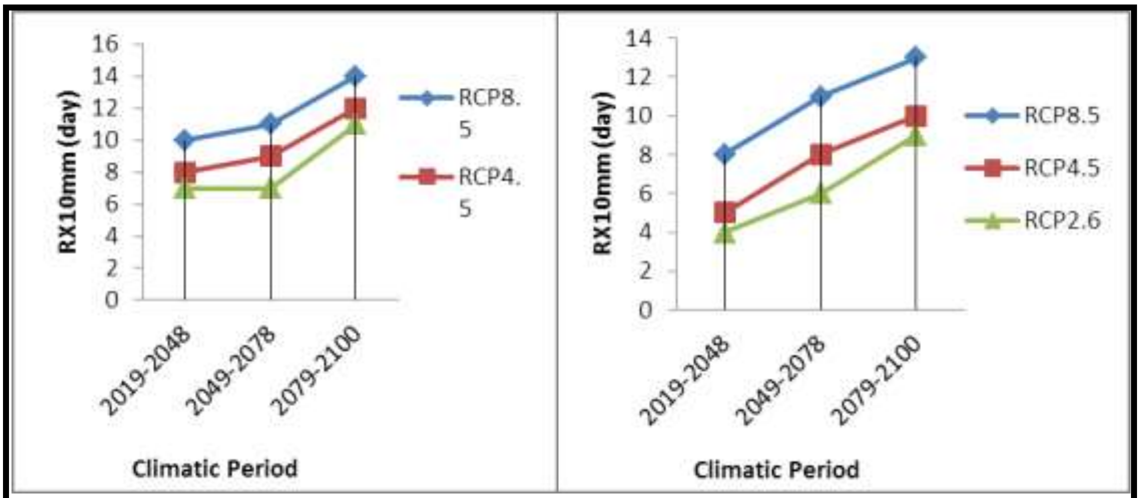


Figure 4.14a: Projected number of heavy rainfall days for KLB

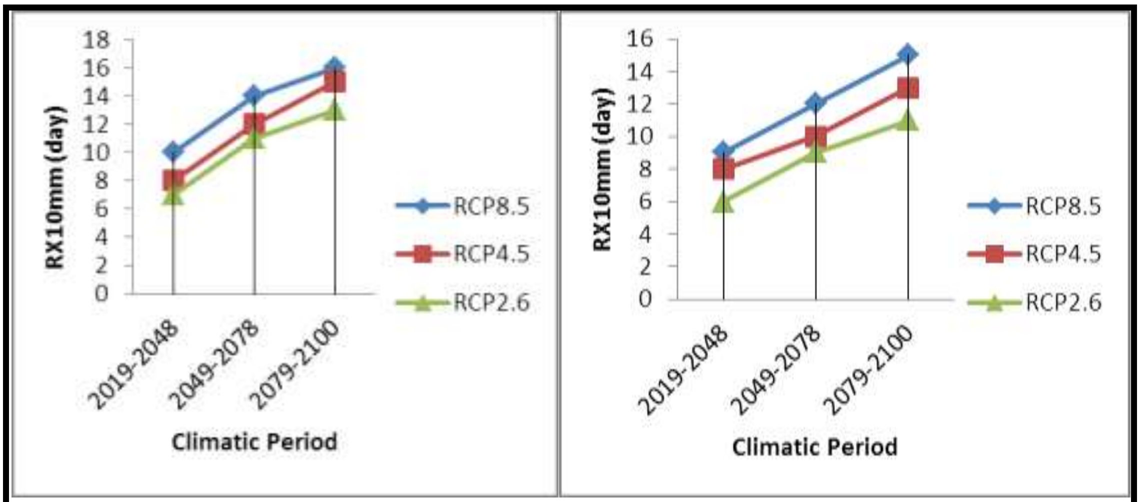


Figure 4.14b: Projected number of heavy rainfall days for SRB

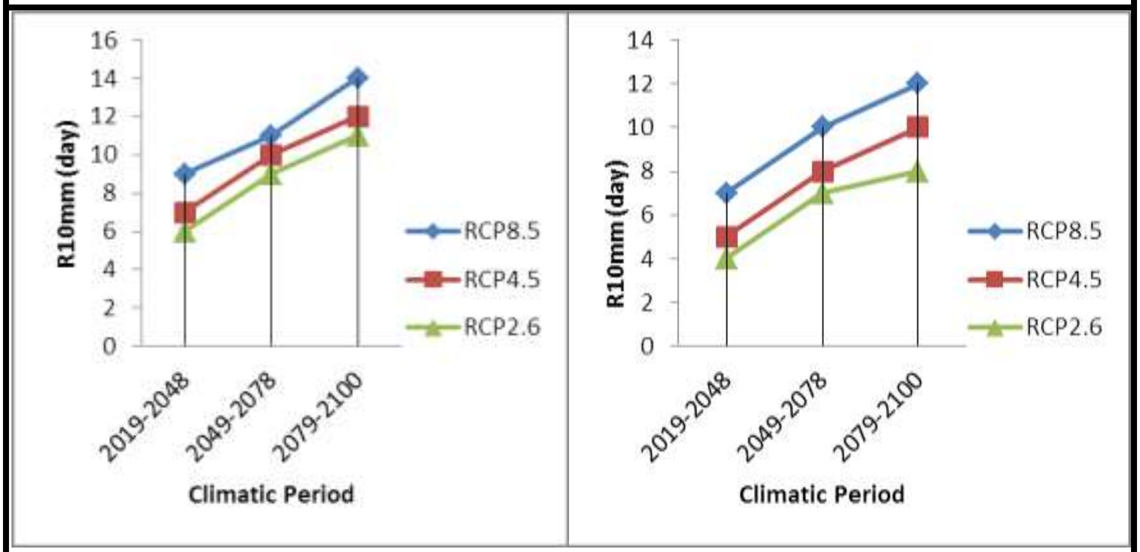


Figure 4.14c: Projected number of heavy rainfall days for KYB

RCP8.5 sustains the lead under the two baselines. Trend analysis result indicates that though no significant trend exist under the low emission pathways but becomes significant with respect to highest emission scenario at 0.05 significant levels (Table 4.11). SRB projected rainfall days with >10mm signify an increase of just between 10-14 days for all the RCPs under 1959-1988 baseline (Figure 4.14b). While under 1989-2018 baseline, the range of 8-11 days are visible. The projected increase is statistically significant at 0.05 significant levels with respect to RCP4.5 and RCP8.5 but not for RCP2.6. On the other hand, the KYB projected number of day with rainfall >10mm ranges between 8-10 days under 1959-1988 baseline with just a little margin between RCP8.5 and RCP2.6 but ranges between 6-10 days under 1989-2018 baseline (Figure 4.14c). The trend analysis shows that there is significant trend at 0.05 significant levels for RCP8.5 nevertheless; RCP2.6 and RCP4.5 have no significant trend (Table 4.11).

During (2079-2100) period, estimated provision in KLB reflects a consistent increase in number of days with rainfall >10mm. That is to say it increases from first projected period of 2019-2048 all the way through 2049-2078 toward third projected period of 2079-2100 in KLB. The range for (2079-2100) period is between 10-13 days (Figure 4.11a). Trend analysis of (2079-2100) period in KLB discloses that there is significant upward trend at 0.05 significant levels for RCP4.5 and RCP8.5 and no trend for RCP2.6 (Table 4.11). Similar pattern of upward trends are noticeable for SRB and KYB. As for SRB, there is significant upward trend in rainfall days >10mm for all the three RCPs but not for RCP2.6 across KYB.

Regional trend analysis of heavy rainfall days over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that there is no significant positive trends for RCP2.6 with respect to the three projected periods under consideration but significant with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to (2049-2078) and (2079-2100) periods. This is consistent with finding of Xiaojun *et al.* (2016) where precipitation extremes in China were projected to be more frequent and more intense and to increase by 25.81 and 69.14 % relative to the baseline climate (1971–2000) for a 1.5^{o}C warming target, and by 95.52 and 162.00 % for a 4.0^{o}C warming target, respectively. More so, Libanda and Chilekana, (2018) stated that with intensified precipitation; adaptive strategies against flooding will be of major importance against erosion of stream banks and lakeshores.

4.3.3: Changes in number of consecutive wet days (CWD)

Total number of wet days projected at KLB, SRB and KYB are shown in Figure (4.15a-c). For each period, projection was done with reference to two baselines as well as under three CO_2 emission trajectories namely RCP2.6, RCP4.5 and RCP8.5.By near-term (2019-2048), projection over KLB reveals that CWD will increase at first during this period with a range of 3-4 days with reference to 1959-1988 while under 1989-2018 baseline the increase ranges between 3-6 days. Under the two baselines, RCP8.5 accounts for highest with an increase of 4 and 6 days while RCP2.6 accounts for lowest days (Figure 4.15a). This increase was subjected to trend analysis but found no significant upward trend over this basin at 0.05 significant levels (Table 4.11). More so, projection over SRB indicates similar pattern of increase in CWD with respect to the two baselines. The increase is within the range of 5-8 days for all the three RCPs and none, was found significant at the 0.05 significance levels. This trend continues over KYB though not significant but, with slightly higher magnitude which ranges between 4-7 days for lower and highest emission pathways.

1959 – 1988 Baseline **1989 – 2018 Baseline**

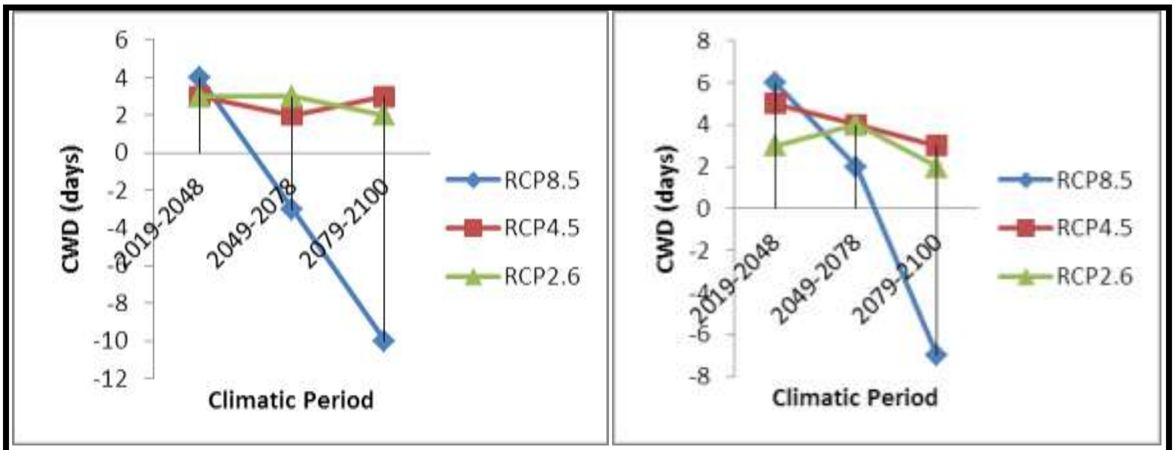


Figure 4.15a: Projected number of consecutive wet days for KLB

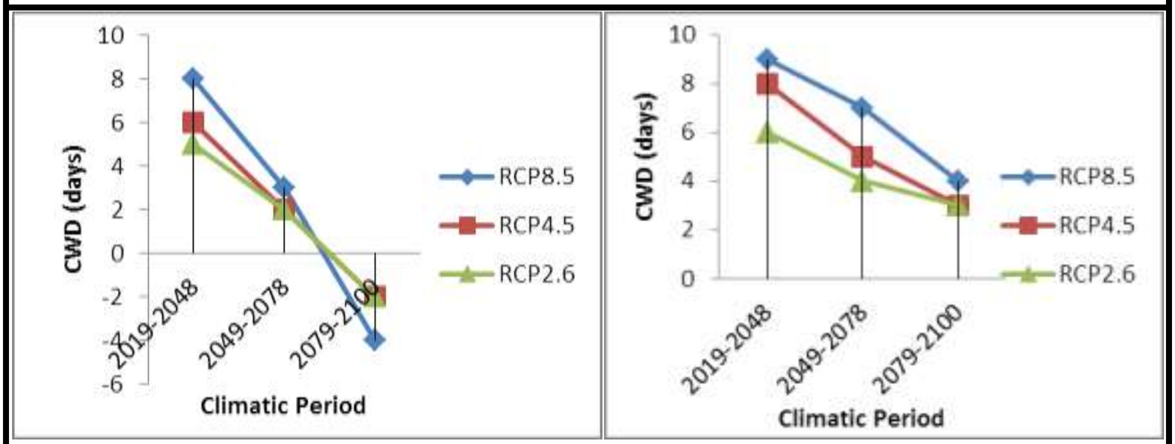


Figure 4.15b: Projected number of consecutive wet days for SRB

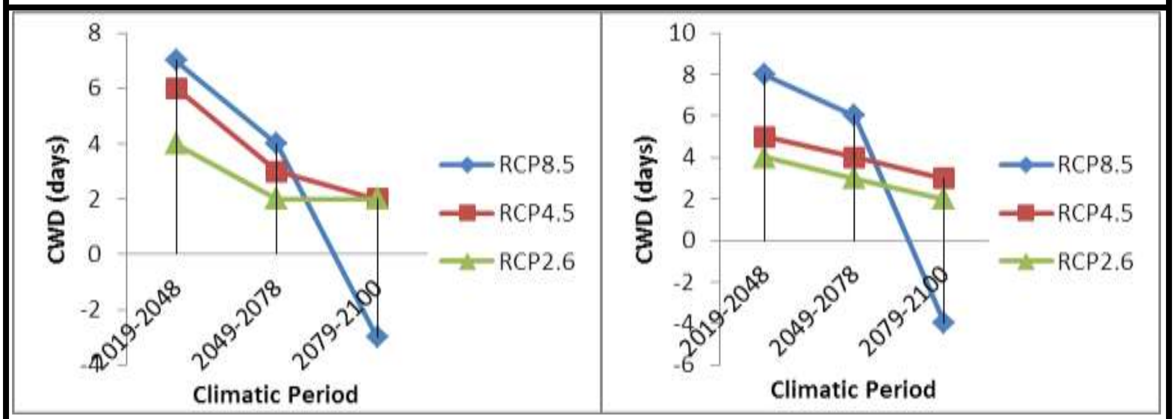


Figure 4.15c: Projected number of consecutive wet days for KYB

At mid-term (2049-2078), projection over KLB indicates that CWD decreases to 3 and 2 days under RCPs 2.6 and 4.5 respectively but, decreases by -2 days under RCP8.5 with reference to 1959-1988 baseline. While with reference to 1989-2018 baseline a decrease of 4 days for RCPs 2.6 and 4.5 but 2 days under RCP8.5. None of the three

RCPs were found significant at 0.05 significant levels (Table 4.11). Situation over SRB during this time shows that CWD decreases in a range of 2-3 days under 1959-1988 baseline but further decreases to 4-7 days under 1989-2018 baseline. As for KYB, CWD decreases to 2, 3 and 4 days for RCPs 2.6, 4.5 and 8.5 respectively under 1959-1988 baseline but, 4, 5 and 8 days under 1989-2018 baseline. The downward trends were not significant at 0.05 significant levels. During the long term (2079-2100), CWD projections demonstrated that RCPs 2.6 and 4.5 will remain constant for KLB as reported under mid-term projection but decreases to -10 days with respect to RCP8.5 under 1959-1988 baseline (Figure 4.15a). However, under 1989-2018 baseline, it decreases to 2 and 3 days for RCPs 2.6 and 4.5 but -7 days with respect to RCP8.5.

Trend analysis established that there is no significant downward trend with respect to lower emission scenarios of RCPs 2.6 and 4.5 but significant with respect to RCP8.5 (Table 4.11). The condition over SRB also confirms that CWD will decreases with higher magnitudes for all the three RCPs under the 1959-1988 baseline. The values indicated -2 day for RCPs 2.6 and 4.5, but -4 for RCP8.5 (Figure 4.12b). As for the 1989-2018 baseline, it ranges between 4 days for RCPs 2.6 and 4.5, but increase to 5 days with respect to RCP8.5. Trend analysis proves that there is no significant negative trend at 0.05 significant levels. At KYB, long term projection ascertain that CWD will decreases with higher magnitudes under the two baselines of (1959-1988) and (1989-2018) with -3 and -4 days for RCP8.5 but just 2-3 days under RCPs 2.6 and 4.5 (Table 4.15c). The downward trends observed were subjected to trend analysis, though not significant with respect to RCPs 2.6 and 4.5 but significant for RCP8.5 at 0.05 significant levels (Table 4.11).

Regional trend analysis of CWD over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria established that there are no significant negative trends. This is with respect to the three projected periods for RCPs 2.6 and 4.5, except RCP8.5 that was significant at 0.05 significant levels for long-term (2079-2100) projection period. This agrees with Sun *et al.* (2015) that confirmed negative trend of CWD in China under the RCP8.5 scenario but that there would be little trend under the RCP2.6 and RCP4.5 scenarios. In addition, Carlos and Veronica (2017) demonstrated related trends of in Brazil. This therefore, entails that the Guinea and Sudano-Sahelian ecological zones of Nigeria will experience episodes of drought in near, mid and long-term future if the rate of global emission of CO_2maintains a steady rise with no commensurate policies to address the issue at stake. However, if stringent measures are put in place it will go a long way to curb the imminent drought devastation that will ensued.

4.3.4: Changes in number of consecutive dry days (CDD)

The CDD are total number of days in a year with rainfall (<1mm) is shown in figure (4.13a-c).The RCP8.5 sustains the lead under the two baselines. Trend analysis result indicates that no significant trend exist under the three CO2 emission pathways at 0.05 significant levels (Table 4.11).However, SRB projected CDD signify an increase of 1-7 days for all the RCPs under 1959-1988 baseline (Figure 4.16b). While under 1989-2018 baseline, the range of 3-8 days are visible. Under the two baselines, emission trajectories follow same pattern from lowest to highest. The projected increase is statistically tested and found no significant upward trend at the 0.05 significance levels.

Similarly, the KYB projected number of CDD ranges between 4-10 days under 1959-1988 baseline but ranges between3-11days under 1989-2018 baseline (Figure 4.16c).

1959 – 1988 Baseline **1989 – 2018 Baseline**

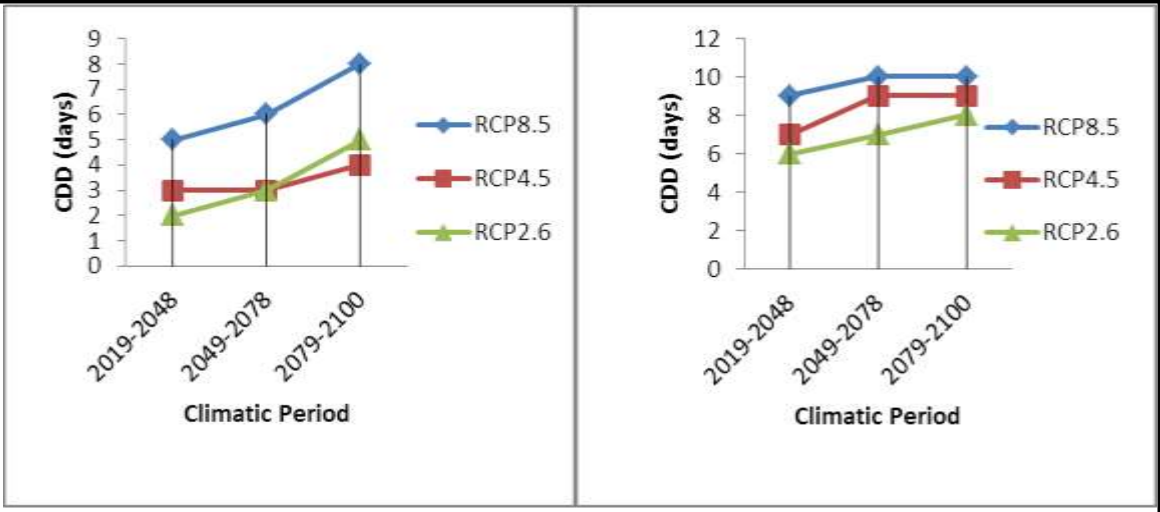


Figure 4.16a: Projected number of consecutive dry days for KLB

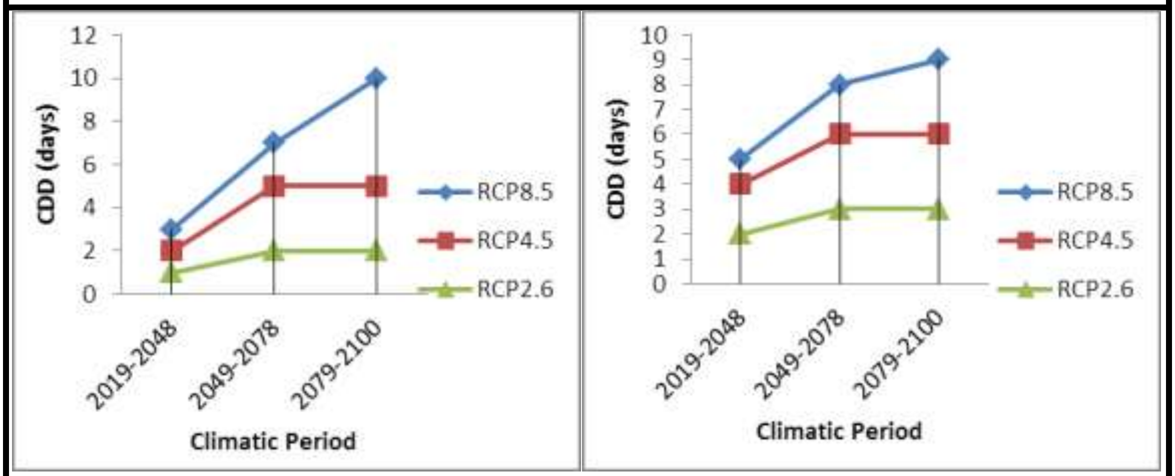


Figure 4.16b: Projected number of consecutive dry days for SRB

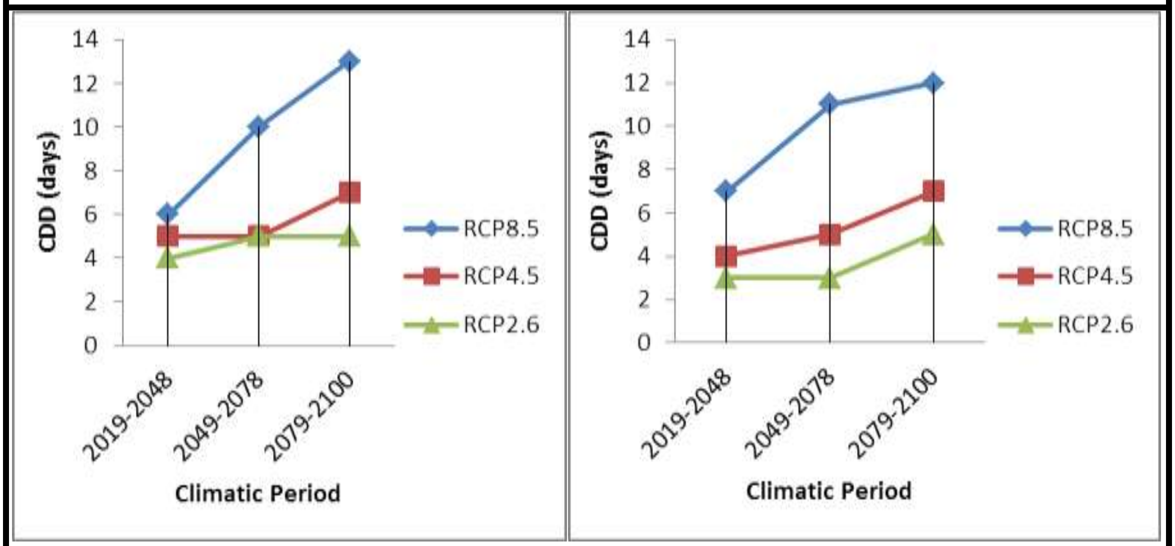


Figure 4.16c: Projected number of consecutive dry days for KYB

The trend analysis shows that there is no significant upward trend at 0.05significant levels for RCPs 2.6, 4.5 but significant with respect to RCP8.5 (Table 4.11).During (2079-2100) period, estimated provision in KLB reflects a consistent increase in CDD. That is to say it increases from first projected period of 2019-2048 all the way through 2049-2078 toward third projected period of 2079-2100. The range for (2079-2100) period is between 3-8 days (Figure 4.16a). Trend analysis of (2079-2100) period in KLB discloses that there is no significant upward trend at 0.05 significant levels for RCP2.6 and RCP4.5 but significant for RCP8.5 (Table 4.11). Similar pattern of upward trends are noticeable for SRB and KYB. These trends were found not to be significant under lower CO_2 emissions of 2.6 and 4.5 but become significant with respect to RCP8.5.

Regional trend analysis of CDD over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that there are no significant positive trends with respect to the three projected periods and emission pathways except RCP8.5 that is significant at 0.05 significant levels for long term (2079-2100) projection period. This corroborate with the work of Chan *et al.* (2016) that attested significant increase in CDD for the 21st century is inevitable in Hong Kong under RCP8.5 but not with regard to lower emission trajectories. Abdullah (2015) discovered similar increasing trends of CDD at Turkey. While Libanda and Chilekana (2018) reported results from the spatial analysis of frequency and intensity of extreme precipitation in Zambia show that the greatest increase in the number of consecutive dry days is around Siavonga, Kasama and Isoka, up to the border of Zambia and Tanzania.

4.3.4: Decadal departures of extreme rainfall indices from 2030-2100 average

In order to determine the decadal deviations in the extreme rainfall indices from the projected climate for the period under investigation (2030-2100), the departure of extreme rainfall indices were computed over KLB, SRB and KYB for three RCPs namely RCP2.6, RCP4.5 and RCP8.5. The indices considered include maximum 5-day rainfall (Rx5day), heavy rainfall days (R10 mm), consecutive wet days (CWD) and consecutive dry days (CDD) shown in (Figure 4.17a-c), (4.18a-c), (4.19a-c) and (4.20a-c) respectively. The line corresponding to zero is the baseline, which indicates the average extreme rainfall for projected period of 2021-2100. The baseline as can be observed in each of the figures is the line that correspond to zero and it is the average extreme rainfall for the year under consideration. The positive values (above zero) suggest extreme rainfalls higher than average; while the negative value (below zero) entails extreme rainfalls that were lower than average for the particular decade under consideration.

4.3.5: Decadal departures of maximum 5-day rainfall from 2030-2100 average

As for the maximum 5-day rainfall, the decadal departure observed over KLB indicates those three decades 2030, 2040 and 2050 associated with above average for the RCPs 2.6, 4.5 and 8.5 within the range of (25 to 50%) while decades 2060, 2070 and 2090 oscillate with a range of (+28 to -45%) such that RCP2.6 accounts for the highest positive departure and RCP8.5 being highest negative departure with both departures under 2090 decade. Decades 2080 and 2100 Decades 2060, 2070 and 2080 alternate within the range of (-15 to +20%) such that RCP2.6 accounts for the highest positive departure and highest negative departure under RCP4.5. It is important to state that decade 2070 shows the lowest margin between positive and negative departures which ranges from (+5%) under RCP2.6 to (-5%) for RCP4.5.

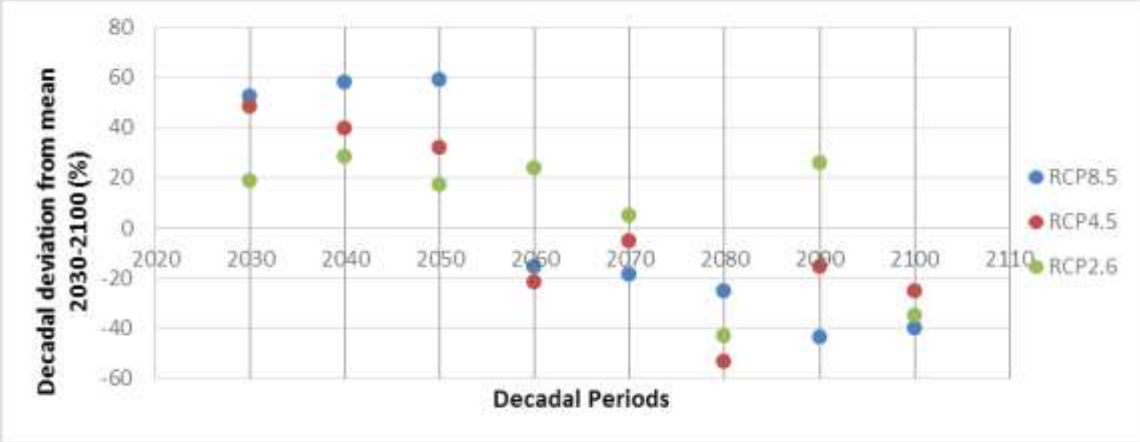


Figure 4.17a:Scatter plot of decadal mean maximum 5-day rainfall days for KLB

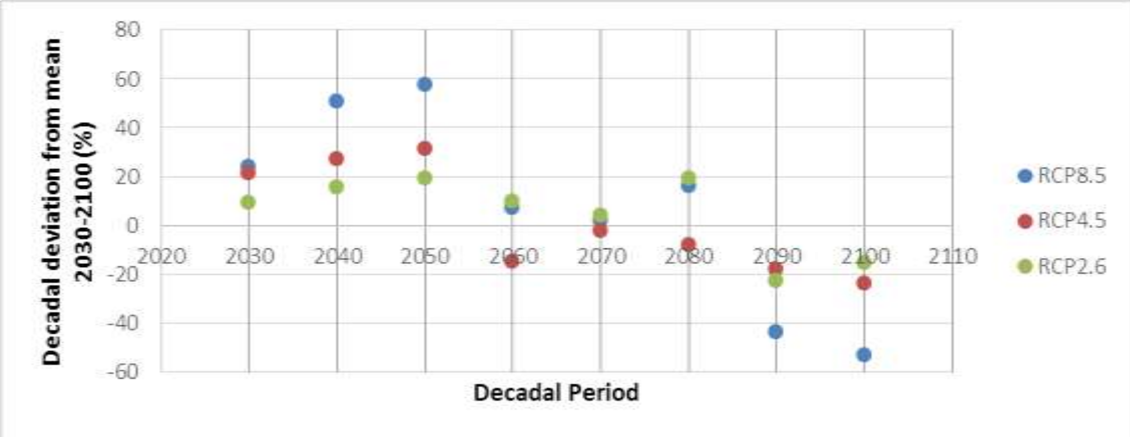


Figure 4.17b:Scatter plot of decadal mean maximum 5-day rainfall days for SRB

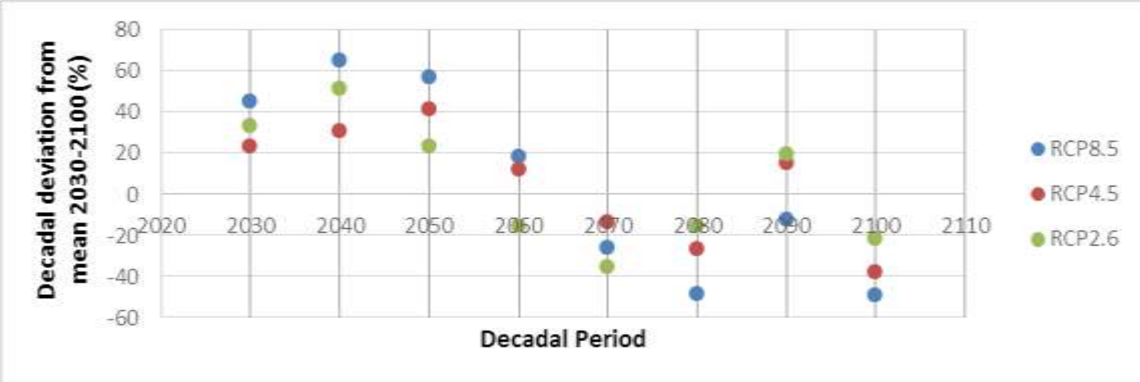


Figure 4.17c:Scatter plot of decadal mean maximum 5-day rainfall days for KYB

Decades 2090 and 2100 indicate negative departures with a range of (-15 to -55%). RCP2.6 responsible for the lowest negative departure while RCP8.5 highest negative departure both under 2100 decade. More so, KYB reveal that positive departure is concentrated in 2030, 2040 and 2050 with a range of (+20 to 65%).Although RCP8.5

responsible for the highest positive departure but, RCP4.5 accounts for the lowest with respect to 2030 and 2040 while RCP2.6 for 2050 (Figure 4.17c).

4.3.6: Decadal departures of heavy rainfall days from 2030-2100 average

Figure (4.18a-c) show the decadal departure of the heavy rainfall days.

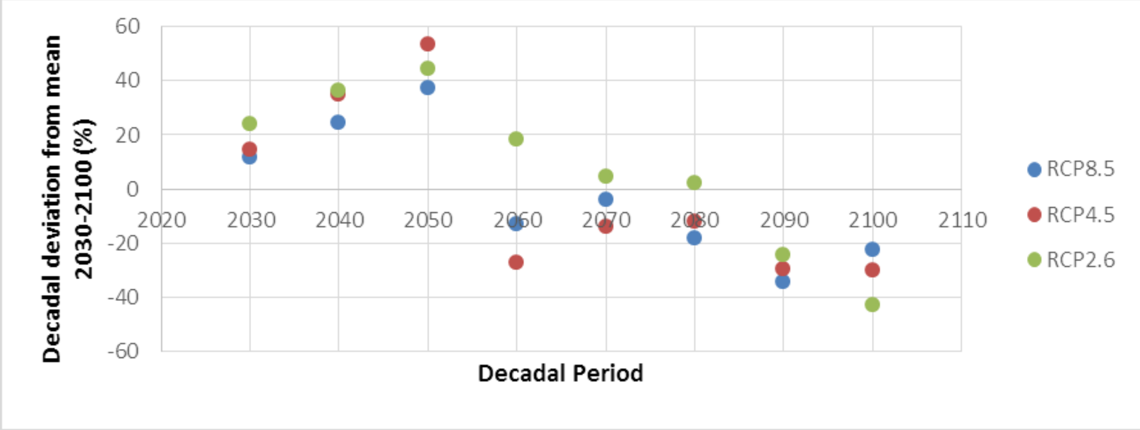


Figure 4.18a: Scatter plot of decadal mean of heavy rainfall days for KLB

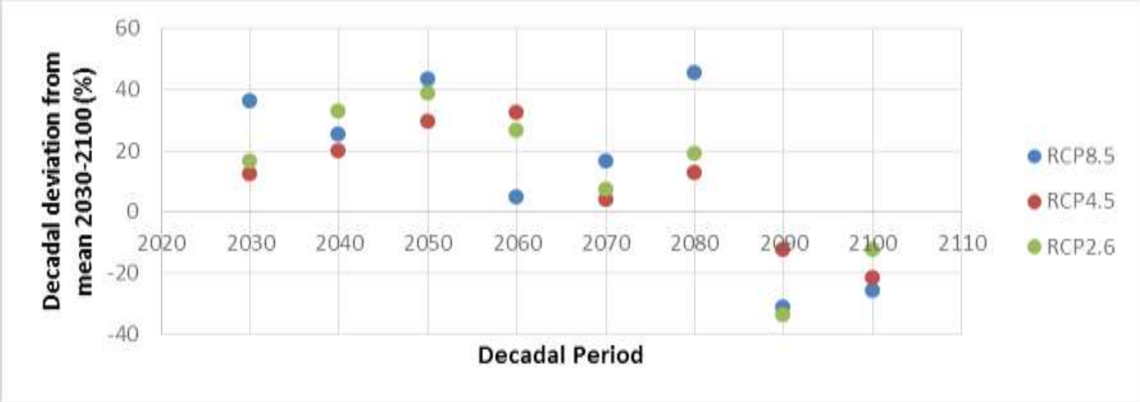


Figure 4.18b: Scatter plot of decadal mean of heavy rainfall days for SRB

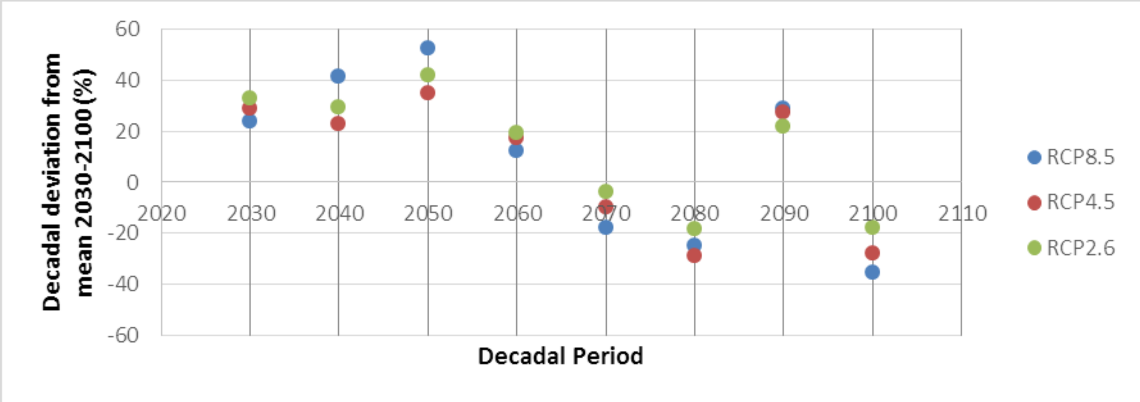


Figure 4.18c: Scatter plot of decadal mean of heavy rainfall days for KYB

decades demonstrate negative departure with a range of (-22 to -44%) mainly under 2100. RCP2.6 accounts for the highest negative departure for 2090 but lowest for 2100 while RCP8.5 lowest negative departure for 2090 but highest for 2100. In SRB, departures of heavy rainfall days indicate continuous positive departure for low and higher CO_2 emission trajectories from 2030 through 2080 with a range of (+5 to +55%). The lowest decade with positive departure being 2060 under RCP8.5 while highest positive departure is 2080 decade still under RCP8.5 (Figure 4.18b). RCP4.5 accounts for the highest positive departure in 2060 but lowest in 2030, 2040, 2070 and 2080. None of the decades experience fluctuation between positive and negative departures. KYB condition suggests positive departure in 2030, 2040, 2050, 2060 and 2090. RCP8.5 responsible for highest positive departure in 2040, 2050 and 2090 with departure rates of 40%, 55% and 30% respectively but lowest in 2030 and 2060 with 22% and 17% respectively. Decade 2040 shows the widest margin of (20% to 40%) while 2060 indicate closest margin of (+5 to +20%). A fluctuation between positive and negative departures has no presence over the basin at this time. However, 2080 and 2100 decades reveal negative departures with a range of (-19 to -38%). Such that RCP2.5 liable for the lowest negative departures under the two decades while RCP4.5 being highest negative departure under 2080 but RCP8.5 for 2100 (Figure 4.18c).

4.3.7: Decadal departures of consecutive wet days from 2030-2100 average

CWD decadal departure observed over KLB indicates that decades 2030, 2040, 2050, 2060, 2070 and 2080 fluctuates between positive and negative departures with a range of (+35 to -38%) for the RCPs 2.6, 4.5 and 8.5. RCP8.5 accounts for the highest positive departure and lowest being RCP2.6 while RCP8.5 indicates the highest negative departure and lowest being RCP4.5 (Figure 4.19a). Both the lowest and highest negative departures occur in 2050 decade which also experience closest margin between

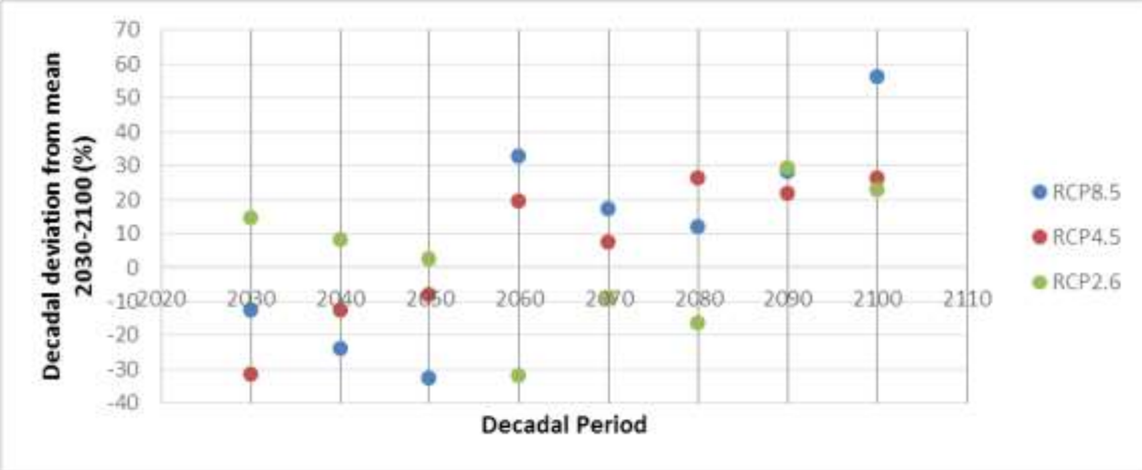


Figure 4.19a: Scatter plot of decadal mean deviation of consecutive wet days for KLB

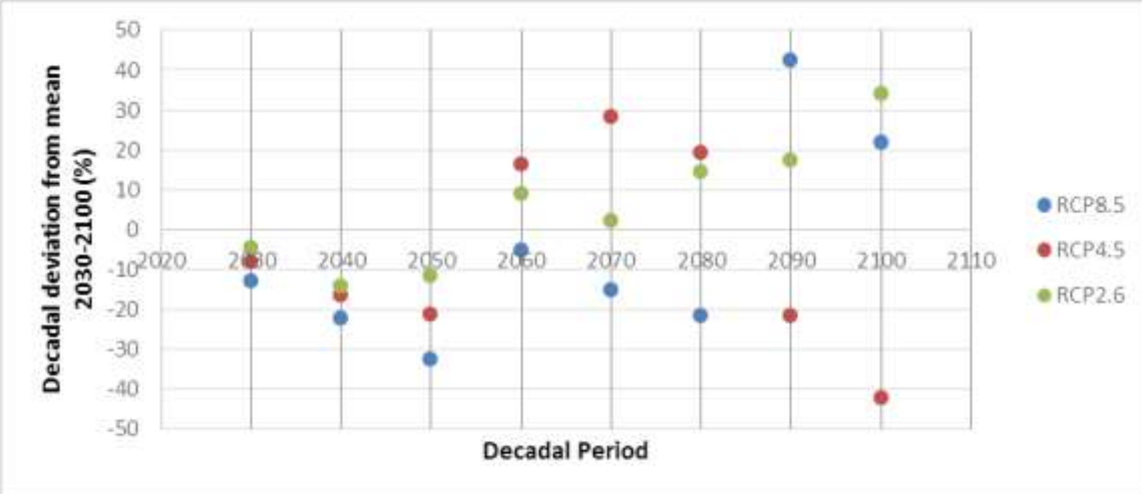


Figure 4.19b: Scatter plot of decadal mean deviation of consecutive wet days for SRB

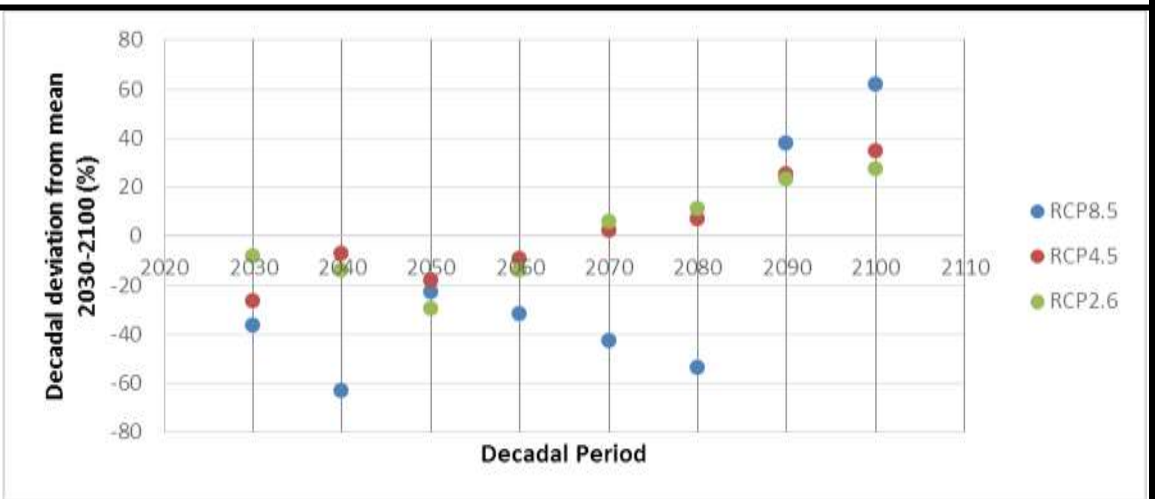


Figure 4.19c: Scatter plot of decadal mean deviation of consecutive wet days for KYB

positive and negative departures of (-10 to +5%) while the widest margin of (-35 to +30%) between negative and positive departures is observed in 2060. However, there is no single decade that experience complete negative departure for the three RCPs but 2090 and 2100 decades indicate complete positive departure of between (+25 to +60%) with highest in 2100 being RCP8.5 and lowest in 2090 being RCP4.5. In SRB, decades 2030, 2040 and 2050 associated completely with negative departures within the range of (-5 to 32%). Decade 2050 accountable for the highest negative departure under RCP8.5 while 2030 accounts for lowest negative departure under RCP2.6 (Figure 4.19b). Decades 2060, 2070, 2080, 2090 and 2100 alternate within the range of (-42 to +41%) such that RCP8.5 accounts for the highest positive departure and highest negative departure under RCP4.5. It is important to emphasis that there is no decade that witness complete positive departure. Decade 2060 shows the lowest margin between positive and negative departures which ranges from (-5%) under RCP8.5 to (+18%) for RCP4.5. Similarly, KYB shows that negative departure is concentrated in 2030, 2040, 2050 and 2060 with a range of (-62%) under 2040 to (+5%) in 2030 (Figure 4.19c). Fluctuation between negative and positive departure exist in 2070 and 2080 which ranges from (-58 to +17%) both in 2080. RCP8.5 accounts for the highest negative departure in 2080 and also responsible for highest positive departure in 2100.

4.3.8: Decadal departures of consecutive dry days from 2030-2100 average

Decadal departure of CDD (rainfall < 1 mm) from the projected average of 2030-2100 over KLB, SRB and KYB collectively refer to the Guinea and Sudano-Sahelian ecological zone of Nigeria is shown in (Figure 4.20a-c). KLB decadal departure of CDD indicates that 2030, 2040 and 2050 will experience absolute positive departure with a range of (+5 to +38%) such that RCP4.5 responsible for lowest positive departure occurring in 2030 while RCP8.5 being highest positive departure happening in 2050.

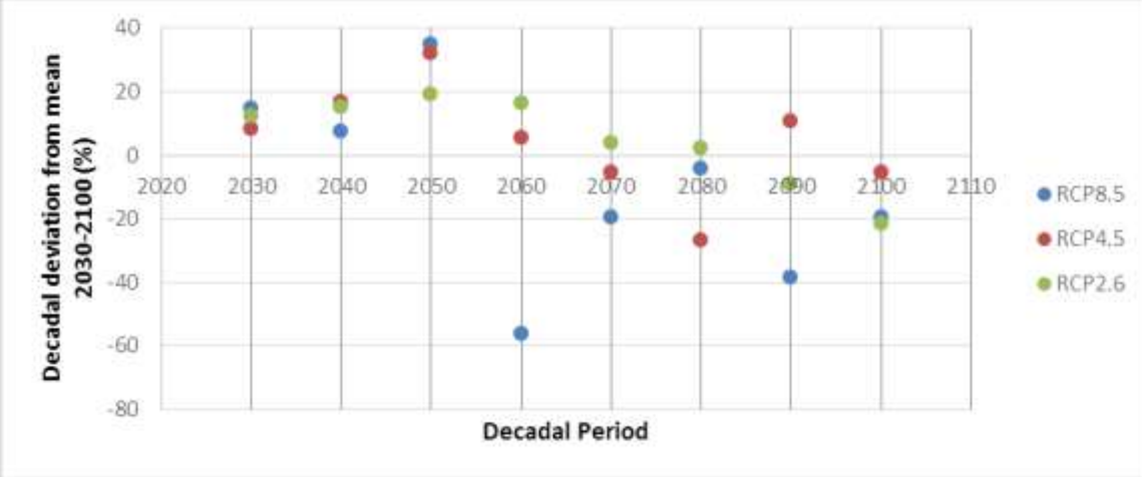


Figure 4.20a: Scatter plot of decadal mean deviation of consecutive dry days for KLB

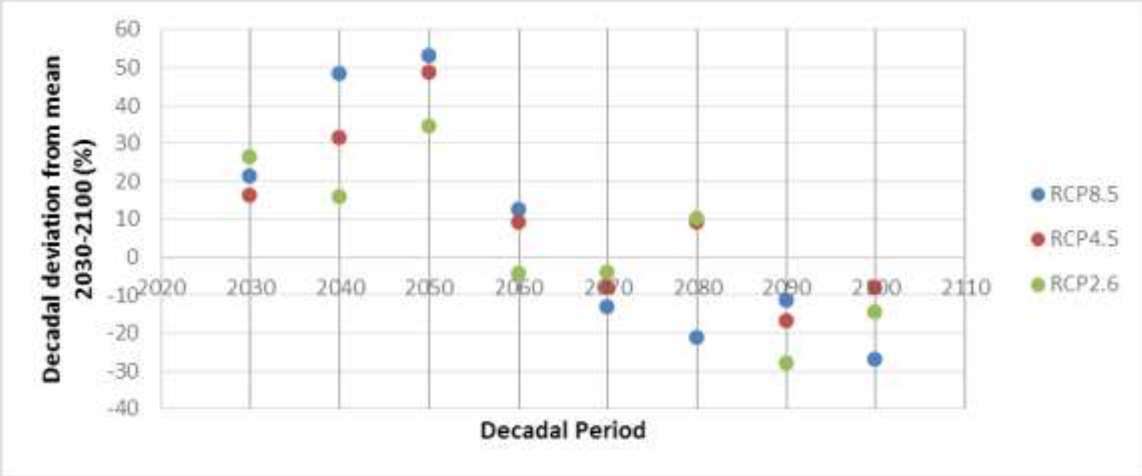


Figure 4.20b: Scatter plot of decadal mean deviation of consecutive dry days for SRB

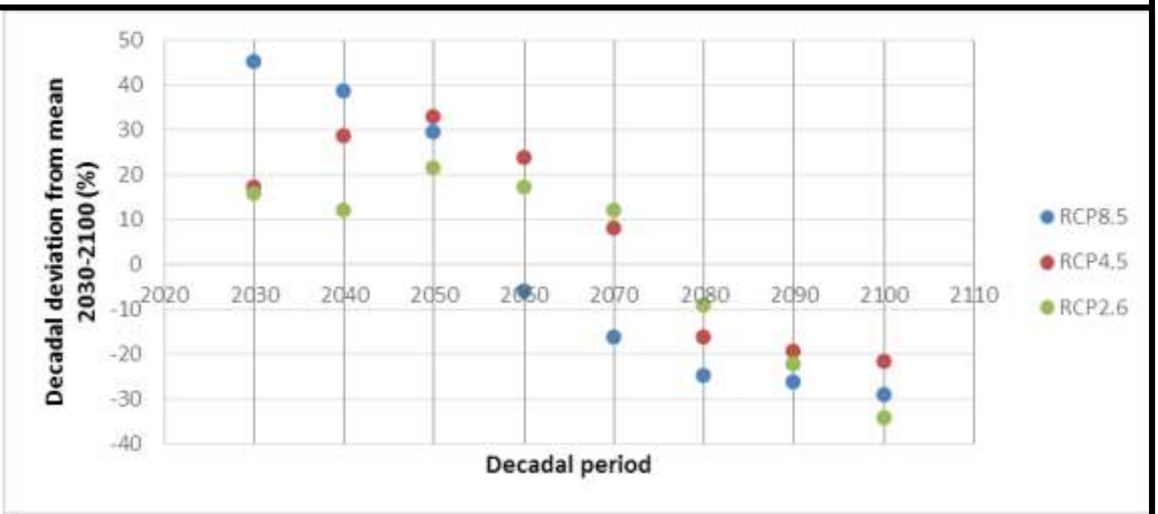


Figure 4.20c: Scatter plot of decadal mean deviation of consecutive dry days for KYB

Decades 2060, 2070, 2080 and 2090 fluctuate between positive and negative departure that ranges from (-58 to +19%) mainly under 2060. RCP2.6 singly responsible for the positive departures under the three decades (Figure 4.20a). Only 2100 decade demonstrates negative departure with a range of (-7 to -20%). RCP2.6 accounts for the highest negative departure while RCP4.5 lowest negative departure. In SRB, departures of CDD reveal continuous positive departure for low and higher CO_2 emission trajectories from 2030 through 2050 with a range of (+17 to +55%). The decade with lowest positive departure being 2040 under RCP2.6 while highest positive departure is 2050 under RCP8.5 (Figure 4.20b).Decades 2060 and 2080 experience fluctuation between positive and negative departures within the range of (-22%) in 2080 to (+12%) in 2060 for RCPs 2.6, 4.5 and 8.5. Absolute negative departure are confirm in 2070, 2090 and 2100 with a range of (-2 to -29%). The lowest in 2070 and highest in 2090 are both under RCP2.6. In addition, the situation over KYB implies positive departure in 2030, 2040 and 2050. RCP8.5 responsible for highest positive departure in 2030 and 2040 but 4.5 in 2050 with departure rates of 55%, 40% and 33% respectively. The lowest departure rate in 2030, 2040 and 2050 are 15%, 11% and 21% respectively. Fluctuations between positive and negative departures exist in 2060 and 2070 which ranges from (-18%) in 2070 to (+23%) in 2060. Decades 2080, 2090 and 2100 reveal absolute negative departures with a range of (-17 to -35%) such that RCP4.5 responsible for the lowest negative departure while RCP2.6 being highest negative departure (Figure 4.20c).

4.4: Estimation of Water Stress

4.4.1: Water Stress under climate change with constant population

The projected changes under climate change at constant population growth over the area are shown (Table 4.12). The per capita water across the KLB, SRB and KYB reveals a

Table 4.12: Water stress under climate change with constant population in KLB, SRB and KYB

Basin	Years	Population (Millions)	TWA (MCM/year)	Per Capita W(CM/year)	Falkenmark Index		
					rcp2.6	rcp4.5	rcp8.5
KLB	1991-2005	172,835	13700	79266	NS	NS	NS
	2006-2018	172,835	12,250	70876	NS	NS	NS
	2019-2048	172,835	11,500	66537	NS	NS	NS
	2049-2078	172,835	10,850	62776	NS	NS	NS
	2079-2100	172,835	9,610	55602	NS	NS	NS
SRB	1991-2005	16,100,000	1,789	111	AS	AS	AS
	2006-2018	16,100,000	1,336	82	AS	AS	AS
	2019-2048	16,100,000	1,092	67	AS	AS	AS
	2049-2078	16,100,000	823	51	AS	AS	AS
	2079-2100	16,100,000	693	43	AS	AS	AS
KYB	1991-2005	18,400,000	4,182	227	AS	AS	AS
	2006-2018	18,400,000	3,845	208	AS	AS	AS
	2019-2048	18,400,000	3,328	180	AS	AS	AS
	2049-2078	18,400,000	3,164	171	AS	AS	AS
	2079-2100	18,400,000	2,852	155	AS	AS	AS

Total Water Availability (TWA), Per Capita Water (PCW), Million Cubic Metre (MCM)
No Stress (NS), Absolute Scarcity (AS)

space and time differentials. Based on the 2006 population census, which stand at 172.8 thousand for KLB, the total available water was 13.7 BCM/year and the per capita water was 79,266 CM/year which reveals that there was no water stress with respect to the three CO_2 emission pathways namely RCP2.6, RCP4.5 and RCP8.5. Conversely, the emission trajectories for lower scenario as well as highest scenario indicate that there is absolute scarcity of water in this basin (Table 4.12). As for the KYB, it had a population of 18.4 million under the same time with total water availability of 4.2 BCM/year and per capita water of 227 CM/year. At 2018, the population projection based on the 2006 census of 2.6% growth rate, the total population of KLB was 212.3 thousand with total water availability was 12.25 BCM/year and per capita water was 70876 CM/year which means there was no water stress in the basin.However, the situation at SRB during the same time shows a total water availability of 1.34 BCM and per capita water of 88CM/year which is far below the minimum per capita water of 500 CM/year and indicate that the basin is in condition of absolute scarcity. Similarly, the condition over KYB at the same period confirms that total water availability stood at 3.8 BCM/year and per capita water of 208 CM/year. This also indicates condition of absolute scarcity in KYB but the magnitude is less compare to condition over SRB.

By near-term (2019-2048), projected total available water will be 11.5 BCM/year and per capita water will be 66,537 CM/year over the KLB which indicate absence of water stress under the three CO_2 emission scenarios. The condition changes over the SRB with total water availability of 1.1 BCM/year and per capita water of 67CM/year. All the three RCPs show condition of absolute scarcity over the SRB. At KYB, the total available water will stand at 3.4 BCM/year and per capita water will be 180 CM/year. This also indicates absolute scarcity of water in this basin under the lower and highest emission trajectories. During mid-term projection (2049-2078), KLB total water availability will decrease to 10.85 BCM/year and per capita water is put at 62,776 CM/year. The CO_2 emission under the three RCPs indicates that there will be no water stress over this basin (Table 4.12). However, the situation over SRB during the same period put total available water at 823MCM/year and per capita water at 51 CM/year. Also, the emission trajectories of the three RCPs reveal that absolute scarcity of water will prevail over this basin. More so, the situation over KYB is not much different from that obtainable over SRB just that the magnitude is less with total available water of 3.2 BCM/year and per capita water stand at 171 CM/year. Just like over SRB, the lower and higher emission scenarios indicate absolute water scarcity in KYB.

Long-term projection (2079-2100) of per capita water over KLB reveals that total water availability of 9.6 BCM/year and per capita water stand at 55, 60 CM/year. The condition with respect to RCP2.6, RCP4.5 and RCP8.5 indicate no water stress. SRB condition under this time period projected total water availability of 693 MCM/year and per capita water of 43 CM/year with all the three CO_2 emission pathways portraying water condition of the basin to be under absolute scarcity. Furthermore, projected water condition over KYB at this time period shows that total available water will be 2.9 BCM/year and per capita water of 155 CM/year (Table 4.12). The representative concentration pathways of 2.6, 4.5 and 8.5 indicate absolute water scarcity. In addition, per capita water availability over KLB, SRB and KYB during the short, mid and long-term projections was subjected to Mann-Kendal trend analysis tested at the 0.05 significance levels. Trend analysis at individual basin confirms that at the KLB there is no positive trend in water stress but at the SRB and KYB there is significant positive trend in water stress for all three RCPs and the projection periods. This will no doubt affect the agricultural activities which predominantly is the major occupation of people within these basins. Regional trend of all the three basins as a whole, indicate that absolute water scarcity is alarming in the entire Guinea and Sudano-Sahelian ecological zones of Nigeria with respect to all the three emission scenarios as well as across the projection time periods. These upward trends were tested at the 0.05 significance levels were all found to be significant (Table 4.13).

Table 4.13: Mann–Kendall trend analysis of projected water stress for KLB, SRB and KYB

Climatic Period	Water Stress											
	Climate Change			Population Growth			Combined Impacts			Regional Trend		
	RCP8.5											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	1.96*	1.30	2.48*	2.35*	1.82	2.39*	2.31*	1.93*	0.36	2.86*
2049-2078	1.06	2.31*	2.67*	0.89	2.39*	1.94*	0.19	2.63*	2.53*	2.05*	2.75*	2.31*
2079-2100	0.82	2.61*	1.98*	0.56	2.05*	2.64*	0.33	2.24*	2.51*	2.48*	2.33*	2.38*
	RCP4.5											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	2.36*	1.30	1.98*	2.35*	1.82	2.39*	2.31*	1.97*	2.36	2.86*
2049-2078	1.06	2.31*	1.97*	0.89	2.39*	2.74*	0.19	2.63*	2.53*	2.05*	1.95*	2.31*
2079-2100	0.82	2.61*	2.08*	1.56	2.05*	2.64*	0.33	2.24*	2.51*	1.94*	2.33*	2.38*
	RCP2.6											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	2.36*	1.30	1.98*	2.35*	1.82	2.39*	2.31*	1.93*	0.36	2.86*
2049-2078	1.06	2.31*	2.67*	0.89	2.39*	1.94*	0.19	2.63*	2.53*	2.05*	2.75*	2.31*
2079-2100	0.82	2.61*	2.88*	2.56	2.05*	2.64*	0.33	2.24*	2.51*	1.92*	2.33*	2.38*

**= Statistically significant trends at the 0.05 significance level.*

From the forgoing it is evident that climate change will amplify water stress condition due mainly from decreasing rainfall with corresponding increasing temperature. This is in agreement with Lapidez, (2016) that projected for the future three periods (2006–2030, 2031–2055, and 2056–2080) an increase in water deficiency in all seasons for parts of the Philippines due to a projected increase in temperature and decrease in precipitation. That the decrease in water availability will increase water stress in the basin, further threatening water security for different sectors. Similar scenarios have been reported by Pervez and Henebry (2015) in Bangladesh, Ahmed *et al.* (2017) in Morroco, Deniz *et al.* (2017) in Chile, Lulii *et al* (2017) in Ukrain, and Xiaoqiang and Wenjie (2019) in China. In addition, Gebre and Ludwig (2015) reported that around 2010, the southern and eastern rims of Mediterranean basin were experiencing high to severe water stress. By the 2050 horizon, this stress could increase over the whole Mediterranean basin, notably because of a 30–50% decline in freshwater resources as a result of climate change. That the worrying trend indicate the need to develop mitigation scenarios. Likewise, Pengpeng *et al.* (2017) stated that in China, estimates of 368 million people (nearly one third of the total population) were affected by severe water stress annually during the historical period (1979-2008), while future projections indicate that more than 600 million people (43% of the total) might be affected by severe water stress, and half of China's land area would be exposed to stress. Besides, aggravating water stress conditions could be partly attributed to the elevated future water withdrawals.

4.4.2: Water Stress under population growth with constant climate

Table 4.14 shows projected changes in per capita water under population growth at constant climate over the KLB, SRB and KYB in the Guinea and Sudano-Sahelian ecological zones of Nigeria. At the KLB during the 2005, the population was 172,835 thousand with total water availability of 13.7 BCM/year and per capita water of 79,266 CM/year. This means there was no water stress in this basin based on the Falkenmark index which indicates minimum per capita water of 500 CM/year. However, the situation over the SRB duringthis period shows that the population was 16.1 million with total water availability of 1.8 BCM/year and per capita water of 111 CM/year. The per capita water according toFalkenmark index indicates that the basin was in absolute scarcity.

Table 4.14: Water stress under population growth with constant climate in KLB, SRB and KYB

Basin	Year	Population (Millions)	TWA (MCM/year)	Per Capita W(CM/year)	Falkenmark Index
KLB	1991 – 2005	172,835	13,700	79266	NS
	2006 – 2018	212,231	13,700	70677	NS
	2019 – 2048	446,768	13,700	33574	NS
	2049 – 2078	940,492	13,700	15949	NS
	2079 – 2100	1,571,456	13,700	9545	NS
SRB	1991 – 2005	16,100,000	1,789	111	AS
	2006 – 2018	21,907,569	1,789	82	AS
	2019 – 2048	46,117,701	1,789	39	AS
	2049 – 2078	97,082,535	1,789	18	AS
	2079 – 2100	162,213,996	1,789	11	AS
KYB	1991 – 2005	18,400,000	4,182	227	AS
	2006 – 2018	25,037,222	4,182	167	AS
	2019 – 2048	52,705,944	4,182	79	AS
	2049 – 2078	110,951,469	4,182	38	AS
	2079 – 2100	185, 387, 424	4,182	23	AS

Total Water Availability (TWA), Per Capita Water (PCW), Million Cubic Metre (MCM) No Stress (NS), Absolute Scarcity (AS)

Similar situation is obtainable over KYB though, with less magnitude. The population stood at 18.4 million with total available water of 4.2 BCM/year and per capita water of 227 CM/year.By2018 based on projected population, water stress has already intensified in the Guinea and Sudano-Sahelian ecological zones of Nigeria as represented by the KLB, SRB and KYB. The population was projected to be 212.2 thousand, 21.9 million, and 25.1 million for KLB, SRB and KYB respectively. While per capita water for KLB stand at 70,677 CM/year, for SRB is 82 CM/year and KYB is 167 CM/year. This is an indication that water stress is imminent over SRB and KYB but no stress over KLB. For near term projection (2019-2048), the population is projected to be 446.7 thousand over KLB with per capita water of 33,574 CM/year indicating no stress. While over the SRB, population will be 46.2 million with per capita water of 39 CM/year indicating absolute scarcity. Estimation over the KYB reveals population of 52.8 million with per capita water of 79 CM/year portraying the basin to be under absolute scarcity condition (Table 4.14). This means that underground water will be highly exploited to augment the shortages from the surface water.

By mid-term projection (2049-2078), population of the KLB will be 940.5 thousand with per capita water of 15,949 CM/year indicating no water stress. The SRB population stands at 97.1 million with per capita water of 18 CM/year, while the KYB population will be 111.0 million with per capita water of 38 CM/year. Still at the KLB there is no water stress but the situation over the SRB and KYB will be absolute water scarcity with a little variation. During the long term projection (2079-2100), it is estimated that population over the KLB will be 1.6 million with per capita water of 9,545 CM/year. While the SRB will have population of 162.3 million with per capita water of 11 CM/year. As for the KYB, population will be 185.4 million with per capita water of 23 CM/year. These figures are indications that the Guinea and Sudano-Sahelian ecological zones already stressed water condition will intensified toward the end of the century. This is in agreement with Coffel *et al*. (2019) that regional water scarcity will continue to be a chronic issue for the Upper Nile from population growth alone, but runoff deficits during future hot and dry years will amplify this effect, leaving an additional 5-15% of the future population facing water scarcity. That adaptation and climate resilient water management policies informed by an understanding of compound extremes will be essential to manage these risks.

4.4.3: Water Stress under climate change and population growth

Per capita water under the combined influence of climate change and population growth is projected for near, mid and long-term period (Table 4.15). The 2018 projected population based on 2.6% growth rate reveals that, KLB stood at 212.3 thousand with total water availability of 12.2 BCM/year under the impact of climate change gives a corresponding per capita water of 57,720 CM/year. This value according to Falkinmark index indicates that the basin is not in water stress condition at this time. However, the situation over SRB shows population of 22.0 million and total water available under climate change to be 1.4 BCM. The per capita water stood at 60 CM/year, an indication that the basin is under absolute scarcity of water condition. Similar condition is obtainable over KYB with population of 25.1 million and total available water of 3.9 BCM/year give per capita water of 154 CM/year. This is also less than the minimum of 500CM/year.

By near term projection (2019-2048), water stress condition would have deteriorated especially over SRB and KYB given the existing situation at 2018 coupled by the ever increasing population growth and CO2 emission. These combined influences reveal that per capita water over KLB will be 25,740 CM/year, a condition of no water stress. The SRB condition under the same influence stands at per capita water of 24 CM/year. This positive trend of water stress is significant at the 0.05 significance levels for all the three RCPs. While the KYB will have a per capita water of 79 CM/year with alsosignificant positive trend of water stress with respect to lower and highest emission pathways.

Table 4.15: Water Stress under combined impacts in KLB, SRB and KYB

Basin	Year	Population (Millions)	TWA (MCM/year)	Per Capita W(CM/year)	Falkenmark Index		
					rcp2.6	rcp4.5	rcp8.5
KLB	1991-2005	172,835	13700	79266	NS	NS	NS
	2006-2018	212,231	12,250	57720	NS	NS	NS
	2019-2048	446,768	11,500	25740	NS	NS	NS
	2049-2078	940,492	10,850	11536	NS	NS	NS
	2079-2100	1,571,456	9,610	6115	NS	NS	NS
SRB	1991-2005	16,100,000	1,789	111	AS	AS	AS
	2006-2018	21,907,569	1,336	60	AS	AS	AS
	2019-2048	46,117,701	1,092	24	AS	AS	AS
	2049-2078	97,082,535	823	8	AS	AS	AS
	2079-2100	162,213,996	693	4	AS	AS	AS
KYB	1991-2005	18,400,000	4,182	227	AS	AS	AS
	2006-2018	25,037,222	3,845	154	AS	AS	AS
	2019-2048	52,705,944	3,328	63	AS	AS	AS
	2049-2078	110,951,469	3,164	29	AS	AS	AS
	2079-2100	185,387,424	2,852	15	AS	AS	AS

Total Water Availability (TWA), Per Capita Water (PCW), Million Cubic Metre (MCM) No Stress (NS), Absolute Scarcity (AS)

At mid-term projection (2049-2078) per capita water over the KLB decreases to 11,536 CM/year but still not under water stress condition. Trend analysis of water stress at the 0.05 significance levels indicates no significant positive trend for RCP2.6, RCP4.5 andRCP8.5 CO_2 emissions. But at the SRB, per capita water decreases to 8 CM/year.

A condition of absolute water scarcity and found to be significant at the 0.05 significance levels with respect to the three emission scenarios. In KYB per capita water will decreases to 29 CM/year though higher than in SRB. The trend analysis shows that the positive trend of water stress is still significant at the 0.05 significance levels for all the three emission trajectories.

During the long-term (2079-2100), estimated per capita water of KLB would have decreases to 6,115 CM/year but no significant positive trend of water stress with regard to RCP2.6, RCP4.5 and RCP8.5. However, the SRB per capita water would stand at 4 CM/year. This indeed portray a serious danger because the surface water condition of this basin at this time cannot meet the basic domestic need of the population, talk less of the agriculture water need which is highly demanded. Similar situation exist over the KYB though with lesser magnitude comparable to the SRB. Per capita water would be 15 CM/year in KYB. This value also indicates deficiency of the surface water to meet the domestic and agricultural water need of the people in this basin. The decline in per capita water was subjected to trend analysis at the 0.05 significance levels. Analysis shows a significant positive trend in water stress condition.

Regional trend analysis shows that the entire region will experience significant upward trend in water stress under the combined impacts of climate change and population growth for the short, mid and long-term projection in the Guinea and Sudano-Sahelian ecological zones of Nigeria. The implication of this finding is that surface water resources cannot meet the ever increasing water demand for various uses. Hence, serious exploitations of the underground water. This is in agreement with Corneliu *et al.* (2015) that confirmed similar trends in water availability in Kenya where as much as climate change impacts the recharge rate, the impact is dwarfed by the effect of demand driven chiefly by population growth. Further, effective volume of freshwater in the aquifer is expected to be exhausted, that is, be reduced to the zero level between 2022–2027 for the RCP 2.6 scenario and 2023–2028 for the RCP 8.5. Also, Pankaj *et al.* (2017) reported similar trend in Indonesia as well as Gneneyougo *et al*. (2017) in Côte D'ivoire. Anastasia *et al.* (2018) reported climate change will alter the hydrological regimes of rivers in Europe. This will create additional challenges for water resources which are already stressed due to extensive anthropogenic activities. Therefore, the impacts of the projected climate change have to be understood and incorporated into the regional water management strategies to ensure sustainable approach in governing the water systems.

4.4.4: Decadal departures of per capita water availability under climate change

The figure 4.21a-c show decadal departure of per capita water under climate change at constant population.

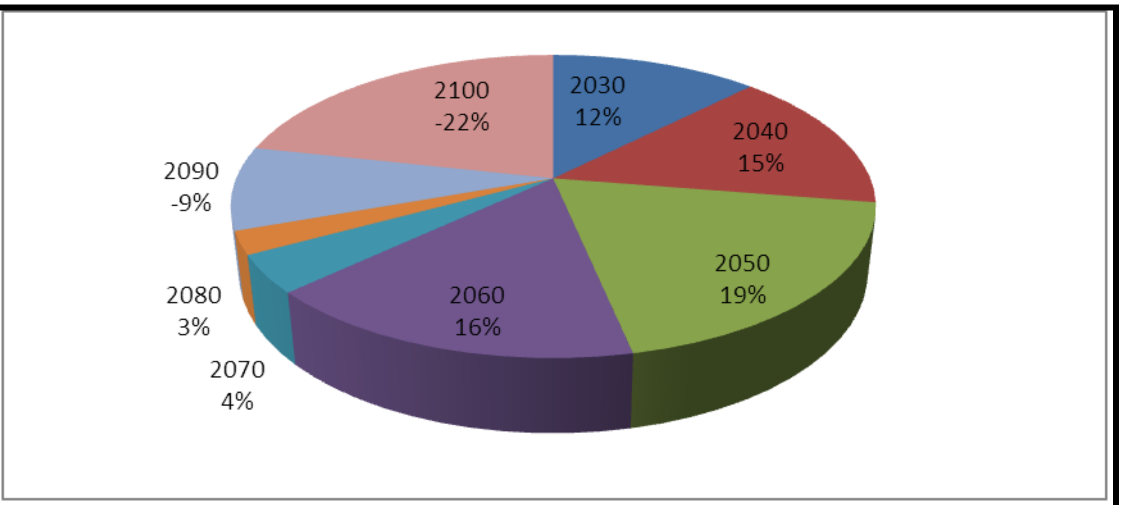


Figure 4.21a:deviation of per capita water under climate change for KLB

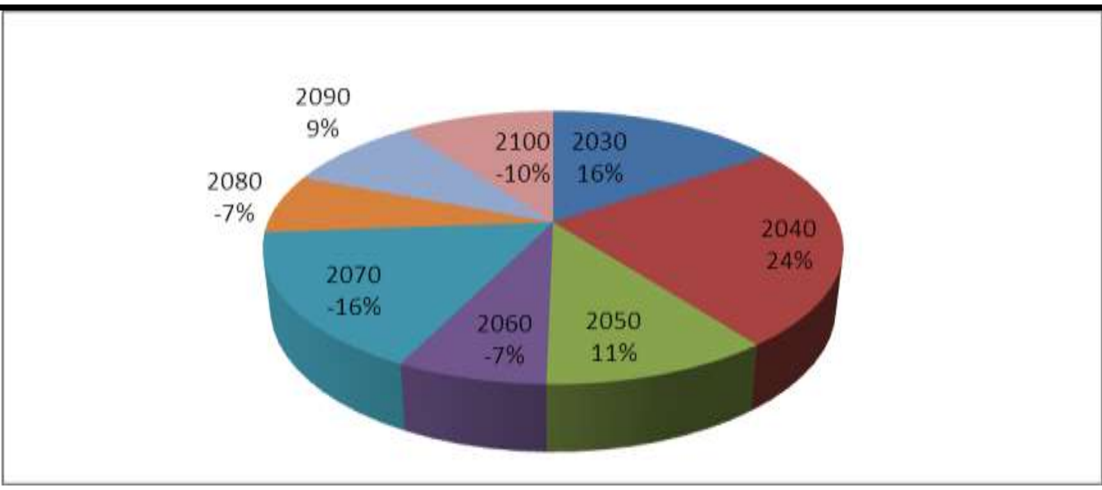


Figure 4.21b:deviation of per capita water under climate change for SRB

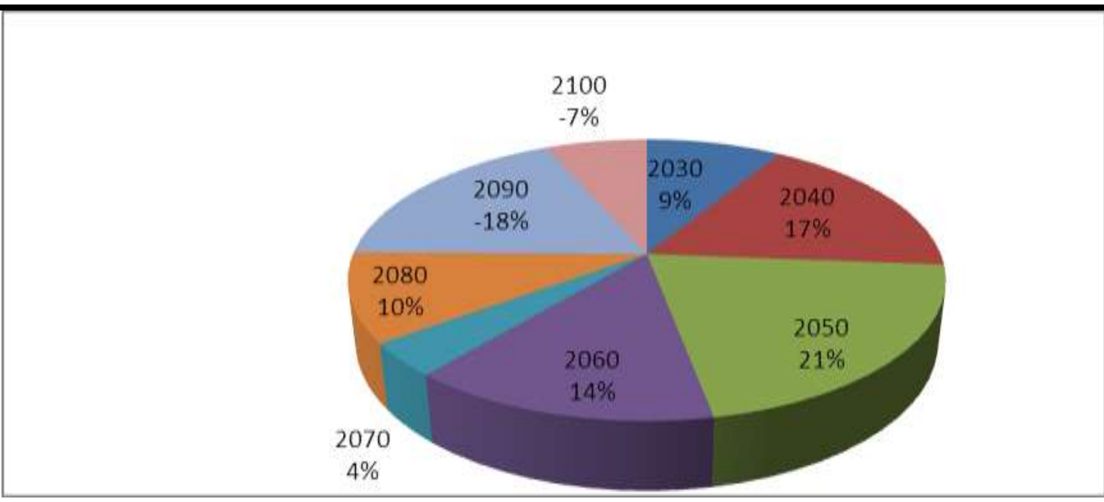


Figure 4.21c:deviation of per capita water under climate change for KYB

from the projected average of 2030-2100 over KLB, SRB and KYB. The KLB decadal departure of per capita water under the influence of changing climate but constant population informs that 2090 and 2100 will experience absolute negative departure with a range of (-9%) to (-22%) respectively. This are clear indication that the incidence of water stress are likely to manifest over this basin at this time given the fact that the per capita water is below the average toward the end of the 21st century.

However, 2030, 2040, 2050, 2060, 2070 and 2080 show a positive departure from the average. Among these decades, 2070 and 2080 are just slightly above average with (+4%) and (+3%) respectively. Decade 2050 has the highest positive departure with departure rate of (19%) indicative of surplus per capita water. Moreover, SRB situation reveal that 2060, 2070, 2080 and 2100 will witness prevalence of negative departure in per capita water indicative of water deficit condition (-7%), (-16%), (-7%) and (-10%) correspondingly. Conversely, 2030, 2040, 2050 and 2090 will experience positive departures in per capita water with 2040 responsible for the highest positive departure (24%). In KYB, it is also likely to experience both positive and negative departure.Figure (4.21c) confirms that 2090 and 2100 will be worse hit by water stress with negative departure rate of (-18%) for the former while (-7%) for the latter. Over this basin, 2050 will witness highest positive departure (+21%) while 2070 responsible for the lowest positive departure (+4%).

4.4.5: Decadal departures of per capita water availability under population growth at constant climate

The figure 4.22a-c show decadal departure of per capita water under population growth at constant climate over the three basins under study namely KLB, SRB and KYB.

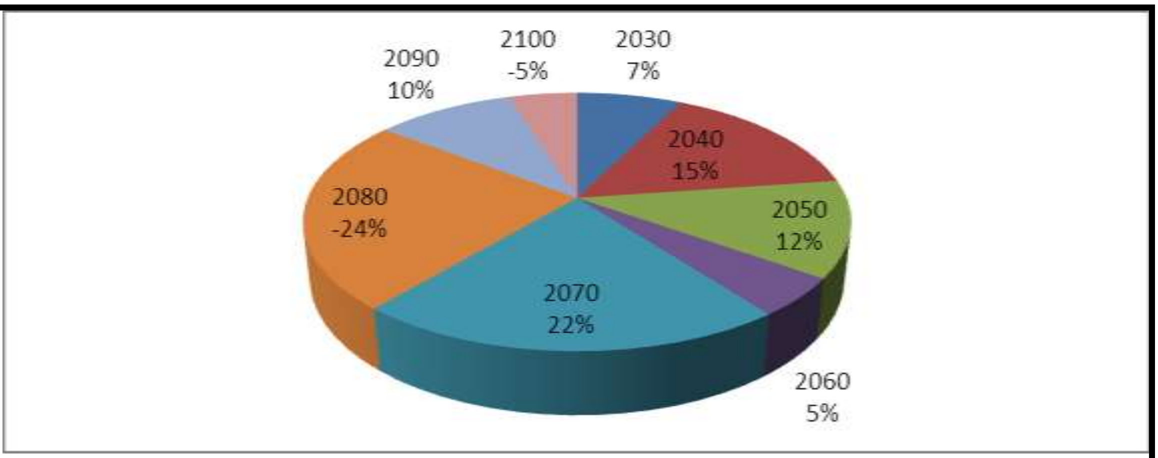


Figure 4.22a: deviation of per capita water under population growth for KLB

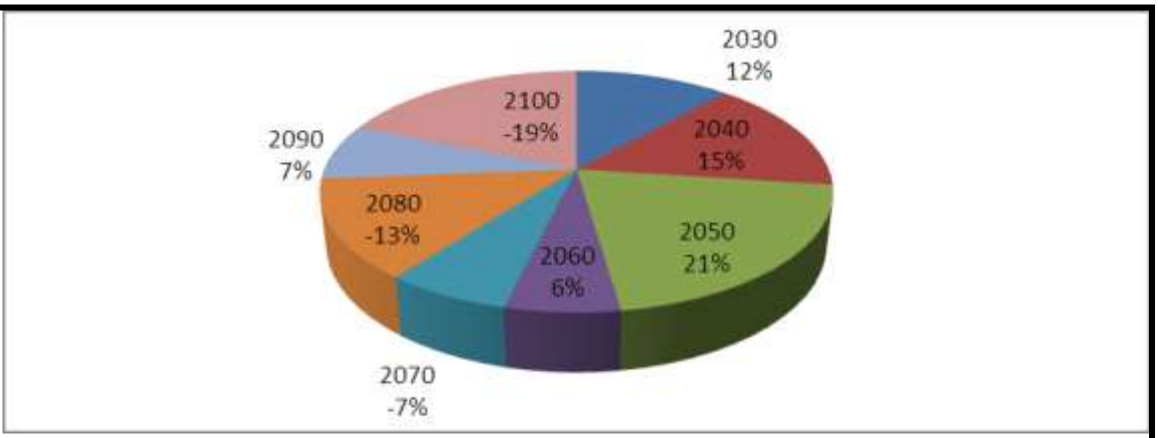


Figure 4.22b:deviation of per capita water under population growth for SRB

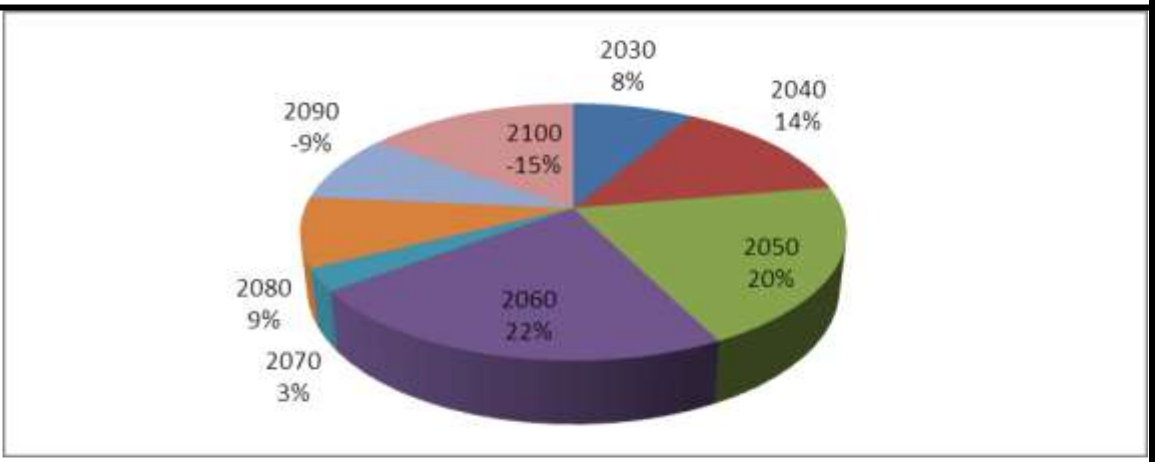


Figure 4.22c: deviation of per capita water under population growth for KYB

At the KLB, per capita water shows occurrence of negative departure in 2080 with (-24%) and 2100 (-5%). This entails that 2080 will accounts for the lowest per capita water under population growth. Decades 2030, 2040, 2050, 2060, 2070 and 2090 will experience positive departure in per capita water with 2070 (+22%) being the highest while 2060 will be least (+5%) figure (4.22a). In the SRB, negative departure in per capita water are likely in 2070, 2080 and 2100 with a rate of (-7%), (-13%) and (-19%) respectively. This show that 2100 will experience the worst water stress while 2070 will be the least. Conversely, positive departure in per capita water is expected in 2030, 2040, 2050, 2060 and 2090 within the range of (+6% to +21%) such that 2050 accounts for the highest and least is obtainable in 2060. Similarly, the KYB decadal per capita water does not show distinct pattern as witness from other basins. It indicate negative departure in 2090 and 2100 with (-9%) and (-15%) respectively. While positive departures are shown in 2030, 2040, 2050, 2060, 2070 and 2080 with 2060 accountable for the highest (+22%) and lowest in 2070 with (+3%) as shown in (Figure 4.22c)

4.4.6: Decadal departures of per capita water availability under combined impacts

With regard to combined impacts of climate change and population growth, per capita water for the KLB, SRB and KYB are presented in figure 4.23a-c.

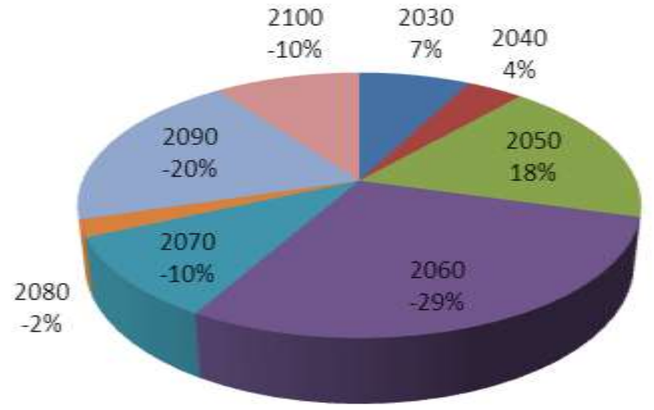


Figure 4.23a: deviation of per capita water under combined impact for KLB

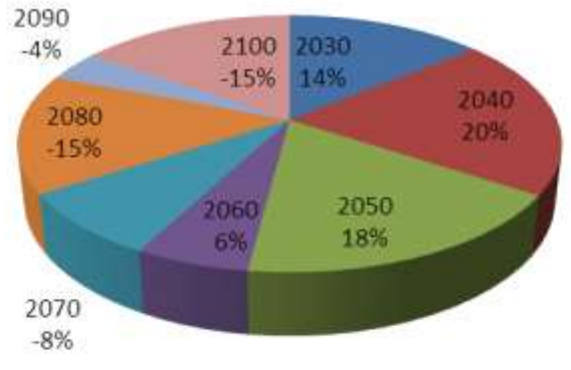


Figure 4.23b: deviation of per capita water under combined impact for SRB

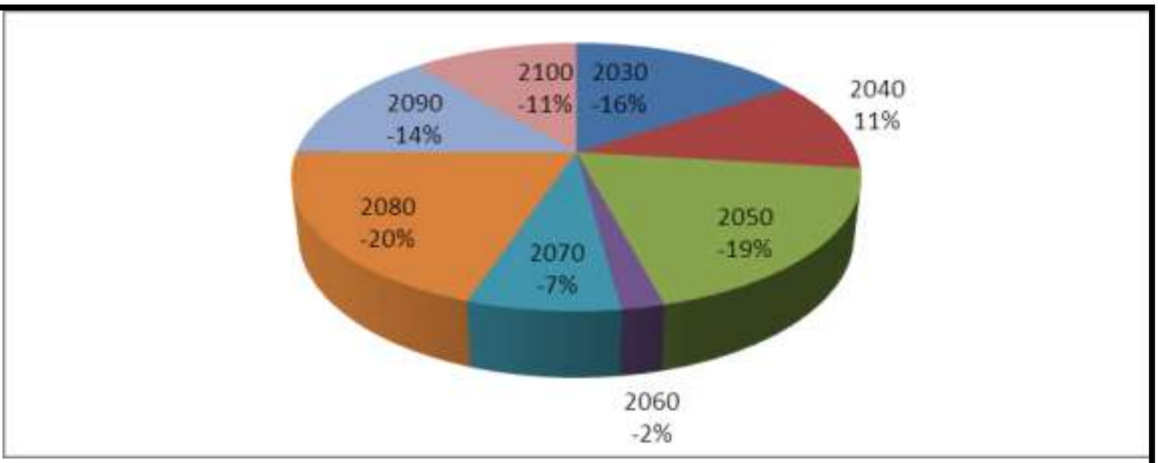


Figure 4.23c: deviation of per capita water under combined impact for KYB

At the KLB, combined impacts of climate and population confirms a decrease in per capita water. Per capita water over this basin will experience negative departure in 2060, 2070, 2080, 2090 and 2100. This is not surprising considering the facts that these periods are associated with spontaneous emission of CO_2 with nomitigation measures combined with increasing population. However, the worst hit among thesedecades is 2060 with negative departure rate of (-29%) while the least is 2080 (-2%). Conversely, positive departure in per capita water ranges from (+4% to +18%) mainly concentrated in the first three decades of 2030, 2040 and 2050.SRB per capita water under the influence of climate change and population growth authenticate that incidences of negative departure in per capita water will manifest from 2070 – 2100 which ranges from (-15% to -4%) with 2080 and 2100 accountable for the highest departure in magnitude of (-15%) each. But, positive departures are likely in 2030 – 2060 within the range of (+6% to +20%) such that 2040 responsible for the highest positive while least is 2060 (Figure 4.23b). Moreover, the condition over KYB reveals a worst case scenario given the fact that most of the decades are likely to experience negative departure in per capita water. The only exception to this is 2040 where it is observed that there will be positive departure in per capita water with rate of (+11%). As earlier mentioned, the negative departure ranges from (-2% to -20%) with 2080 responsible for the former while 2060 for the latter.

4.5: Summary of findings

CMIP5 multi-model ensemble mean simulation compared with observed rainfall and temperature in the Guinea and Sudano-Sahelian ecological zones of Nigeria was evaluated using statistical metrics. The metrics were root mean square error (RMSE), Mean Absolute Error (MAE) and Nash-Sutcliffe Efficiency (NSE). In general, despite the variations in the ability of the CMIP5 multi-model ensemble mean to reproduce seasonal and annual temperature and rainfall across the three basins, the errors between the observed and simulated were within the acceptable threshold.Therefore, the multi-model ensemble mean was used to project with references to 1959-1988 and 1989-2018 baselines. The projection periods were near-term (2019-2048), mid-term (2049-2078) and long-term (2079-2100) for three CO_2 emission trajectories (RCPs 2.6, 4.5 and 8.5).

Furthermore, analysis based on the stated objectives reveal that seasonal and annual temperature will increase from the near-term through mid-term to the long term projected period with reference to the first and second baselines of (1959-1988) and (1989-2018) respectively in the KLB, SRB and KYB. The increase will be for RCP8.5 from (1^oC to 5.8^oC), RCP4.5 (1^oC to 2.5^oC) and RCP2.6 (1^oC to 1.5^oC). Regional trend analysis of the three basins refers to as the Guinea and Sudano-Sahelian ecological zones of Nigeria tested at the 0.05 degree of alpha confirm significant positive trends for (2019-2048), (2049-2078), and (2079-2100) with respect to highest emission trajectories. On the other hand, seasonal and annual rainfall projection over Guinea and Sudano-Sahelian ecological zones of Nigeria for the same time horizon confirm high level of variability unlike temperature. The ranges of (0.1 to 0.7 mm/day) dry season projections were observed, (0.4 to 3.0 mm/day) for wet season while in annual (0.2 to 2.2 mm/day) were obtainable. Regional trend analysis of the three basins refers to as Guinea and Sudano-Sahelian ecological zones of Nigeria tested at the 0.05 degree of alpha prove there is no significant positive trends for (2019-2048), (2049-2078), and (2079-2100) in dry season and annual time series but significant in wet season with respect to medium and high emission trajectories.

However, water yield during dry season reveals decreasing range of (-0.05 to -0.1 mm/day) with reference to the two baselines of 1959-1988 and 1989-2018. Regional trend analysis of the three basins as a whole confirms that the Guinea and Sudano-Sahelian ecological zones of Nigeria will experience decreasing dry season water yield from the near term (2019-2048), mid-term (2049-2078) and long term (2079-2100) with reference to 1959-1988 and 1989-2018 baselines. It is observed that the decreasing dry season water yield were only significant for RCP8.5 but not under middle and low emission trajectories. As for wet season, regional trend analysis of water yields over Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that under 2019-2048 period there is no significant increasing trends at the 0.05 significance levels. This is with respect to high emission scenario (RCP8.5) but significant in low and middle emission scenarios (RCPs 2.6 and 4.5). Regional trend analysis of average annual water yields over the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that there were no significant positive trends for RCPs 2.6, 4.5 and 8.5 with respect to the three projected periods under consideration. This is to say that despite the projected creasing pattern of average annual water yield observed over Guinea and Sudano-Sahelian ecological zones, incidences of water crisis cannot be ruled out because the anticipated increase not statistically significant at the 0.05 degree of alpha.

It is evident that regional trend analysis of maximum 5-day rainfall over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria demonstrate that under 2019-2048 period there is no significant positive trend at the 0.05 significance levels. This is with respect to lower emission scenarios (RCP2.6 and RCP4.5) but significant in higher emission scenario (RCP8.5). By (2049-2078) through (2079-2100) period, there is significant positive trend in the whole Guinea and Sudano-Sahelian ecological zone as a region for maximum 5-day rainfall time series with respect to all the RCPs. The total number of days in a year with rainfall >10 mm (heavy rainfall days) in the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100 illustrate that the heavy rainfall days will increase within the range of 7–10 days and 3-8 days for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018) respectively. Regional trend analysis of heavy rainfall days over the Guinea and Sudano-Sahelian ecological zone of Nigeria point out that there is no significant positive trends for RCP2.6 with respect to the three projected periods under consideration but significant with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to (2049-2078) and (2079-2100) periods.

CWD decreases to 3 and 2 days under RCPs 2.6 and 4.5 respectively but, decreases by -2 days under RCP8.5 with reference to 1959-1988 baseline. While with reference to 1989-2018 baseline a decrease of 4 days for RCPs 2.6 and 4.5 but 2 days under RCP8.5. Regional trend analysis of CWD over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zone of Nigeria established that there were no significant negative trends. This is with respect to the three projected periods for RCPs 2.6 and 4.5, except RCP8.5 that was significant at the 0.05 significance levels for long term (2079-2100) projection period. Conversely, CDD will increases within the range of 2-5 days and 6-10 days for all the three RCPs under the two baseline periods of (1959-1988) and (1989-2018) respectively over the KLB. RCP8.5 accounts for the highest increase, while RCP2.6 accounts for the lowest under the two baselines. Regional trend analysis of CDD over the Guinea and Sudano-Sahelian ecological zone of Nigeria reveals that there are no significant positive trends with respect to the three projected periods and emission pathways except RCP8.5 that is significant at the 0.05 significance levels for long-term (2079-2100) projection period.

The per capita water condition was projected based on three different circumstances which are changes under climate change at constant population growth, changes under population growth at constant climate as well as changes under the combined influence of climate change and population growth. The per capita water of KLB, SRB and KYB were unified as one region that is the Guinea and Sudano-Sahelian ecological zones of Nigeria. Regional trend analysis shows that the entire region will experience significant positive trend in water stress with respect to climate change impact for mid and long term periods whereas no significant trend under the short term projection. Trends were tested at the 0.05 significance levels. However, regional trend under the influence of population growth at constant climate observed that there are significant positive trends in water stress for the three projected periods. More so, the same positive trends were obtained under the combined impacts of climate change and population growth for the short, mid and long term projection in the Guinea and Sudano-Sahelian ecological zones of Nigeria.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1: CONCLUSION

In this thesis, climate change impact on water resources availability in the Guinea and Sudano-Sahelian ecological zones of Nigeria has been undertaken using various approaches for different functional analysis. The following conclusions are drawn. Seasonal and annual temperature in Guinea and Sudano-Sahelian ecological zones will continue to warm up from the near-term (2019-2048) through mid-term (2049-2078) to long-term (2079-2100).There are slight differences in the warming pattern from KLB, SRB and KYB. The anticipated seasonal warming will be higher during dry than wet season which range from (0.5^{o}C to 6^{o}C).Furthermore, regional trend analysis of seasonal and annual temperature tested at the 0.05 degree of alpha confirm significant positive trends of the Guinea and Sudano-Sahelian ecological zones of Nigeria and therefore, communicate the sensitive nature of these zones to climate change. On the other hand, seasonal and annual changes of rainfall unlike temperature reveal high level of variability throughout the projected periods. Both dry and wet season will witness increase in rainfall amount but will be highest under wet season across the Guinea and Sudano-Sahelian ecological zones of Nigeria with a range of (0.2 to 2.5 mm/day). Regional Kendal test at the 0.05 confidence level confirm significant increase during wet season but not in dry season alongside annual projection.

Water yield based on (P-E) projections were generated for three periods - the near-term (2019-2048), mid-term (2049-2078), and long-term (2079-2100). The results indicate that water yield can be expected to be characterized by higher variability under all climate change scenarios, such that dry season water yield will decreases across the entire Guinea and Sudano-Sahelian Ecological zones though not significant but significant with respect to wet season and annual water yield. Overall, this indicates increasing risk of both flooding during wet season and drought in dry season.

Based on the results generated from the analysis of the extreme rainfall indices, it can be deduced that there is significant upward trend in the whole Guinea and Sudano-Sahelian ecological zone as a region for maximum 5-day rainfall time series with respect to all the three RCPs. As for heavy rainfall(>10mm)reveals that there is no significant positive trends for RCP2.6 with respect to the three projected periods under consideration but significant positive trends with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to (2049-2078) and (2079-2100) periods. Decrease (increase) in CWD(CDD) both not significant at the 0.05 confidence levels indicate that extreme rainfall in the region becomes more evenly distributed over the coming periods. Therefore, it is expected that this study will aid guidance to the understanding of the ongoing changes as well as possible changes in rainfall and rainfall-related extremes in the study area, which in turn will help in adopting necessary adaptation measures to mitigate the negative impacts of climate change in the Guinea and Sudano-Sahelian ecological zones of Nigeria.

Changes under climate change at constant population growth suggest that regional trend of all the three basins as a whole, indicate that absolute water scarcity is alarming in the entire Guinea and Sudano-Sahelian ecological zones of Nigeria with respect to all the three emission scenarios as well as across the projection time periods. These upward trends were tested at the 0.05 significance levels were all found to be significant. Conversely, under population growth at constant climate, the population was projected to be 212.2 thousand, 21.9 million, and 25.1 million for KLB, SRB and KYB respectively. While per capita water for KLB stand at 70,677 CM/year, for SRB is 82 CM/year and KYB is 167 CM/year. This is an indication that water stress is imminent over SRB and KYB but no stress over KLB. This implies that future water scarcity will by primarily caused by population growth and only secondarily by climate change in Guinea and Sudano-Sahelian ecological zones of Nigeria.

5.2 RECOMMENDATIONS

Based on the findings of the study and conclusion drawn, it is recommended that:

i. These results can act as guidelines for strategic planning for flood and drought prevention as envisaged by the projection. This will also forms a baseline for future, more robust, climate research in the Guinea and the Sudano-Sahelian ecological zones and Nigeria in general.
ii. It is necessary to incorporate climate change issues into every planning, design, construction, operation and maintenance of water infrastructure.
iii. There is the need for stakeholders' participation, farmers' education and awareness on the imminent dangers posed by the anticipated warming and its effects on crop production.
iv. It is essential for the government to put machinery in place for inter-basin water transfer to augment the imminent water stress in Sokoto-Rima and Komadugu-Yobe basins capable of affecting the livelihood of the communities around these basins.
v. Future research should explore the comparative analysis of CMIP5 and CMIP6 in reproducing historical seasonal as well as annual temperature and rainfall in the Guinea and Sudano-Sahelian ecological zones of Nigeria. This will facilitate a robust climate projection for the study area.

REFERENCES

Abaje, I. B., Ati, O. F. & Iguisi, E. O. (2012). Recent Trends and Fluctuations of Annual Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria: Risks and Opportunities. *Journal of Sustainable Society,* 1(2), 44-51.

Abaje, I. B., Ati, O. F., Iguisi, E. O. & Jidauna, G. G. (2013). Droughts in the Sudano-Sahelian Ecological Zone of Nigeria: Implications for Agriculture and Water Resources Development. *Global Journal of Human Social Science Geography, Geo-Sciences and Environmental,* 13 (2), Online ISSN: 2249-460x & Print ISSN: 0975-587X

Abdulkadir, A., Usman, M. T., & Shaba, A. H. (2015). An Integrated Approach to Delineation of the Eco-Climatic Zones in Northern Nigeria. *Journal of Ecology and the Natural Environment*, 7(9), 247-255, doi:10.5897/jene2015.0532.

Abdullahi, S. A., Muhammad, M. M., Adeogun, B. K., & Mohammed, I. U. (2014). Assessment of Water Availability in the Sokoto-Rima River Basin. *Resources and Environment,* 4(5): 220-233, doi:10.5923/j.re.20140405.03.

Abdussalam, A. F. (2015). Change in Indices of Daily Temperature and Precipitation Extremes in Northwest Nigeria. *Science World Journal,* 10 (2), ISSN 1597-6343.

Abdussalam, A. F. (2017). Potential Future Risk of Cholera Due to Climate Change in Northern Nigeria. *African Research Review: an International Multi-Disciplinary Journal,* 11 (1), 205-218. doi: 10.4314/afrrev.v11i1.15

Abghari, H., Tabari, H., & Talaee, P. H. (2013). River Flow Trends in the West of Iran during the Past 40 years: Impact of Precipitation Variability. *Global and Planetary Change,* 101, 52–60. doi:10.1016/j.gloplacha.2012.12.003

Adam, B., Martin, H., Magdalena, N., & Adam, V. (2016).Increasing Water Resources Availability under Climate Change. *International Conference on Efficient & Sustainable Water Systems Management toward Worth Living Development*, 2nd EWaS 2016.

Adeaga, O. A., Bello, A. A., & Akinbaloye, T. (2019). Water Resources Uncertainty in Yewa River Basin,Ogun state, South-West Nigeria. *World Scientific News,* 131 (2019) 37-53

Adefisan, E. (2018). Climate Change Impact on Rainfall and Temperature Distributions over West Africa from Three IPCC Scenarios. *Journal of Earth Science and Climatic Change,* 9:476.doi:10.4172/2157-7617.1000476

Adeoluwa, A., Ana, C. C., Jorge, M. & Roberto, H. (2017).Geospatial Analysis of Extreme Weather Events in Nigeria (1985–2015) Using Self-Organizing Maps. *Advances in Meteorology,* 2017: 1-11, https://doi.org/10.1155/2017/8576150

Adeyeri, O. E., Lawinb, A. E., Laux, P., Ishola, K. A., & Ige, S. O. (2019). Analysis of Climate Extreme Indices over the Komadugu-Yobe Basin, Lake Chad Region: Past and Future Occurrences. *Weather and Climate Extremes, 23(2019),* doi.org

/10.1016/j.wace.2019.100194

Agbebaku, H. U. (2015). Environmental Challenges and Climate Change: Nigeria Experience. Quest Journals: *Journal of Research in Environmental and Earth Science,* 2, (4), 01-12.

Agumagu, O., & Todd, M. (2015). Modelling the Climatic Variability in the Niger Delta Region: Influence of Climate Change on Hydrology. *Journal of Earth Science and Climate Change,* 6: 284. doi:10.4172/2157-7617.1000284

Ahmed, M., Yves, T., Lahoucine, H., Denis, R. & Lionel, J. (2017). Climate Change Impacts on Surface Water Resources in the Rheraya Catchment (High Atlas, Morocco). *Hydrological Sciences Journal*, 62, (6), doi:10.1080/02626667.2017. 1283042

Aich, V., Liersch, S., Vetter, T., Fournet, S., Andersson, J., Calmanti, S., van Weert, F., Hattermann, F. F., & Müller, E. N. (2016). Flood Projections for the Niger River Basin under Future Land use and Climate Change. *Science Total Environment*, 562, 666–677. http://dx.doi.org/10.1016/j.scitotenv.2016.04.021.

Aizebeokhai, A. P. (2011). The Impacts of Climate Change on Groundwater Resources in Nigeria. Energy, *Environment and Climate Change Research Group,* February 17, Covenant University, Ota.

Ajay, R. B., Sagar, R. B., Arun, B. S., & Sudan, B. M. (2018). Climate Change Impact Assessment on the Hydrological Regime of the Kaligandaki Basin, Nepal. *Science of the Total Environment,* 625 (2018), 837 848,https://doi.org/10.1016/j.scitotenv. 2017.12.332

Akinsanola, A. A. & Ogunjobi, K. O. (2014). Analysis of Rainfall and Temperature Variability over Nigeria. *Global Journal of Human-Social Science: B Geography, Geo-Sciences, Environmental Disaster Management,* 14 (3), Online ISSN: 2249-460x & Print ISSN: 0975- 587X

Akio, K., & Hirokazu, E. (2016). Changes in Precipitation Extremes Projected by a 20-km mesh Global Atmospheric Model. *Weather and Climate Extremes,* (11) 41–52, doi.org/10.1016/j.wace.2015.09.001

Amar, V. V. N., Leah, B., Luca, L., Berry, G., Matthew, R. H., & Anas, G. (2017). Adaptation Tipping points of Urban Wetlands under a Drying Climate. *Journal of Hydrology and Earth System Sciences Discussions,* doi: 10.5194/hess-2017-307

Amir, K. B., Haishen, L., Abubaker, O., Abubaker, B. A., & Abdeldime, M. S. A. (2016). Impacts of Climate Change under CMIP5 RCP Scenarios on the Streamflow in the Dinder River and Ecosystem Habitats in Dinder National Park, Sudan. *Hydrology and Earth System Sciences,* 20, 1331–1353, doi: 10.5194/hess-20-1331-2016

Ammar, R. E. (2015). *Impact of Climate and Land use Change on Water Resources, Crop Production and Land Degradation in a Semi-arid area (using Remote Sensing, GIS and Hydrological Modeling).* Dissertation for the award of the degree "Doctor rerumnaturalium" (Dr.rer.nat.) of the Georg-August University Gottingen.

Anastasia, L., Stefan, L., Joao, P, N., Iulii, D., Judith, S., Shaochun, H., Hagen, K., María, R. R. L., Cathrine, F. M., Fred, H., & Valentina, K. (2018). Hydrological Impacts of Moderate and High-End Climate Change across European River Basins. *Journal of Hydrology: Regional Studies,* (18) 15-30, https://doi.org/10.1016/j.ejrh.2018.05. 003

Asemota, O. J., M. A. Bamanga, M. A., & Alaribe, O. J. (2016).Modelling Seasonal Behaviour of Rainfall in Northeast Nigeria. A State Space Approach. *International Journal of Statistics and Applications,* 6(4): 203-222.doi: 10.5923/j.statistics.20160604.02

Ayansina, A., Maren, R., John, F. M., & Tabitha, M. (2018). Rainfall Variability and Drought Characteristics in two Agro-climatic Zones: An Assessment of Climate Change Challenges in Africa. *Science of the Total Environment,* 630, 728–737, doi: 10.1016/j.scitotenv.2018.02.196

Ayeni, A. O., Kapangaziwiri, E., Soneye, A. S. O., & Engelbrecht, F. A. (2015). Assessing the Impact of Global Changes on the Surface Water Resources of Southwestern Nigeria, *Hydrological Sciences Journal,* 60:11, 1956-1971, doi: 10.1080/02626667.2014.993645

Babagana, A. (2017). *The Impacts of Global Climate Change in Africa: The Lake Chad, Adaptation and Vulnerability.* https://www.researchgate.net/publication/2375253.

Babatolu, J. S. & Akinnubi, R. T. (2014). Influence of Climate Change in Niger River Basin Development Authority area on Niger Runoff, Nigeria. *Journal of Earth Science and Climate Change,* 5: 230, doi:10.4172/2157-7617.1000230

Bao, J., Sherwood, S. C., Alexander, L.V., & Evans, J. P. (2017). Future Increases in Extreme Precipitation Exceed Observed Scaling Rates. *Nature Climate Change,* https://doi.org/ 10.1038/nclimate3201.

Benjamin, J. H., Murray, C. P., Rory, N., Andrew, D. K., David, J. K., & Kim, S. T. (2019). Amplification of Risks to Water Supply at 1.5^{o}C and 2^{o}C in Drying Climates, Australia. *Environmental Research Letters*. 14, 084028.https://doi.org/10.1088/1748-9326/ab26ef

Berghuijs, W. R., Woods, R. A., & Hrachowitz, M. (2014). A Precipitation Shift from Snow towards Rain leads to a Decrease in Streamflow. *Nature Climate Change,* 4, 583–586, http://dx.doi.org/10.1038/nclimate2246.

Berghuijs, W. & Greve, P. (2015). A review of the Budyko Water Balance Framework: Moving from a rich history to a bright future. *Geophysical Research Abstracts*, 17, EGU2015-15654, EGU General Assembly.

Burger, G., Sobie, S. R., Cannon, A. J., Werner, A. T., & Murdock, T. Q. (2013). Downscaling Extremes: An Intercomparison of Multiple Methods for Future Climate, (test 1).pp. 3429–3449,https://doi.org/10.1175/JCLI-D-12-00249.1.

Carlos, A. C. S. & Veronica, G. O. (2017). Trends in Extreme Climate Indices for Pará State, Brazil. *Revista Brasileira de Meteorologia*, 32, (1), 13-24, dx.doi.org/10.1590/0102-778632120150053

Chai, T. & Draxler, R. R. (2014). Root Mean Square Error (RMSE) or Mean Absolute Error (MAE)?–Arguments against Avoiding RMSE in the literature. *Geoscientific Model Development,* 7, 1247 1250,https://doi.org/10.5194/gmd-7-1247-2014

Chan, H., Tong, H., & Lee, S. (2016). Extreme Rainfall Projection for Hong Kong in the 21st Century using CMIP5 Models. *The 30th Guangdong-Hong Kong-Macao Seminar on Meteorological Science and Technology*, Guangzhou.

Charles, O., Hossein, T., Agnieszka, R., Paul, N., & Patrick, W. (2016). Comparison of Different Statistical Downscaling Methods for Climate Change and Rainfall Projections over the Lake Victoria Basin Considering CMIP3 and CMIP5.*Journal of Hydro-environment Research,* 12, 31-45.doi: 10.1016/j.jher.2016.03.001.

Chanapathi, T., Thatikonda, S., & Raghavan, S. (2018). Analysis of Rainfall Extremes and Water Yield of Krishna River Basin under Future Climate Scenarios. *Journal of Hydrology: Regional Studies,* (19) 286-306,https://doi.org/10.1016/j.ejrh. 2018.10 .004

Chen, J., Brissette, F.P., & Leconte, R. (2011). Uncertainty of Downscaling Method in Quantifying the Impact of Climate Change on Hydrology. *Journal of Hydrology,* 401 (3–4), 190–202,https://doi.org/10.1016/j.jhydrol.2011.02.020.

Chewe, J., & Levermann, A. (2017). Non-linear Intensification of Sahel Rainfall as a Possible Dynamic Response to Future Warming. *Earth System Dynamic and Discussions*, 8, 495–505,https://doi.org/10.1073/pnas.1312330110.

Chu, P. S., Chen, D. J., & Lin, P. L. (2014).Trends in Precipitation Extremes during the Typhoon Season in Taiwan over the last 60 years. *Atmospheric Science Letters*, 15, 37–43, doi: 10.1002/ asl2.464

Chukwuma, O. (2015). Climate Change and Conflict in Nigeria: The Boko Haram Challenge. *American International journal of Social Science,* 4, (2), ISSN 2325 - 4149.

Coffel, E. D., Keith, B., Lesk, C., Horton, R. M., Bower, E., Lee, J., & Mankin, J. S. (2019). Future Hot and Dry years Worsen Nile Basin Water Scarcity despite Projected Precipitation Increases. *Earth's Future,* 7, 967–977, https://doi. org/10.1029/2019EF001247.

Daramola, M. T., Eresanya, E. O & Erhabor S. C. (2017). Analysis of Rainfall and Temperature over Climatic Zones in Nigeria. *Journal of Geography, Environment and Earth Science International,* 11(12): 1-14, doi: 10.9734/JGEESI/2017/35304

David, A. (2009). *The Long Thaw: How Humans are changing the Next 100,000 Years of Earth's Climate.* Princeton University Press.p.19.ISBN 978-0-691-13654-7.

Dayon, G., Boe, J., & Martin, E. (2015). Transferability in the Future Climate of a Statistical Downscaling method for Precipitation in France. *Journal of Geophysical Research,* 120, (3), doi: 10.1002/2014JD022236

Dehua, Z., Samiran, D., & Qiwei, R. (2017).Hydrological Appraisal of Climate Change Impacts on the Water Resources of the Xijiang Basin, South China.*MDPI Journal/Water,* 9(10), 793, doi: 10.3390/w9100793

De Sa, M. C., Vieira, E. O., Albuquerque, L. C., & Caldeira, N. R. (2017). *Impacts of Climate Changes on the Sustainability of Water Resources of the Rio Verde Grande Basin, Minas Gerais, Brazil.* IV Inovagri International Meeting, Brazil. TC3390479.pdf.

Demircan, M., Gurkan, H., Eskioglu, O., Arabaci, H., & Coskun, M. (2017). Climate Change Projections for Turkey: Three Models and Two Scenarios. *Turkish Journal of Water science and Management,* 1 (1) : 134-144.

Deniz, B., Maisa, R., Juan, P. Boisier., & Jonas, V. (2017). Climate Change Impacts on Hydroclimatic Regimes and Extremes over Andean Basins in Central Chile. *Journal of Hydrology and Earth System Sciences Discussions,* doi: 10.5194/hess-2016-690, 2017

Dile, Y. T., Berndtsson, R., & Setegn, S. G. (2013). Hydrological Response to Climate Change for Gilgel Abay River, in the Lake Tana Basin - Upper Blue Nile Basin of Ethiopia. *PLoS ONE* 8(10): e79296, doi: 10.1371/0079296.

Doll, P. & Muller, H. S. (2012). How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale Analysis. *Environmental Research Letters,* 7, 014037, doi:10.1088/1748-9326/7/1/014037

Edvinas, S., Egidijus, R., Andrius, S., Justas, K., & Gintaras, V. (2017). Climate Change Impact on the Nemunas River Basin Hydrology in the 21st century. *Boreal Environment Research, 22*: 49–65, ISSN 1797-2469 (online).

Ekstrom, M., Grose, M. R., & Whetton, P. H. (2015). An Appraisal of Downscaling Methods used in Climate Change Research. *Wires Climate Change,* 6, 301–319, https://doi.org/10.1002/wcc.339.

Elguindi, N., Giorgi, F., & Turuncoglu, U. (2014). Assessment of CMIP5 Global Model Simulations over the subset of CORDEX domains used in the Phase I CREMA. *Climatic Change,* 125, 7–21, https://doi.org/10.1007/s10584-0130935

Elsner, M., Cuo, L., Voisin, N., Deems, J., Hamlet, A., Vano, J., Mickelson, K.B., Lee, S.-Y., & Lettenmaier, D., (2010). Implications of 21st Century Climate Change for the Hydrology of Washington State. *Climate Change,* 102, 225–260, http://dx.doi.org/10.1007/s10584-010-9855-0.

Emeribe, C., Ogbomida, E., Fasipe, O., Biose, O., Aganmwonyi, I., Isiekwe, M. & Omoregie, I. (2016). Hydrological Assessments of Some Rivers in Edo State, Nigeria for Small-Scale Hydropower Development. *Nigerian Journal of Technology,* 35, 656, doi-10.4314/njt.v35i3.26

Endo, H., Kitoh, A., Ose, T., Mizuta, R., & Kusunoki, S. (2012). Future Changes and Uncertainties in Asian Precipitation Simulated by Multi-physics and Multi-sea Surface Temperature Ensemble Experiments with High-resolution Meteorological Research Institute atmospheric general circulation models (MRIAGCMs). *Journal of Geophysical Research*, 117,D16118,http://dx.doi.org/10.1029/2012JD017874

Eric, A. A., Ezechiel, O. & Abel, A. (2017).Assessment of Future Water Resources Availability under Climate Change Scenarios in the Mekrou Basin, Benin. *MDPI/ Hydrology*, 4(4), 51, doi: 10.3390/hydrology4040051.

Erum, A. & Ishitaq H. (2018). Trend Analysis in Precipitation at Individual and Regional Levels in Baluchistan, Pakistan. *IOP Conference Series: Materials Science and Engineering*, doi:10.1088/1757-899X/414/1/012042.

Esther, S. P., Evan, K., Karsten, S., & Auroop, R. G. (2012). Estimating Future Global Per Capita Water Availability Based on Changes in Climate and Population. *Computers and Geosciences*, 42, 79-86. doi: 10.1016/j.cageo.2012.01.019.

Eylon, S., Sharon, B. M., Carlos, C., Christopher, L. C., Hsin, C., Karletta, C., Frank, E. C., Susanna, E., Konstantine, P. G., Keith M. N., & Jacob, P. (2015). Climate Change and Water Resources Management in the Upper Santa Cruz River, Arizona. *Journal of Hydrology*, (521) 18–33, doi: 10.1016/j.jhydrol.2014.11.062

Fan, M. & Shibata, H. (2015). Simulation of Watershed Hydrology and Stream Water Quality under Land use and Climate Change Scenarios in Teshio River Watershed, Northern Japan. *Ecological Indicators*, 50, 79–89, doi:10.1016/j.ecolind.2014.11.003

Farzan, K., Wang, G., Silander, J., Wilson, A. M., Allen, J. M., Horton, R., & Anyah, R. (2013). Statistical Downscaling and Bias Correction of Climate Model Outputs for Climate Change Impact Assessment in the U. S. Northeast. *Global and Planetary Change*, 100, 320–332,https://doi.org/10.1016/j.gloplacha.2012.11.003.

Felix, W. Z., Genesis, T. Y., & Abdouraman T. (2017). Seasonal Migration and Settlement around Lake Chad: Strategies for the Control of Resources in an Increasingly Drying Lake. *MDPI Journal / Resources*, 6, (41), doi:10.3390//resources6030041.

Filippo, G. & William, J. G. (2015). *Regional Dynamical Downscaling and the CORDEX Initiative.* Annual Review of Environment and Resources. 40: 467-490, doi: 10.1146/annurev-environ-102014-021217

Firth, R., Kala, J., Lyons, T. J., & Andrys, J. (2017). An Analysis of Regional Climate Simulations for Western Australia's Wine Regions-Model Evaluation and Future Climate Projections. *Journal of Applied Meteorology and Climatology*, 56, 2113–2138,https://doi.org/ 10.1175/JAMC-D-16-0333.1.

Fischer, E. M., & Knutti, R. (2016). Observed Heavy Precipitation Increase Confirms Theory and Early Models. *National Climate Change*, 6 (11), 986–991, http://dx.doi.org/10.1038/nclimate3110.

Flato, G. J., Marotzke, B., Abiodun, P., Braconnot, S. C., Chou, W., Collins, P., Cox, F., Driouech, S., Emori, V., Eyring, C., Forest, P., Gleckler, E., Guilyardi, C., Jakob, V., Kattsov, C.Reason & M. Rummukainen, (2013). *Evaluation of Climate Models.In: Climate Change 2013:* The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, and G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Gabriela, C. G., Paulo, T. S. O., Dulce, B. B. R. & Hoshin, V. G. (2019). Assessing Water Security in the Sao Paulo Metropolitan Region under Projected Climate Change. *Hydrology and Earth System Sciences Discussions*, https://doi.org/10.5194/hess-2019-134

Gebre, S. L., Tadele, K., & Mariam, B. G. (2015). Potential Impacts of Climate Change on the Hydrology and Water resources Availability of Didessa Catchment, Blue Nile River Basin, *Ethiopia Journal of Geology and Geosciences,* 4: 193, doi:10.4172/2329-6755.1000193

Gebre, S. L., & Ludwig, F. (2015). Hydrological Response to Climate Change of the Upper Blue Nile River Basin: Based on IPCC Fifth Assessment Report (AR5). *Journal of Climatology and Weather Forecasting,* 3: 121, doi:10.4172/2332-2594.1000121

Gijs, S., Wim, B., Le an, N., Christopher, R. H., Martha, A., & Gabriel, S. (2016). Integrating Global Satellite-Derived Data Products as a Pre-Analysis for Hydrological Modelling Studies: A Case Study for the Red River Basin. *MDPI Journal/Remote Sensing,* 8, 279, doi: 10.3390/rs8040279

Giorgi, F., Coppola, E., & Raffaele, F. (2014). A Consistent Picture of the Hydroclimatic Response to Global Warming from Multiple Indices: Models and Observations. *Journal of Geophysical Resources Atmosphere*, 119, doi: 10.1002/ 2014JD022238, 2014.

Gloria, C. O. & Kingsley, N. O. (2018).Assessment of the impact of climate change on the freshwater availability of Kaduna River basin, Nigeria. *Journal of Water and Land Development*, 38: 105–114. doi:10.2478/jwld-2018-0047

Gneneyougo, E. S., Affoue, B. Y., Yao, M. K., & Tie, A. G. (2017).Climate Change and Its Impacts on Water Resources in the Bandama Basin, Côte D'ivoire. *MDPI Journal/ Hydrology,* 4, 18, doi: 10.3390/hydrology4010018.

Greve, P., Gudmundsson, L., Orlowsky, B., & Seneviratne, S. I., (2016). A two-parameter Budyko function to represent conditions under which evapotranspiration exceeds precipitation. *Hydrology and Earth System Sciences,* 20, 2195–2205,http:// dx.doi.org/10.5194/hess-20-2195-2016.

Grose, M. (2015). *Southern Slopes Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions:* Cluster Reports, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology, Australia.

Grouillet, B., Ruelland, D., VaittinadaAyar, P., & Vrac, M. (2016). Sensitivity analysis of runoff modeling to statistical downscaling models in the western Mediterranean. *Hydrology and Earth System Sciences,* 20, 1031-1047, doi: 10.5194/hess-20-1031-2016

Guidelines for Assessing the Impact of Climate Change on Water Supplies (2016). Victorian Department of Environment, Land, Water and Planning. Victoria State Government.Arming.

Guoyong, L., Maoyi, H., Nathalie, V., Xuesong, Z., Ghassem, R. A., & Ruby, L. L. (2016). Emergence of new Hydrologic Regimes of Surface Water Resources in the Conterminous United States under Future Warming. *Environmental Research Letters*, 11, doi:10.1088/1748-9326/11/11/114003

Gutjahr, O. & Heinemann, G. (2013). Comparing Precipitation Bias Correction Methods for High-resolution Regional Climate Simulations using COSMO-CLM. *Theoretical and Applied Climatology,* 114 (3–4), 511–529, doi:10.1007/ s00704-013-0834-z

Habets, F., Boe, J., Deque, M., Agnes, D., Simon, G., Ali, H., Eric, M., Christian, P., Eric, S., Laurent, T., Dominique, T., Ludovic, O. & Pascal, V. (2013). *Impact of Climate Change on the Hydrogeology of two Basins in Northern France.* Springer Science Business Media Dordrecht, doi: 10.1007/s10584-013-0934-x

Hagemann, S., Chen, C., Clark, D. B., Folwell, S., Gosling, S. N., Haddeland, I., Hanasaki, N., Heinke, J., Ludwig, F., Voss, F., & Wiltshire, A. J. (2013). Climate Change Impact on Available Water Resources obtained using Multiple Global Climate and Hydrology Models, *Earth System Dynamics,* 4, 129-144, doi.org/10.5194/esd-4-129-2013, 2013.

Hamid, R. G. H. Y., Nasrin, S., Sohrab, K., & Gerrit, H. (2019). Prediction of Climate Variables by Comparing the K-nearest Neighbor Method and MIROC5 outputs in an Arid Environment. *Climate Research,* 77, 99-114, doi.org/10.3354/cr01545.

Harding, R. J., Weedon, G. P., van Lanen, H. A. J., & Clark, D. B., (2014). The Future for Global Water Assessment. *Journal Hydrology*, 518, 186 193,http://dx.doi.org/ 10.1016/j.jhydrol.2014.05.014.

Hashim, I. J. A., & Ranjan, P. S. (2017). Evaluation of the Impacts of Future Hydrological Changes on the Sustainable Water Resources Management of the Richmond River Catchment. *Journal of Water and Climate Change,* 9 (1), 137-155, doi:10.2166/wcc.2017.144

Heejun, C. & Matthew, R. B. (2016). Climate Change and Water - related Ecosystem Services: Impacts of Drought in California, USA. *Journal of Ecosystem Health and Sustainability,* 2 (12), doi:10.1002/ehs2.1254

Herold, N., Ekstrom, M., Kala, J., Goldie, J., & Evans, J. P. (2017). Australian Climate Extremes in the 21st Century According to a Regional Climate Model Ensemble: Implications for Health and Agriculture. *Weather and Climate Extremes*, 1-15,doi.org/10.1016/j.wace.2018.01.001

Honings, J. (2018). "Modeling Climate Change Impacts on Water Balance Components of the Mackinaw River Watershed, Central Illinois *Theses and Dissertations*. 938. htps://ir.library.illinoisstate.edu/etd/938

Hosea, M. M., Stefan, J., Sopan, D. P., Morag, A. M., & Karl-Heinz, F. (2016).Relative Contribution of Land Use Change and Climate Variability on Discharge of Upper Mara River, Kenya. *Journal of Hydrology: Regional Studies,* (5) 244–260, doi: 10.1016/j.ejrh.2015.12.059.

Ibrahim, H., Robert, M. K., Jamiu, A. A., & Christopher, J. W. (2020). Potential Impacts of Climate Change on Extreme Weather Events in the Niger Delta Part of Nigeria. *MDPI/ Hydrology,7* (19), doi: 10.3390/hydrology7010019

Ibrahim, N. M., Arne, B., & Beverley, C. W. (2015). the use of CMIP5 data to Simulate Climate Change Impacts on Flow Regime within the Lake Champlain Basin. *Journal of Hydrology: Regional Studies,* (3) 160-186, doi:10.1016/j.ejrh.2015.01.002.

Ifabiyi, I. P. & Ojoye, S. (2013). Rainfall Trends in the Sudano-Sahelian Ecological Zone of Nigeria. *Journal of Earth Science Research,* 2, (2), doi: 10.5539/esr. v2n2p194.

Imoleayo, E. G., Oluwafemi, E. A., Kaah, P. M.,Joseph, D. K. I., Vincent, O. A., Jerome, A. O., & Akintomide, A. A. (2019). Observed Changes in Climate Extremes in Nigeria. *Meteorological Applications,* 26:642–654. doi:10.1002/ met.1791

Intergovernmental Panel on Climate Change (IPCC) (2013). The Physical Science Basis. In: Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. Midgley, P. M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, New York, NY, USAhttp: //dx.doi. org/10.1017/CBO9781107415324

Intergovernmental Panel on Climate Change (IPCC) (2014). *Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland, 151.

Jacquelyn, F. E., Jonatan, A. L., Eric, P. P., & Kertin, K. Z. (2018). Understanding Climate Change Impacts on Water Buffalo Production through Farmers' Perceptions. *Climate Risk Assessment.* 20 (2018), 50-63, doi: 10.1016.crm.2018.03.003.

Janssen, E., Wuebbles, D. J., Kunkel, K. E., Olsen, S. C., & Goodman, A. (2014). Observational and Model-based Trends and Projections of Extreme Precipitation over the Contiguous United States. *Earth's Future,* 2, 99–113,http://dx.doi.org/10.1002/2013EF000185.

Jayasekera, D. & Kaluarachchi, J. J. (2015). Climate Change Impacts on Water Sustainability in the Nam Ngum River Basin of Laos. *WIT Transactions on Ecology and the Environment,* (196), 279-287, doi: 10.2495/WRM150241

Jones, R. N. (2012). Detecting and Attributing Nonlinear Anthropogenic Regional Warming in South-eastern Australia, *Journal of Geophysical Resources*, 117, D04105, doi: 10.1029/2011JD016328.

Kahil, M. T., Dinar, A., & Albiac, J.: (2015). Modeling Water Scarcity and Droughts for Policy Adaptation to Climate Change in Arid and Semiarid Regions, *Journal of Hydrology*, 522, 95 – 109, https://doi.org/https://doi.org/10.1016/j.jhydrol.2014.12

Kang, H. & Sridhar, H. (2017). Combined Statistical and Spatially Distributed Hydrological Model for Evaluating Future Drought Indices in Virginia. *Journal of Hydrology: Regional Studies*, 12: 253-272, https://doi.org/10.1016/j.ejrh.2017.06.

Kang, H. and Venkataramana, S. (2018). Assessment of Future Drought Conditions in the Chesapeake Bay Watershed. *Journal of the American Water Resources Association (JAWRA)* 54(1): 160-183. doi.org/10.1111/1752-1688.12600

Kara, F. (2014). *Effects of Climate Change on Water Resources in Omerli Basin.*An unpublished PhD thesis of Department of Geodetic and Geographic Information Technology, submitted to the Graduate School of Natural and Applied Sciences of Middle East Technical University, Turkey.

Karl, W. & Anders, G. (2010). Roadmap for Assessing Regional Trends in Groundwater Quality. *Environmental Monitoring and Assessment*, (165), 1-4, 217-231,http://dx.doi.org/10.1007/s10661-009-0940-7

Khan, N., Shahid, S., Ahmed, K., Ismail, T. (2018). Performance Assessment of General Circulation Model in Simulating Daily Precipitation and Temperature Using Multiple Gridded Datasets.https://doi.org/10.3390/w10121793

Klutse, N. A. B., Ajayi, V. O., Gbobaniyi, E. O., Egbebiyi, T. S., Kouadio, K., Nkrumah, F., Quagraine, K. A., Olusegun, C., Diasso, U., Abiodun, B. J., Lawal, K., Nikulin, G., Lennard, C., & Dosio, (2018). A Potential Impact of 1.5 °C and 2 °C Global Warming on Consecutive Dry and Wet Days over West Africa, *Environmental Research Letters*, 13, 055013, 2018.

Kumar S., Merwade V., Kinter J. L., & Niyogi D. (2013). Evaluation of Temperature and Precipitation Trends and Long-term Persistence in CMIP5 Twentieth-century Climate Simulations. *Journal of Climate*, 26(12), 4168–4185, https://doi.org/10.1175/JCLI-D-12-00259.1

Kwak, J., Kim, D., Kim, S., Singh, V. P., & Kim, H. (2013).“Hydrological Drought Analysis in Namhan River Basin, Korea.”*Journal of Hydrologic Engineering*, 19, (8), doi: 10.1061/ (ASCE) HE.1943-5584. 0000889.

Lapidez, J. P. (2016). Assessment of Changes in the Water Resources Budget and Hydrological Regime of the Pampanga River Basin (Philippines) due to Climate Change. *United Nations Peace and Progress*, 3 (1), 15-31,http://upp.unu.edu/

Lal, M., Aditya, S., Matthew, M., Nishchitha, S. S., & Alfred,O. (2018). Understanding the Impacts of Climate Change in the Tana River Basin, Kenya. (379), 37–42,https://doi.org/10.5194/piahs-379-37-2018

Lei, R., Lian-qing, X., Yuan-hong, L., Jia, S., Qiang, H. & Peng-fei, Y. (2017). Study on Variations in Climatic Variables and their Influence on Runoff in the Manas River Basin, China. *Water*, 2, *9*, 258.https://doi.org/10.3390/w9040258

Libanda, B. & Chilekana, N. (2018). Projection of Frequency and Intensity of Extreme Precipitation in Zambia: A CMIP5 Study. *Climate Research,* 76: 59–72, https://doi.org/10.3354/cr01528.

Lin, L., Sills, E., & Cheshire, H. (2014).Targeting areas for Reducing Emissions from Deforestation and forest Degradation (REDD+) Projects in Tanzania.*Global Environmental Change,* 24, 277–286, doi: 10.1016/j. gloenvcha.2013.12.003

Liu, J., Hong, Y., Simon, N. G., Matti, K.,Martina, F., Stephan, P., Naota, H., Yoshihide, W., Xinxin, Z., Chunmiao, Z., Joseph, A., & Taikan, K. (2017). Water Scarcity Assessments in the Past, Present, and Future. *Earth's Future*, 5, 545–559, doi: 10.1002/2016EF000518.

Lobanova, A., Koch, H., Liersch, S., & Hattermann, F. F. (2016). Impacts of Changing Climate on the Hydrology and Hydropower Production of the Tagus River Basin. *Hydrological Processes,* 30, 5039–5052,http://dx.doi.org/10.1002/hyp. 10966.

Lobanova, A., Liersch, S., Tàbara, J. D., Koch, H., Hattermann, F. F., & Krysanova, V. (2017) Harmonizing Human-hydrological System under Climate Change: a Scenario based Approach for the case of the Headwaters of the Tagus River. *Journal of Hydrology,* 548, 436-447, http://dx.doi.org/10.1016/j.jhydrol.2017 .03.015.

Luck, M., Landis, M. & Gassert, F. (2015). *"Aqueduct Water Stress Projections: Decadal Projections of Water Supply and Demand Using CMIP5 GCMs." Technical Note.* Washington, D.C.: World Resources Institute. Available online at: wri.org/publication/aqueduct-water-stress-projections.

Iulii, D., Anastasia, L., Axel, B., Sergiy, S., Cathrine, F. M., & Valentina, K. (2017). Assessment of Climate Change Impacts on Water Resources in three Representative Ukrainian Catchments Using Eco-Hydrological Modelling. *MDPI Journal/Hydrology,* 9, 204, doi: 10.3390/w9030204.

Mariotti, L., Diallo, I., Coppola, E., & Giorgi, F. (2014). *Seasonal and Intraseasonal Changes of Africa Monsoon Climates in 21st century CORDEX projections.* Climate Change 125:53–65.

Meehl, G. A., Arblaster, J. M., Fasullo, J. T., Hu, A., & Trenberth, K. E. (2011). Model-based Evidence of Deep-ocean Heat uptake during Surface-temperature Hiatus Periods, *National Climate Change,* 1(7), 360–364, doi: 10.1038/nclimate1229.

Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four Billion People facing Severe Water Scarcity. *Science Advancement,* 2,https://doi.org/10.1126/sciadv.1500323.

Michael, S. A., Graham, P.W. J., & Michele, L. W. T. (2017). Scenario-based Impacts of Land use and Climate Changes on the Hydrology of a Lowland Rainforest Catchment in Ghana. *West Africa Journal of Hydrology and Earth System Sciences Discussions,* doi: 10.5194/hess-2017-591

Miguel A. L., Omar, V. M., Ernesto, H. B. & Gabriela, V. M. (2018).Evaluation of CMIP5 Retrospective Simulations of Temperature and Precipitation in Northeastern Argentina. *International Journal of Climatology,* 38 (1), 1158-1175, https://doi.org/10.1002/joc.5441

Mihretab, G. G., Taibao, Y. & Xuemei, Y. (2016).Long-Term Trend of Climate Change and Drought Assessment in the Horn of Africa. *Advances in Meteorology*, https://doi.org/10.1155/2016/8057641

Milano, M., Denis, R., Sara, F., Alain, D., Julie, F., Eric, S., Jean-Marie, F., Sandra, A. & Gaelle, T. (2013). Current State of Mediterranean Water Resources and Future Trends under Climatic and Anthropogenic Changes, *Hydrological Sciences Journal,* 58:3, 498- 518, http://dx.doi.org/10.1080/02626667.2013.774458

Mitchell, T. J., Knapp, P. A., & Patterson, T. W. (2019). Changes in Southeastern USA Summer Precipitation Event Types Using Instrumental (1940-2018) and Tree-Ring (1790-2018) Data. *Environmental Research Communications,* 1 (2019), doi:10.1088/2515-7620/ab4cd6.

Mizuta, R., Arakawa, O., Ose, T., Kusunoki, S., Endo, H., & Kitoh, A. (2014). Classification of CMIP5 Future Climate Responses by the Tropical Sea Surface Temperature Changes. *SOLA*, 10, 167–171, http://dx.doi.org/10.2151/sola.2014-035

Mo, X., Shi, H.,Zhong-Hui, L., Su-Xia, L., & Jun, X. (2017). Impacts of Climate Change on Agricultural Water Resources and Adaptation on the North China. *Advances in Climate Change Research*,8, (2), 93-98,https://doi.org/10.1016/j.accre.2017.05.007

Mohammed, A. (2015). Water for Development and Development for Water: Realizing the Sustainable Development Goals (SDGs) Vision. *Science Direct: Aquatic Procedia*, (6)106 – 110, doi: 10.1016/j.aqpro.2016.06.013

Mohammed, A. K., Martin, F. P., Asma, A., Mushtaque, A., & Timothy O. (2014). Vulnerability Assessment of Environmental and Climate Change Impacts on Water Resources in Al Jabal Al Akhdar, Sultanate of Oman. *MDPI Journal/Water*, 6, 3118-3135, doi: 10.3390/w6103118

Mohammad, E., & Abdurrahman, A. (2013). *Effect of Climate Change on Spatio-Temporal Variability and Trends of Evapotranspiration, and its Impact on Water Resources Management in the Kingdom of Saudi Arabia*, Climate Change - Realities, Impacts over Ice Cap, Sea Level and Risks, Bharat Raj Singh (Ed.), In Tech, doi:10.5772/54832

Monireh, F., Karim, C. A., Saeid, A. V., Mohammad, R. F., Alexander, J. B. Z., Raghavan, S. f., & Hong, Y. (2013). Modeling Impacts of Climate Change on Freshwater Availability in Africa. *Journal of Hydrology,* 480, 85–101, doi: 10.1016/j.jhydrol.2012.12.016

Moss, R. H., Edmonds, J. A., Hbbard, K. A., Manning, M. R., Rose, & S. K. (2010). The Next Generation of Scenarios for Climate Change Research and Assessment. *Nature*, 463: (7), 47–56

Muhammad, T. A. & Naim, H. (2018).Assessing the Impacts of Population Growth and Climate Change on Performance of Water Use Systems and Water Allocation in Kano River Basin, Nigeria. *MDPI/Water, 10,* 1766; doi: 10.3390/w10121766

Nabil, E. M., Suchul, K., & Elfatih, A. B. E. (2019). Climate Change Impacts the *Water Highway* Project in Morocco. *Hydrology and Earth System Sciences Discussions,* https://doi.org/10.5194/hess-2019-238

Nahlah, A., Saleh, A. W., & Nadhir, A. (2017). Impacts of Climate Change on Water Resources of Greater Zab and Lesser Zab Basins, Iraq, Using Soil and Water Assessment Tool Model. *International Journal of Environmental and Ecological Engineering,* 11, (10), doi: 1307-6892/10007957

Nakaegawa, T., Kitoh, A., Murakami, H., & Kusunoki, S. (2014). Annual maximum 5-day Rainfall Total and Maximum number of Consecutive Dry days over Central America and the Caribbean in the late Twenty-first Century Projected by an Atmospheric General Circulation Model with three Different Horizontal Resolutions. *Theory of Applied Climatology,* 116, 155–168,http://dx.doi.org/ 10.1007/s00704-013- 0934-9.

Nana, A. B. K., Vincent, O. A., Emiola, O. G., Temitope, S. E., Kouakou, K., Francis, N., Kwesi, A. Q., Christiana, O., Ulrich, D., Babatunde, J. A., Kamoru, L., Grigory, N., Christopher, L., & Alessandro, D. (2016). Potential Impact of 1.5 °C and 2 °C Global Warming on Consecutive Dry and Wet Days over West Africa.*Environmental Research Letters*,13, doi.org/10.1088/1748- 9326/aab37b

Navneet, K.,Bernhard, T.,Jurgen, K.,Patrick, L.,Mirza, K. B. & Janos, J. B. (2017). Impact of Climate Change on Water Resources of Upper Kharun Catchment in Chhattisgarh, India.*Journal of Hydrology: Regional Studies,*13, 189 207.https://doi.org/10.1016/j.ejrh.2017.07.008

Ndhlovu, G. Z., & Woyessa, Y. E. (2020). Modelling Impact of Climate Change on Catchment Water Balance, Kabompo River in Zambezi River Basin. *Journal of Hydrology: Regional Studies,* https://doi.org/10.1016/j.ejrh.2019.100650

Nezar, H., Fayez, A., Hani, A. Q., & Muwafaq, F. (2015).*Assessing the Impacts of Climate Change on Water Resources of Jordan.* World Water Congress XV: International Water Resources Association. Edinburgh, Scotland. 25-29 May.

Nurmohamed, R. & Donk, P. (2017). The Impacts of Climate Change and Climate Variability on the Agricultural Sector in Nickerie Distict. *Journal of Agricultural and Environmental Sciences,* 6 (1), 51-65, doi:10.15640/jaes.v6n1a6.

Nwoke H. U. & Nwaogazie I. L. (2013). Rainfall Intensity Duration Frequency Regime for Onitsha city. *American Journal of Engineering Research (AJER).* 02(06), 19-24.

Nyeko, M. (2014). Hydrologic Modelling of Data Scarce Basin with SWAT Model: Capabilities and Limitations. *Water Resources Manag*ement 29, 81–94, http://dx.doi.org/10.1007/s11269-014-0828-3.

Oguntunde, P. G., Abiodun, B. J., & Gunnar L. (2012). Spatial and temporal temperature trends in Nigeria, 1901–2000. *Meteorology and Atmospheric Physics*118:95–105.

Ojoye, S., Sulyman, A. O., & Yahaya, T. I. (2016). Climate Change and Adaptation Strategies to Water Resources in some parts of Sudano-Sahelian Zone of Nigeria. *Ethiopian Journal of Environmental Studies and Management,* 9(3): 326 – 338, doi:10.4314/ejesm.v9i3.7

Olaniyi, O. A., Ojekunle, Z. O., & Amujo, B. T. (2013). Review of Climate Change and Its Effect on Nigeria Ecosystem. *International Journal of African and Asian Studies,* 1.

Olkeba, T. L., Aly, I. E., Henrietta, D., & Kariem, A. G. (2016). Assessment of Climate Change Impacts on Water Balance Components of Heeia Watershed in Hawaii. *Journal of Hydrology: Regional Studies*, (8), 182-197, http://dx.doi.org/10. 1016/j.ejrh.2016.09.006

Oroud, I. M. (2016). The Impacts of Anthropogenic and Climate Change Forgings on Water Resources Demands and Availability in Jordan in the Near Future. *Qatar Foundation Annual Research Conference Proceedings,* doi: 10.5339/qfarc. 2016. EEPP3380.

Pancheewan, P. & Jessada, T. (2016). Effects of Climate and Land Use Changes on Water Balance in Upstream in the Chao Phraya River Basin, Thailand. *Agriculture and Natural Resources,* 50, doi- 10.1016/j.anres.2016.10.005

Pankaj, T., Pamela, B., Gopal, S. R., Ishwari D. R., & Gautam T. (2021). Experimental Warming increases Ecosystem Respiration by increasing above-ground Respiration in Alpine Meadows of Western Himalaya. *Scientific Reports,* 11:2640https://doi.org/10.1038/s41598-021-82065-y

Pengpeng, J., Dafang, Z., & Yong, W. (2017). Impacts of Temperature and Precipitation on the Spatiotemporal Distribution of Water Resources in Chinese Mega Cities: the case of Beijing. *Journal of Water and Climate Change,* 038, doi:10.2166/wcc.2017.038

Pervez, M. S. & Henebry G. M. (2015). Assessing the Impacts of Climate and Land use and Land Cover Change on the Freshwater Availability in the Brahmaputra River Basin, Bangladesh. *Journal of Hydrology: Regional Studies*, 3 (2015), 285–311, doi: 10.1016/j.ejrh.2014.09.003

Peterson, T.C., W.M. Connolley, & J. Fleck (2016). "The Myth of the 1970s Global Cooling Scientific Consensus". Bulletin of the American Meteorological Society. *American Meteorological Society*, 89: 1325–1337, doi: 10.1175/2008BAMS2370.

Pieczka, I., Pongracz, R., Szabone Andre, K., Kelemen, F.D., & Bartholy, J. (2017). Sensitivity Analysis of Different Parameterization Schemes using RegCM4.3 for the Carpathian region. *Theoretical Applied Climatology,* 130, 1175–1188,https://doi.org/10.1007/s00704-016-1941-4

Potter, N. J., Chiew, F. H. S., Zheng, H., Ekstrom, M., & Zhang, L. (2016). *Hydroclimate Projections for Victoria at 2040 and 2065.* Draft Version 1.7. CSIRO for the Department of Environment, Land, Water and Planning.

Prein, A. F. & Gobiet, A. (2017).Impacts of Uncertainties in European Gridded Precipitation Observations on Regional Climate Analysis. *International Journal of Climatology,* 37, 305–327, https://doi.org/10.1002/joc.4706

Rana, S., Assaf, H., Anat, B., Amir, G., Yoav, L., Yizhak, Y., Hadas, S., Baruch, Z., Tzvika, H., & Pinhas, A. (2017). Evaluation and Projection of Extreme Precipitation Indices in the Eastern Mediterranean based on CMIP5 Multi-model Ensemble. *International Journal of Climatology,* doi: 10.1002/Joc.5334

Razavi, T., Switzman, H., Arain, A., & Coulibaly, P. (2016). Regional Climate Change Trends and Uncertainty Analysis using Extreme Indices: A Case Study of Hamilton, Canada. *Climate Risk Management,* 13, 43–63,https://doi.org/10.1016/j.crm.2016.06.002

Reiner, P., Samir, C., Sonia, R. G., Yolanda, C., & Maria, J. E. (2017). Climate Change Projections of Boreal Summer Precipitation over Tropical America by using Statistical Downscaling from CMIP5 Models. *Environmental Research Letters,* (12), doi:10.1088/1748-9326/aa9bf7

Revadekar, J. V., Patwardhan, S. K., & Rupa, K. K. (2011). Characteristic Features of Precipitation Extremes over India in the Warming Scenarios. *Advances in Meteorology,* doi:10.1155/2011/138425

Rijsberman, F. R. (2006). Water Scarcity: Fact or fiction? *Agricultural Water Management,* 80, 5–22,https://doi.org/10.1016/j.agwat.2005.07.001.

Richard, T. C. (2019). Projection of Future Precipitation Extremes across the Bangkok Metropolitan Region. *Science Direct,* doi.org/10.1016/j.heliyon.2019.e01678

Rubab, F. B. (2014). *Analysis of Climate Change Impact on Hydrological Ecosystem Services and Water Allocation in Water Scarce Mediterranean River Basins*. Unpublished Doctoral Thesis, Universitat Rovira I Virgili, Tarragona.

Sadoff, C. W., Hall, J. W., Grey, D., Aerts, J. C. J. H., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosengrant, M., Whittington, D., & Wiberg, D. (2015). *Securing Water, Sustaining Growth:* Report of the GWP/OECD Task Force on Water Security and Sustainable Growth.University of Oxford, Oxford.

Salami, A. W., Ibrahim, H. A., & Sojobi, A. O. (2015a).Evaluation of Impact of Climate Variability on Water Resources and Yield Capacity of Selected Reservoirs in the North Central Nigeria. *Environmental Engineering Research,*doi.org/10.4491/eer.

Salami, A. W., Mohammed, A. A., Adeyemo, J. A., & Olanlokun, O. K. (2015b). Assessment of Impact of Climate Change on Runoff in the Kainji Lake Basin using Statistical Methods. *International Journal of Water Resources and Environmental Engineering*, 7 (2), 7-16, doi: 10.5897/IJWREE2014. 0513.

Sang, L., Seung, Y., Jin, C. & Seungjong, B. (2017). Assessment of the Impact of Climate change on Drought Characteristics in the Hwanghae Plain, North Korea Using Time- Series SPI and SPEI: 1981-2100. *MPDI Water*, 9, 579, doi: 10.3390/w9080579

Scheffran, J., Brzoska, M., Kominek, J., Link, M., & Schilling, J. (2012). Climate Change and Violent Conflict. *Science*, 336, 869-871, doi:0.1126/science. 1221339

Scherrer, S. C., Fischer, E. M., Posselt, R., Liniger, M. A., Croci-Maspoli, M., & Knutti, R. (2016). Emerging Trends in Heavy Precipitation and Hot Temperature Extremes in Switzerland.*Journalof Geophysical Resources Atmosphere.* 121, 2626–2637, http://dx.doi.org/ 10.1002/ 2015JD024634

Schewe, J., Heinke, J. D., Gerten, I., Haddeland, N. W., Arnell, D. B., Clark, R., Dankers, S., Eisner, B., Fekete, F. J., Colón-González, S. N., Gosling, H., Kim, X., Liu, Y., Masaki, F. T., Portmann, Y., Satoh, T., Stacke, Q., Tang, Y., Wada, D., Wisser, T., Albrecht, K., Frieler, F., Piontek, L., Warszawski, & Kabat, P. (2013). Multi-model Assessment of Water Scarcity under Climate Change. *Proceedings of the National Academy of Sciences of the United States of America (in press).* doi:10.1073/pnas.1222460110.

Sharif, J. S., Kamran, S., Mehdi, G., Mahmood, A., Roberto, S. & Juan, I. L. (2017). Impacts of Future Land Cover and Climate Change on the Water Balance in Northern Iran. *Hydrological Sciences Journal*, 62:16, 2655-2673, doi: 10.1080/02626667.2017.1403028

Shrestha, S. & Htut, A. Y. (2016). Land use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar. *Environmental Modeling and Assessment*, 21 (6), 819–833, doi: 10.1007/s10666-016-9511-9

Sillmann, J., Kaharin, V. V., Zwiers, F. W., Zhang, X. & Bronaugh, D. (2013). Climate extreme indicies in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *Journal of Geophysical Resources Atmosphere*, 118, 2473–2493, doi: 10.1002/ jgrd.50188

Simon, N. G., & Nigel, W. A. (2013). A Global Assessment of the Impact of Climate Change on Water Scarcity. *Climatic Change*, doi: 10.1007/s10584-013-0853-x

Simon, D. & Richard, T.(2017). The Measurement of Water Scarcity: Defining a meaningful indicator. *Ambio***,** 46:513,https://doi.org/10.1007/s13280-017-0912-z

Singh, R. & Kumar, R. (2015). Vulnerability of water availability in India due to climate change: A bottom-up probabilistic Budyko Analysis, *Geophysical Research. Letters*, 42, 9799–9807, doi: 10.1002/2015GL066363.

Spencer, W. (2013). *"The Carbon Dioxide Greenhouse Effect"*. The Discovery of Global Warming.

Stella, T., Adeline, B., & Arona, D. (2019). Intensification of the Hydrological Cycle Expected in West Africa over the 21st Century. *Earth System Dynamics Discussions,* doi.org/10.5194/esd-2019-38

Sun, Q. H., C. Y. Miao & Q. Y. Duan, (2015). Extreme Climate Events and Agricultural Climate Indices in China: CMIP5 Model Evaluation and Projections. *International Journal of Climatology*, 36(1), 43-61.

Sung, J. H., & Chung, E., (2018). Reliability- Resiliency- Vulnerability Approach for Drought Analysis in South Korea using 28 GCMs. *Sustainability*, https://doi.org/10. 3390/su10093043.

Sunyer, M. A., Sørup, H. J. D., Christensen, O. B., Madsen, H., & Rosbjerg, D. (2013). The Importance of Observational Data Properties when Assessing Regional Climate Model Performance of Extreme Precipitation. *Hydrology and Earth System Sciences*, 17:4323–37

Teng, J., Chiew, F. H. S., Timbal, B., Wang, Y., Vaze, J., & Wang, B. (2012). Assessment of an Analogue Downscaling Method for Modelling Climate Change Impacts on Runoff. *Journal of Hydrology*, 472, 111-125, doi: 10.1016/j.jhydrol.2012.09.024.

Timbal, B. (2015). *Murray Basin Cluster Report*. Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekstrom, M. et al., CSIRO and Bureau of Meteorology, Australia.

Toreti, A., Naveau, P., Zampieri, M., Schindler, A., Scoccimarro, E., Xoplaki, E., Dijkstra, H. A., Gualdi, S., & Luterbacher, J. (2013). Projections of Global Changes in Precipitation Extremes from Coupled Model Intercomparison Project Phase 5 models.*Geophysical Research Letters*, http://dx.doi.org/10.1002/grl. 50940

Torma, C., Giorgi, F., & Coppola, E. (2015). Added value of Regional Climate Modeling over areas Characterized by Complex Terrain-Precipitation over the Alps. *Journal of Geophysics and Resources Atmospheric*, 120, 3957–72.

Trzaska, S., & Schnarr, E. (2014). A Review of Downscaling Methods for Climate Change Projections. African and Latin American Resilience to Climate Change (ARCC). United States Agency for International Development by Tetra Tech ARD, 1–42, https://doi.org/10.4236/ojog.2016.613098.

Umesh, A., & Pouyan, N. (2016). Impacts of Climate Change on Water Resources in Malawi. *Journal of Hydrologic Engineering*, 21 (11), doi:10.1061/1943-5584.0001436.

UNFCC, (2014). *Introduction to the Convention*, Archived from the original on 8 January 2014**,** retrieved 27 January 2014.

Vaittinada, A. P., Vrac, M., Bastin, S., Carreau, J., Deque, M., & Gallardo, C. (2016). Intercomparison of Statistical and Dynamical Downscaling Models under the

EURO- and MED-CORDEX initiative framework: Present climate evaluations. *Climate Dynamics*, 46, 1301-1329, doi: 10.1007/s00382-015-2647-5

Valentina, K., Chantal, D., Alexander, G., Dieter, G., Berit, A., Fred, H. & Zbigniew, W., K. (2018). How the Performance of Hydrological Models |Relates to Credibility of Projections under Climate Change, *Hydrological Sciences Journal*, 63:5, 696-720, doi:10.1080/02626667.2018.1446214

Vera, C. S. & Diaz, L. (2015). Anthropogenic Influence on Summer Precipitation Trends over South America in CMIP5 models. *International Journal of Climatology*, 35: 31723177. https://doi.org/10.1002/joc.4153

Vetter, T., Reinhardt, J., Flörke, M., van Griensven, A., Hattermann, F., Huang, S., Koch, H., Pechlivanidis, I.G., Plötner, S., Seidou, O., Su, B., Vervoort, R. W., & Krysanova, V. (2016). Evaluation of Sources of Uncertainty in Projected Hydrological Changes under Climate Change in 12 large-scale River Basins. *Climate Change,* 1–15,http://dx.doi.org/10.1007/s10584-016-1794-y.

Villarini, G., Smith, J. A., & Vecchi, G. A. (2013). Changing Frequency of Heavy Rainfall over the Central United States. *Journal of Climate*, doi: 10.1175/JCLI-D-12-00043.1

Vorosmarty, C.J., Pahl-Wostl, C., Bunn, S.E., & Lawford, R. (2013). *Global water, the anthropocene and the transformation of a science.* Current opinion in Environmental Sustainability 5, 539 - 550.

Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. (2011). The Representative Concentration Pathways: An Overview. *Climatic Change*.109: 5. https://doi.org/10.1007/s10584-011-0148-z

Wada, Y., Wisser, D. & Bierkens M. F. P. (2014).Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources. *Earth System Dynamics,* 5:15–40, doi: 10.5194/esd-5-15-2014

Weart, S. (2011). *"International Cooperation: Democracy and Policy Advice (1980s)".* The Discovery of Global Warming. Physics.Retrieved 9 July 2012**.**

Wei, L., Zhihong, J., Jianjun, X., and Laurent, L. (2016).Extreme Precipitation Indices over China in CMIP5 Models. Part II: Probabilistic Projection. *American Meteorological Society,* doi: 10.1175/JCLI-D-16-0377.1

Wenchao, S., Jie, W., Zhanjie, L., Xiaolei, Y., & Jingshan, Y. (2014). Influences of Climate Change on Water Resources Availability in Jinjiang Basin, China. Hindawi Publishing Corporation. *Scientific World Journal,* doi: 908349, 7 pages

World Meteorological Organisation (WMO) (2011*). "Report of the International Conference on the assessment of the role of carbon dioxide and of other greenhouse gases in climate variations and associated impacts".* Villach, Austria. Archived from the original on 21 November 2013.Retrieved 28 June 2011.

World Meteorological Organisation (2016). *WMO Statement on the Status of Global Climate in 2015*.World Meteorological Organisation.

Wu, F., Zhan, J., & Güneralp, İ. (2015). Present and Future of Urban Water Balance in the Rapidly Urbanizing Heihe River Basin, Northwest China. *Ecological Modelling,* 318, 254–264, doi:10.1016/j.ecolmodel.2014.11.032

Xiaoqiang, R., Xi, L., & Wenjie, D. (2019). Evaluation and Projection of Extreme Precipitation over Northern China in CMIP5 Models. *MDPI Journal/Atmosphere*, 10, 691, doi: 10.3390/atmos10110691

Xiaojun G., Jianbin, H., Yong, L., Zongci, Z. & Ying, X. (2016). Projection of Precipitation Extremes for Eight Global Warming Targets by 17 CMIP5 Models. *Natural Hazards,* 84: 2299–2319, doi: 10.1007/s11069-016-2553-0

Xu, X., Liu, W., Scanlon, B.R., Zhang, L., & Pan, M., (2013). Local and Global Factors Controlling Water-energy Balances within the Budyko Framework. *Geophysical Research Letters*, 40, 6123–6129, http://dx.doi.org/10.1002/2013GL058324.

Yang, N., Men, B., & Lin, C., (2011).Impact Analysis of Climate Change on Water Resources.*International Conference on Advances in Engineering,* doi: 10.1016/j.proeng.2011.11.2710

Yanga, H., Faramarzi, M., & Abbaspoura, K. C. (2013). Assessing Freshwater Availability in Africa under the Current and Future Climate with Focus on Drought and Water Scarcity. *20th International Congress on Modelling and Simulation,* Adelaide, Australia, 1–6 December,www.mssanz.org.au/modsim2013

Yared, B., Shreedhar, M., Tsegaye, T., Schalk, J. A., Semu, M., Ann van, G., & Dimitri, S. (2018). Comparison of the Performance of Six Drought Indices in Characterizing Historical Drought for the Upper Blue Nile Basin, Ethiopia. *MDPI Journal of Geosciences*, 8, 81; doi: 10.3390/geosciences8030081

Yunana, D. A., Shittu, A. A., Ayuba, S., Bassah, E. J., & Joshua, W. K. (2017). Climate Change and Lake Water Resources in Sub-Saharan Africa: Case Study of Lake Chad and Lake Victoria. *Nigerian Journal of Technology,* 36 (2), 648-654, doi:org/10.4314/njt.v36i2.42.

Zobel, Z., Wang, J., Wuebbles, D. J., & Kotamarthi, V. R. (2018). Analyses for High-Resolution Projections through the end of the 21st Century for Precipitation Extremes over the United States. *Earth's Future*, 6, 1471–1490, doi.org/10. 1029/2018EF00095.

APPENDICES

APPENDIX A

The GCMs in Coupled Model Intercomparison Project (CMIP5) under World Climate Research Programme (WCRP) used for this study

Modelling Centre	Model	Institution
BCC	BCC-CSM1.1, BCC-CSM1.1(m)	Beijing Climate Centre, China Meteorological Administration
CCCma	CanAM4 , CanCM4, CanESM2	Canadian Centre for Climate Modelling and Analysis
CMCC	CMCC-CESM, CMCC-CM, CMCC-CMS	Centro Euro-Mediterraneo per| Cambiamenti Climatici
CNRM-CERFACS	CNRM-CM5, CNRM-CM5-2	Centre National de Recherches Meteorologiques /Centre Européen de Recherche et Formation Avancée en Calcul Scientifique
COLA and NCEP	CFSv2-2011	Center for Ocean-Land-Atmosphere Studies and National Centers for Environmental Prediction
CSIRO-BOM	ACCESS1.0, ACCESS1.3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
CSIRO-QCCCE	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
EC-EARTH	EC-EARTH	EC-EARTH consortium
FIO	FIO-ESM	The First Institute of

Oceanography, SOA, China		
GCESS Earth System	BNU-ESM	College of Global Change and
INM Mathematics	INM-CM4	Institute for Numerical
IPSL	IPSL-CM5A-LR, IPSL-CM5A-MR, PSL-CM5B-LR	Institut Pierre-Simon Laplace
LASG-CESS Physics, and CESS,	FGOALS-g2	LASG, Institute of Atmospheric Chinese Academy of Sciences; Tsinghua University
LASG-IAP Physics, Chinese	FGOALS-g1, FGOALS-s2	LASG, Institute of Atmospheric Academy of Sciences
MIROC Research Institute (The Institute for Japan Agency for Technology	MIROC4h, MIROC5	Atmosphere and Ocean University of Tokyo), National Environmental Studies, and Marine-Earth Science and
MIROC Science and Ocean Research Tokyo) and Environmental Studies	MIROC-ESM MIROC-ESM-CHEM	Japan Agency for Marine-Earth Technology, Atmosphere and Institute (The University of National Institute for
MOHC (additional (additional HadGEM2-ES realizations by INPE) nstitutoNacional	HadCM3, HadGEM2-A, HadGEM2-ES	Met Office Hadley Centre realizations contributed by de PesquisasEspaciais)
MPI-M Meteorology (MPI-M)	MPI-ESM-LR, MPI-ESM-MR MPI-ESM-P	Max Planck Institute for

MRI	MRI-AGCM3.2H, MRIAGCM3.2S, MRI-CGCM3, MRI-ESM1	MeteorologicalResearch Institute
NASA GISS Space Studies	GISS-E2-H, GISS-E2-H-CC	NASA Goddard Institute for
NASA GMAO Assimilation Office	GEOS-5	NASA Global Modeling and
NCAR Research	CCSM4	National Center for Atmospheric
NCC	NorESM1-M, NorESM1-ME	Norwegian Climate Centre
NICAM Atmospheric Model	NICAM.09	NonhydrostaticIcosahedral Group
NIMR/KMA Meteorological Research/ Korea	HadGEM2-AO	National Institute of Meteorological Administration
NOAA GFDL Laboratory	GFDL-CM2.1, GFDL-ESM2G, GFDL-CM3, GFDL-ESM2M, GFDL-HIRAM-C180, GFDL-HIRAM-C360	Geophysical Fluid Dynamics
NSF-DOE-NCAR Department of Atmospheric	CESM1(BGC), CESM1(CAM5), CESM1(CAM5.1, FV2), CESM1(FASTCHEM), CESM1(WACCM	National Science Foundation, Energy, National Centre for Research

Source: (Elguindi*et al.*, 2014; Sung and Chung, 2018)