UNIVERSITY FOR DEVELOPMENT STUDIES

WEST AFRICAN CENTER FOR WATER, IRRIGATION AND SUSTAINABLE AGRICULTURE

ANALYSIS OF RIVER FLOW VARIABILITY FOR IRRIGATION PLANNING AND FLOOD PREDICTION – A CASE OF WHITE VOLTA RIVER

EMMANUEL CHIMWEMWE BANDA

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BY

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(BSc. Irrigation Engineering)

(UDS/MID/0024/21)

THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

SEPTEMBER 2023

DECLARATION

DECLARATION BY CANDIDATE

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

Emmanuel Chimwemwe Banda Tuesday, August 8, 2023
(UDS/MID/0024/21) (Signature) (Date)

DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

Analysis of river flow variability under changing flow regimes is required for planning of dry season irrigation and flood prediction. River flow characteristics are changing in response to change in climate, as well as land use and land cover changes. The objective of this study was to analyze flow variability of the White Volta River for irrigation planning and flood prediction. The daily discharge data of the river was collected from Pwalugu, Nawuni and Daboya hydrological stations and trends in discharge were analysed by applying the Mann Kendall statistical test and Sen's Slope method at significant level of 0.05. The statistic calculated value of 0.0001 was found to be lower than the alpha significance level of 0.05 which supports the hypothesis that there is flow variability in the White Volta River, with a magnitude of 0.003 as provided by the Sens Slope. Land use and land cover changes were characterized using GIS and remote sensing and, over the study period, agricultural land increased by 56.5%, whereas savannah vegetation and grassland decreased by 46.5% and 56.25%, respectively. This has affected the total dry season flows that are used for irrigation farming, hence, the need for proper planning for the same. More surface flows within the basin are lost through surface runoff into the sea in the rainy season as compared to what is stored in reservoirs and used for agricultural purposes. During the study period, the year 2020 recorded the highest discharge of 2087 m^3/s at Daboya hydrological station which has a recurrence interval of 50 years or more. Gumbel's method was used for flood prediction and the Gumbel's curve was plotted from which future floods with the return periods between 5 and 150 years can be worked out. The findings of this research work will be used for dry season irrigation planning as well as for storm management in the area which is critical in protecting lives and property. The findings will as well help in designing and management of dams, bridges, irrigation canals and other hydraulic structures.

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DEDICATION,

To My Family, Emmanuel Chiutawalinase Banda and My Guardian, Professor John Alphonsus Ryan, Bishop of the Catholic Diocese of Mzuzu, Malawi.

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LIST OF ACRONYMS

ARID : Agricultural Reference Index (ARID)

AVHRR : Advanced Very High-Resolution Radiometer,

DEM : Digital Elevation Method,

DSM : Digital Surface Model,

FAO : Food and Agriculture Organization,

GDP : Gross Domestic Product,

GHc : Ghana Cedis (Ghana Currency),

GIDA : Ghana Irrigation Development Authority,

GIS : Geographic Information System,

GNP : Gross National Product,

GPS : Global Positioning System,

GRCS : Ghana Red Cross Society,

GSS : Ghana Statistical Service,

Ha : Hectare,

HSD : Hydrological Services Department,

IWMI : International Water Management Institute,

KM : Ken Mann Test,

LULCC	:	Land Use and Land Cover Changes,
MAIWD	:	Ministry of Agriculture, Irrigation and Water Development In Lilongwe, Malawi,
MKM	:	Modified Ken Mann Test,
MoFA	:	Ministry of Food and Agriculture in Ghana,
NADMO	:	National Disaster Management Organization,
NOAA	:	National Oceanic and Atmospheric Administration
RDI	:	Reconnaissance Drought Index (RDI)
SDG	:	Sustainable Development Goal(s).
SDI	:	Standardized Precipitation Index (SPI)
SDI	:	Streamflow Drought Index (SDI)
SM	:	Sen’s Method,
USDA	:	United States Department of Agriculture
USGS	:	United States Geological Survey
VBA	:	Volta Basin Authority
VRA	:	Volta River Authority

CHAPTER ONE

INTRODUCTION

1.1. Background

The general prosperity and sustainable development of livelihoods in human societies critically depend on availability of water resources for agriculture, domestic and industrial water supply (Arrieta *et al.*, 2020). There are various water resources that exist across the globe ranging from rivers, artificial or man-made reservoirs, lakes, oceans and deep wells of which are all very important as far as human and industrial development is concerned in the modern world. Rivers are the largest water sources for agriculture through irrigation in both dry and rainy season, supply of water to homes and industries and hydroelectric power generation. Furthermore, rivers are vital through provision of water for aquatic farming and providing essential environment amenities like natural water purification and climate regulation (Tena *et al.*, 2019).

Despite the stated benefits, water and other hydrological resources are lessening worldwide due to varying patterns use by users, causing various flow problems (Harley *et al*., 2017). Negative water flow tendencies have direct influences on availability of water for societal economic usages and environmental strength, consequently, disturbing provision of natural environmental services such as regulation of climate change and sustainability of aquatic life (Lugomela *et al*., 2021). In the low catchments of Ghana, peak river flow between 1991 and 2011 have increased by 21% where as and dry season river flows have increased by 37% in the same period (Aduah *et al.*, 2017). The baseline study by Aduah *et al*., (2017) showed the reduction in evergreen vegetation by 18% and secondary woodlands by 39% and a growth in settlements, mineral excavation areas and agricultural land by 81 percent (%), 310 percent (%) and 343 percent (%) respectively.

Historical land cover changes from 1991 to 2011 were so significant that they will have a bearing in flow fluctuations and their study concluded that changes will still prevail in the forthcoming situations. Flow regimes are a key determinant for the running of river environment services such as natural water purification and climate regulation. Changes to high extreme levels results in flooding which destroys people and their property whereas changes to low extremes leads to water shortages for irrigation, domestic uses and hydroelectric power generation (Aduah *et al*., 2017).

Since the quantity of water in rivers differs according to localized conditions and flow behaviours at that particular location, the flow regimes in rivers sometimes become so unstable such that there is little provision for control, management or regulation. If the size of the basin is so big with surface flows of high magnitude, there will be rapid increased of high flows into the rivers which cause floods which destroy crops and human lives. Therefore, an understanding on river flow and the impacts of land practices on rivers is central in resolving water flow problems at river basin level but information about the same is limited in most developing countries (Faiilagi, 2015).

Poor management of various practices along river banks such as bush clearing for purposes like human settlement, firewood and charcoal burning, streambank cultivation and overgrazing are some of the problems that affect uniform water flow in rivers which causes flow of water to vary to high and low extremes (Megdal *et al*., 2017). As a result of these human activities and change in climate, hydrological characteristics are varying in river basins and thus, water flow behaviour in rivers are varying too (Baffour *et al*., 2021). Various hydrological models have been made to evaluate various impacts on variations on river hydrology in West Africa, but there is still lack of knowledge and understating on the effects that disturb river hydrology. This includes the flow regime of rivers at the limited scale, in spite of land use changes being noteworthy over the previous decades (Aduah *et al*., 2017).

According to Aduah *et al*., (2017), there is deficient understanding on changes on the hydrological regimes of rivers and it is significant to comprehend how these variations impacts on hydrology to permit for effective sustainable land use planning and utilization of environment including water and marine life. This as well include analysis of flood frequency in the river basins. To ensure the information on past climate variation is relevant for multipurpose applications such as water supply to homes and industries, generation of electricity and irrigation farming in the dry season, analyses of rainfall or flow variability in rivers should be done as done. Although several studies were conducted on of flow in the White Volta River, they were confined to sub-basins and lacked insight on the influence of model selection on simulation results.

The present study therefore assesses river flow variability in the White Volta River over an extended period and the results will be used to plan for dry season irrigation farming and predict floods. This supports other hydrological research studies such as the biogeochemistry of dry riverbeds Arce *et al.*, (2019), the assessment of environmental flows Acuña *et al.,* (2020) and the understanding of people's perceptions of river ecosystems by Rodríguez *et al.*, (2020) and another one by Jorda *et al.*, (2021).

Vega *et al*., (2018) evaluated hydrological variations caused by discrepancies in the rainfall patterns and by hydraulic constructions in the river basins and their findings found out that water regulation and diversion developments have a substantial consequence on both increasing and decreasing streamflows. Their work though upstretched some questions around other environmental modification issues such as river flooding, droughts, earthquakes, tornadoes and mining which all have effects on river flow. Their research explained little about the relationship between river flow inconsistency and the existence of river flow extreme discharges that causes floods and other unforeseen water flow disasters to the riparian ecosystems.

Ávila *et al*., (2019) calculated climate indices of precipitation data of the Cauca River, aiming at identifying precipitation trends and the relationship between historical floods. The findings suggested a lag time of (Two) 2 – (Three) 3 months, which is very important for flood forecasting. Many flow dimensions can be studied but this research presents some key parameters which are recognised by irrigation engineers, hydrologists and water scientists as essential attributes in social and ecological flow of rivers. Using the same parameters, data about river flow can be organized to explain the natural, the current and future flow characteristics.

1.2. Problem Statement

Disagreements usually happens among water scholars over the behaviour of water flow with respect to climate change and studies about streamflow have resulted into contradictory conclusions (Arfan *et al.*, 2019). Arfan *et al.*, (2019) reported that this state of affairs warrants a detailed investigation of the statistical variations of streamflow at more water measuring points, rather than depending on climate projections only. Furthermore, lack of knowledge about river flow characteristics has resulted into disturbance of river health, lowering of baseflows in the dry season, alteration of streamflow behaviours and severe loss of biodiversity across the world. River studies are regularly deserted by hydrologists and the research on the same can expand the common understanding towards them (Skoulikidis *et al*., 2017). This is the scenario with the basin of the White Volta River and this research tries to study and make river flow variability data available so as to effectively plan for the dry season irrigation and predict flood. Limited flow records limit the capacity of water engineers to plan for upcoming environments in terms of dry season irrigation agriculture, domestic water supply including predicting river floods. Using daily stream gauge records which are short in terms of duration of flow in major rivers often lack description of streamflow changeability covering the period beyond the observations (Harley *et al.*, 2017).

1.3. Justification

Analysis of river flow helps in operational management of hydraulic structures such as culverts, water dykes, hydropower and irrigation structures and flood regulator reservoirs. The analysis helps in calculation of dimensions of these water structures through the data of the features and behaviours of waterways. The analysis will be helpful to water supply commission, hydrological department and Ghana Irrigation Development Authority. The analysis will be used for sustainable management of hydrological resources, river restoration, running of irrigation services, the design of water structures, flood routing procedures and the production of electricity at the Akosombo dam that relies on surface flows of White Volta River to drive power generating turbines. It will also help in understanding the recharge rate of lake Volta, that supports Ghana in various ways.

The analysis also enhances the healthiness of river banks and marshlands and their service and recreational worth. River flow analysis also support the initiatives about water strategies and policies including writing of procedures and lawmaking for state applications. It also adds to the understanding of water resources and their organization issues. Streamflow analysis also helps with riverine regulatory controls which is necessary for authentication of water release requirements downstream of the catchment of riverine. Minimum flows ensure the continued existence of aquatic animals, maintenance of water structures, nonexacerbation and announcement of flood disasters and dry spells within a country. Safety of property and human lives is another important purpose. River flow analysis helps to forecast events of river flooding during high river flows in the rainy season and flood warnings are therefore made known to people in advance so as to stay away from the same to avoid loss of life and property. The makeup of sequences of observations over a long term are crucial in knowing progress of stream flows, raising cognizance of natural hazards, to give a probability to risky flood events including low water heights.

Study of river flow is necessary to the efficient development of current and future procedures in flood and water shortage instances including planning for dry season agriculture. River flows are a key component of the hydrological cycle because they are a great source of water way that plays a significant role in carrying fresh water all around the world. River flow analysis therefore helps in understanding the water cycle system in the entire earth.

knowledge of river flow has contributed to the understanding of hydrological water storage progressions and water budgets, streamflow changing aspects, fundamental hydraulic properties of groundwater, and ecological streamflow conditions (Owolabi *et al*., 2020). Studying the variability of streamflow are necessary for organization and planning of water and other hydrological resources so as to maintain the sustainability resources (Dave, 2018). River studies are very critical and helpful when it comes to the understanding the problems and bringing solutions through development of effective management water opportunities (Dutta *et al*., 2017). Therefore, planning for just supply of water to homes and industries in Ghana, planning for dry season irrigation agriculture and forecasting floods in the White Volta River needs precise quantification of forthcoming water flow situations under varying flow characteristics

Furthermore, flow variability is studied with an opinion to understand the spatial streamflow variability in river basins which have solid signal of changing patterns in annual runoff and river flow magnitude (Eduful *et al*., 2022). Study of river flow aligns with sustainable development goal number 6 (SDG 6) whose overall aim is to make sure of water availability and accessibility including sustainable running of water resources. It as well ensures availability of clean and safe water for all purposes ranging from irrigation, domestic and industrial supply. The goal further fortifies several other SDGs and fulfilling SDG 6 will be a tremendous step towards accomplishing much of the 2030 agenda.

1.4. Research Question

River flow variability should be studied so as to make river flow data available for various planning purposes in a country such as flood prediction, water supply and dry season irrigation planning. This present research answers the following research questions as regards to the study of river flow variability of the White Volta River in Ghana.

i. What are the trends of water flow in the White Volta over the last thirty (30) years?
ii. What are the factors that contribute to the variability of the flows in the river?
iii. How does analysis of hydrological droughts help in planning for dry season irrigation farming?
iv. How do trends in flow regimes of water in the river help in predicting floods?

1.5. Research Objectives

1.5.1. Main objective

The overall objective of this research is to analyze the river flow variability for dry season irrigation planning and flood prediction.

1.5.2. Specific Objectives

Specifically, the study seeks to;

i. Analyze the flow patterns and observe flow trends in the river,
ii. Investigate the key factors that contribute to variability of discharge in the river,
iii. Analyze hydrological droughts for dry season irrigation water management,
iv. Use annual peak stemflow records to predict the frequency of floods in the river.

1.6. Scope and Organization of the Study,

This work analyses flow variability of the White Volta River using flow data of the last thirty (30) years (1991 – 2021). The study establishes the trends in water flow between the stated time duration and identify key factors that contribute to the variability of the flow pattern. The trends in flow will help in planning for irrigation farming and flood prediction. All the data generated for this work and the discussions are all the illustrative of the assessment study during the period between 1991 and 2021. The research work has been organized as listed in the below section;

Chapter One (1) comprises of contextual background of the study with recent literature about the study, problem statement that identifies the gaps that this research tries to bridge, the research questions and research objectives, justification of the study that explains the purpose and relevance of the study and then the scope and the organization of the thesis.

Chapter Two (2) comprises of the applicable literature regarding the philosophy and theories, concepts and ideas, and scientific models that have given shape to this study particularly with the flow variability of water in rivers and the key factors responsible for flow variability of water in rivers. The literature chapter as well highlights different other assessments on the same, their assessment techniques and findings.

Chapter Three (3) comprises the resources, materials, approaches and methods used including the research design and partakers, data gathering procedures and data analysis procedures.

Chapter Four (4) comprises of the results and discussions of the findings of this research study.

Finally, this work is settled with Chapter Five (5) which make available the conclusions drawn from the arguments in Chapter Four (4) as well as commendations for additional research.

CHAPTER TWO

LITERATURE REVIEW

2.1.River Flow

A river is generally described as a large natural movement of water streaming down along a channel within a watershed, crossing small water pools that are generally surrounded by terrestrial features. Rivers empty into larger water pools which are generally oceans but sometimes they can end into other large water bodies such as lakes that doesn’t have outlets and swamps or marshlands (Edgeworth & Benjamin, 2020). As rivers flow within a basin, they provide water to the communities around them, including wildlife and vegetation. Water flow is essential process that governs the extent, outline, structure as well as changing aspects of the ecosystems in the riverine (Zeiringer *et al*., 2018). Streamflow variability is a central feature of river systems and their environmental functioning. The natural aspect of streamflow in rivers differs depending on various time scales as given either in hours, days, seasons, years, and longer.

Changes in streamflow in natural systems brought on by human and natural activities have an impact on the hydrological flow regimes, which in turn have an impact on the processes occurring at the ecosystem level that determine the availability of water resources (Dobriyal *et al.*, 2017). Reduced or increased water availability from precipitation, runoffs, groundwater recharge and discharge are some of the factors that lead to changes in water regimes. Furthermore, the seasonality, frequency, duration, size, and timing of flow episodes may all have an impact on overall hydrological streamflow. Dobriyal *et al*., (2017) further stated that due to substantial regional modifications and spatiotemporal restrictions, there is a substantial amount of uncertainty and ambiguity in trends of hydrological variables.

To describe the behavioural or characteristic flow patterns in terms of flow quantity, flow timing and flow variability, streamflow observations recorded for several years within that river are needed (Poff *et al.*, 2003). This streamflow data is needed for practical analysis of hydrological droughts as well as analysis of floods within a river course. Analysis of hydrological droughts using various indices is key in municipal water supply and planning for irrigated agriculture in irrigating schemes within the watershed. Poff *et al*., (2003) further reported that river flow regimes show local patterns that are governed mainly by river size and by topographical, environmental and physical variations in both micro and macro climate, geology, landscape and groundcover by plant growth (Zeiringer *et al.*, 2018).

Zeiringer *et al*., (2018) also reported that the commonly recognized natural flow behaviours which sustains biodiversity and ecosystem integrity have five important components of flow variability, which are; flow magnitude, flow frequency, flow duration, flow timing and streamflow rate of change. These important components are generally used for describing the whole variety of flows and their exact hydrologic phenomena such as river flooding and river flow shortages, which are the two critical flow characteristics that defines the integrity of river ecosystems including other hydrological resources and their impacts to the environment.

Ground water flow is also key to flow of water in rivers and Welderufael *et al*., (2010) reported that planning for the management of water resources should always take into account how groundwater affects stream flows. One of the known techniques for determining the scope, dynamics and impact of groundwater discharge on river flow is the analysis of the streamflow hydrograph in which base flow is interpreted and distinguished from fast flow. Quick flow is the immediate response to a rainstorm event, whereas base flow is the long-term delayed flow from the storage Welderufael *et al*., (2010).

Welderufael *et al.*, (2010) further reported that many stream flows acquire modified base flow circumstances as a result of direct abstraction and utilization of water resources directly from streams or groundwater storage. Impoundments which are constructed on rivers channels such as dams and weirs, water abstraction for farming and urban supply, maintenance of flows for navigation, structures for drainage and flood control are some of the ways that the world's rivers are being altered on a regular basis. By lowering the overall flow of numerous rivers and changing the seasonality of flows as well as the size and frequency of floods, these interventions have had considerable detrimental environmental effects (Karimi *et al.*, 2012).

2.2.Hydrological and Streamflow Analysis

Hydrological analysis is the process of classifying flow characteristics in rivers which are done generally based on low and high flow thresholds which are calculated from river flow hydrographs (Deb, 2015). The flow characteristics mostly described includes average yearly flows, monthly flows, high or low flows. There are various methods that are used in hydrological analysis so as to know the flow trend and behaviour of water flow in rivers. The decision on which model to use depends on various factors ranging from the type of river, e.g., perennial, seasonal, high base flow and flashy river; apparent environmental reputation; difficulty of the verdict to be made; increased price and difficulty of gathering huge quantities of statistics and severity of different resource developments (Karimi *et al.*, 2012).

The techniques that have been developed are categorized into graphical base flow separation, filtering algorithms, frequency analysis and recession analysis (Welderufael *et al.*, 2010). The Mann Kendal trend test and the Tennant method are some of the commonly used methods for flow trend analysis whereas the Log Pearson III and the Gumbel’s method are some of the methods that are used in flood frequency analysis in rivers (Ganamala & Sundar Kumar, 2017).

According to Karimi *et al*., (2012), the hydrological flow analysis techniques have been developed for broad scale planning and make use of readily available stream flow data alone. The Tennant technique is one among the same, which, depending on specific shares of the mean flow, identifies various minimum flow values. Another recent technique is the Range of Variability Approach (RVA) which estimates flow characteristics grounded on an evaluation of streamflow statistics for the controlled and natural flow behaviours (Karimi *et al*., 2012).

Powell *et al*., (2008) recommended the parsimonious model which is used for evaluating ecologically substantial flood dynamics of floodplain marshlands, but the development and calibration of the technique remains a challenge for the reason of the lack of available data. Hydrological alterations within rivers are indicated by hydrological indices which provides the range and variability of droughts and extreme flows (Javadinejad *et al*., 2020). These indices are used for flood predication and management of low flows for irrigated agriculture. Hydrological analysis depends on historical hydrological data, which is gathered through daily flow measurements for a long period of time (Lohpaisankrit & Techamahasaranont, 2021). Most rivers are not gauged because streamflow measurements require devices that are very expensive and not locally found. Hydrological analysis is simple and time effective in gauged rivers.

Design and analysis of hydrologic disasters such as floods, flood forecasting and protection, water reservoir and spillway designs involve a procedure called flood routing (Hossain, 2015). In this process, the data from one or more upstream stations is utilized to determine the flood hydrograph at a river section. Reservoir routing involves studying the consequence of a flood wave entering a reservoir. In channel routing, the change in the shape of a hydrograph as it travels down a channel is studied. Flood frequency analysis uses the observed historical data to forecast the upcoming flood events along with their probabilities or return periods (Hossain, 2015).

2.3.Application of Hydrological Analysis in Irrigation Water Management

Growing crops along river banks has a variety of effects on water flow, including the presence of substances which affects the quality of the water in the river systems (Kachingwe *et al*., 2019). The banks along the rivers are mostly utilized by farmers during the dry season because they still contain soil moisture that is necessary for plant growth. Continued crop cultivation along river banks lowers the base flow in rivers, affecting the quantity of water that is flowing downstream in the dry season (Hardlife *et al.*, 2017). Streambank cultivation also causes siltation of water bodies, a phenomenon that increases the velocity and continued loss of water in the river course during rainy season. Siltation of water bodies along the river course reduces the amount of water that is stored within the same for dry season irrigation faming.

Farming practices in rivers also increases the rate of soil erosion, that affects the stability of land along river banks (Mlowoka, 2008). Mlowoka, (2008) further reported that there is a significant relationship between farming practices and quantity of water flowing in most rivers in Africa. The findings of this research reported that as land for agricultural production is expanding along most areas along both seasonal and perennial rivers, the rates of soil erosion and land instability in the river systems increases as well. All this affects the quantity of water that is stored within the same for irrigation purposes in the dry season. The expansion of agricultural land and the need for dry season irrigation in the wake of water resources scarcity in several parts in the world have called for the use of irrigation and water management systems that aim at increase the efficiency of water application and water use by plants in the irrigated fields (Jesus *et al*., 2017). Irrigation farming along river banks therefore needs to be performed through techniques that maximize the efficiency water resources which as well promotes environmental sustainability and river flow restoration. This ensures continued flow of water in rivers during the dry season.

Hydrological studies are therefore necessary in proper planning of water resources that are used for irrigated agriculture in most parts of the world. For example, in India, the use of water in for irrigated agriculture is at eighty five percent (85%), which is more than any other uses of water such as domestic supply (6%), hydroelectric power generation (3%) and industrial supply (6%) within the country (Mandal *et al*., 2019). In West Africa, and White Volta in particular, flood water irrigation methods are fundamental part of families located in the flood plains of the Volta River Basin whose total surface area is 400,000 km^2 (Dittoh, 2020). Dittoh, (2020) further reported that irrigation is common in savanna regions using the surface flows from the Volta basin where surface water pumping from rivers on irrigation systems are particularly abundant.

During the dry season, water shortages are common, due to declining levels of water in the basin. The baseflow becomes so low, affecting irrigation water management in the process. The effect of hydrological droughts is very critical and analyzing these effects on water supplies for irrigation plays an important role for water management in (Javadinejad *et al*., 2020). In this process observed hydro-climatic data for a long period of time are used for hydro-meteorological projections to forecast the future scenario of water flow within a river course, or any other sources of water for irrigation faming. The major climate variables that are involved in this procedure includes the total surface air temperature, precipitation and streamflow records. As reported by (Javadinejad *et al*., 2020), all alterations in rainfall and temperature have critical impact in drought and flood incidences directly and subsequently, they have serious impacts on the general livelihoods of people, infrastructure and the general environment. This means that hydrological analysis in most rivers in all parts of the world are necessary and a good tool in addressing water related problems, as well as analysis hydrological droughts, that are critical as far as planning for effective management of water for irrigation farming is concerned.

2.4.Meteorological Drought Indices for Describing Past and Forthcoming Droughts

Studying the impact of past droughts is very significant in river basins as far as management of hydrological resources is concerned (Javadinejad *et al*., 2020). The study helps in management of future droughts that might affect the irrigation farming within river basins, as well as floods that destroys human life and property. Hydrological droughts are characterized by various induces that quantify the magnitude of past and forthcoming droughts. Some of the indices used for the same includes, the Standardized Precipitation Index (SPI), the Reconnaissance Drought Index (EDI) and the Streamflow Drought Index (SDI) just to mention a few (Javadinejad *et al*., 2020). The Standardized Precipitation Index is calculated from meteorological data, especially rainfall, and is used for forecasting future drought within a river basin.

Variations in precipitation and temperature generally contributes in a bigger scale to the outcome of future drought as well as flood incidences. All these have substantial impacts on humans and their infrastructure as well as the general environment. Hydrological droughts take various forms, ranging from meteorology, hydrology, agriculture and socioeconomic droughts. Physical traits and climate variables are used to establish meteorological, hydrological, and agricultural droughts whereas the socioeconomic drought is linked to the water resource shortage that might occur due to socioeconomic factors.

In addition to global warming, Javadinejad *et al*., (2020) stated that future predictions for precipitation and evapotranspiration change on a variety of global scales. Using climate projection models, several scholars have examined past drought features as well as potential changes in drought in the future. The findings have been used to improve the general understating of historical droughts and their impacts, including modelling the same in the forthcoming scenarios. Besides predicting future floods, the findings as well helps in planning for dry season in river basins.

2.5.Activities that Contribute to River Flow Variability,

2.5.1. Rainfall

Precipitation is the major source of water in the White Volta River drainage basin. All river systems within the drainage basin from Burkina Faso (Upper Volta) to Ghana discharges into the White Volta River. According to the rainfall and river flow data in the last three (3) decades (1991 – 2021), water heights in the river are higher during the rainy season, where floods are more prominent, as likened to the dry season. Rainfall in the Volta River Basin is not spaciotemporal consistent. The Sahelian Zone in the north receives a yearly rainfall of about 500 mm and less. In Burkina Faso, the Sudano-Sahelian Zone receives yearly rainfall which ranges from 500 to 900 mm. The Sudanian Zone which comprises of some parts of Ghana, Ivory Coast, Benin and Togo, receives annual rainfall that ranges from 900 and 1,100 mm. This describes how variable rainfall is in the basin.

The southern part of Ghana which is covered by the Guinean Zone receives rainfall ranging from 1,000 and 1,300 mm/yr. There are three (3) months of rainfall in the Sahelian Zone; four (4) to five (5) months in the Sudano-Sahelian Zone; and six (6) to seven (7) months in the Sudan and Guinean Zone. More than half of peak precipitation occurs between July and September, with approximately little rain in April and May. There's no (0) rainfall between November and February which are complete dry months. Whenever there is heavy rainfall, less amount of water goes into the soil horizon through a process called infiltration, so water runs off the ground surface as surface runoff into the White Volta River. If water reaches the river faster, the likelihood of river flooding in the downstream of the river increases. Steep valleys which are prominent in the White Volta River are the most probable areas of floods as compared to valleys which are flat. Rainwater runs quickly in steep valleys than in flat valleys (Nii & Buxton, 2018).

Rainfall has a significant impact on river processes and river flow variability including the landscapes where the river is taking its course (Boateng *et al*., 2021). Areas with very wet environments always have higher amount of water flowing into the streams as opposed to dry environments. Soil erosion as well increases in these areas since the streams have big erosive energy to wear away the soil in river banks. Erosion negatively affects depth of water flow in rivers. Further increase in streamflow causes branching of river necks in the meandering channels of the river leading to formation of ox-bow lakes. Increase in streamflow in the lower course of the river as well causes floods due to the storms which leads to the formation of levees. On the other hand, dry spells reduce the streamflow in a river during which most rivers drastically go down, negatively affecting irrigation farming and supply of water to homes and industries.

Along the bottom and sides of rivers, the water flow is resisted by the rocks or soil that make up the river bed or river banks (Bhat *et al*., 2019). According to the report by (Nii & Buxton, 2018), the most significant factor in the behavior of a river system is streamflow velocity. Rivers with fast streamflow velocity cut more deeply into the earth due to the pressure from the flow. Streamflow velocity as well influences the shape and rate of erosion of a river system. Finally, gravel, stones, sand and other soil particles, tree logs and other sediment load all impacts streamflow velocity and the shape of river channels (Boateng *et al*., 2021). Apart from the discussed relationship between precipitation and increase in floods, there is additional evidence that prove that global warming is also contributing to loading of moisture into the atmosphere which is causing heavy rainfall. However, it is also reported that the evidence is not clear to conclude that this is scientifically leading to increase in floods. Precipitation events of long duration causes more land saturation which increases surface runoff. Modest rainfall amounts can as well cause serious floods, more particularly in urban areas with poor drainage.

Generally, precipitation in the Volta River basin starts in April and May with peak precipitation in July and September each year. There is mild rainy season in September and October, with few rains. In the northern part, a single modal rainfall season starts either in May or June and stops in either September or October, with the most precipitation occurring in the month of September. On average basis, the total annual rainfall in terms of volume is about 500 km^3/year and estimates have been made that for significant runoff to occur, more than 340 km^3/year of rain water must fall on the basin. Historical rainfall and climatic data during the study period have concluded that annual streamflow for the whole Volta River system varies between thirteen (13) to sixteen (16) percent (%) of the average rainfall per year. According to Mul *et al.*, (2015), from 1970, variations in rainfall patterns in the basin have been recorded, accompanied with a reduction in rainfall and surface runoff. There is now one rainfall in some areas where there were bimodal rainfall events. Some minor seasons have started becoming weak with no rain in some extents.

The Ghana tropical climate has two (2) main distinctive seasons; the dry season which comes in winter and the rainy season which comes in the summer. These two distinctive seasons in Ghana comes as a result of the African monsoon climate. Precipitation occurs between April and October in the north and between March to November in the south. Water levels in the White Volta River from the northern catchment increases during this time of the year. In northern part, there is abrupt and sharp rise in wind speed lasting for few minutes during the month of March and April. During this period, occasional rains then follow, that lasts until the month of August and September, during which precipitation reaches its peak, flooding most rivers in the process. The northern part is the driest area among the three major regions where rainfall ranges from 780 millimeters to 2160 millimeters with an average of 1, 000 millimeters a year. There is drastic decline in water in this region in most rivers during the months between December and March.

In the eastern cost of Ghana, the rainy season starts in April through June. It then breaks in July and August. It slightly picks up again in September to October. In the south, a rainy season with two modes occurs from April to June and then from September to November. A rainfall pattern with two modes means that there are two average rainfall data values that happens with the uppermost rate of recurrence. The season has two data values that draw for having the uppermost rate of recurrence. With the possibility of irrigation farming using water from the White Volta River, agriculture might be sustained during wintertime and in autumn and rainfall during spring and summer. The southern part of Ghana is the rainiest region among the three regions and precipitation in this region exceeds 1, 500 millimeters on annual basis. June is the rainiest month in the southern part of Ghana and has an average monthly rainfall of 225 millimeters.

According to the rainfall and river flow data from the last three (3) decades, more water is discharged into the White Volta River in the southern part of Ghana, where there is also more occurrence of river flooding that destroys life and property including crops grown along the banks of the river. Along the west coast, rains are much more abundant from May to mid-July reaching up to 500 millimeters per month. Rain water flows as surface runoff from the river basin and recharges the White Volta and it is the main determinant of flow variability within the river. Flow regimes upsurges during raining period and decreases during the dry period when rains have stopped. Seasonal streams all dries up during the dry months. Floods occur the in the season of rains on each occasion where flows exceed the river banks following a severe rainfall event or failure of dams. Irrigation using water from the river is done the most during the dry season during which the river has its lowest flows. High temperatures, water obstruction for industrial and domestic supply and ground water seepage are the other key reasons for the decline in flows within the White Volta River in the dry season.

2.5.2. Climatic

Climate change is another factor that contributes to variability in flow regimes in the rivers at global level (Dutta *et al.*, 2017). Climate change causes reductions in flow regime in the downstream of the river which results in shortage of water for dry season habitat. The management of hydrological resources including water under changing climatic conditions brings several hydrological challenges (Pittock, 2015). It is the stated challenges within the ecosystems that calls for an assessment of river flow variability. Due to the continued disturbances in the hydrological resources due to macro and microclimate change, the stress on rivers and its resources will as well continue to increase. All this will continue to affect stream flow over time (Dutta *et al.*, 2017). River flow characteristics are critical indicators of river health as they represent the amount of water, the flow duration and yearly characteristics of flows.

Climate has encouraged more variations in river discharge as measured at the stream gauging sites along rivers. Air temperature, rainfall and glaciers are some of the direct climatic parameters that affect water flow in rivers. Though the case, agriculture and other economic practices done by humans on land and water resources have altered flow of water in rivers on a greater scale than the changes brought about by climatic parameters in Ghana and in the world in general (Baffour *et al.*, 2021). Climate change affects streamflow and its characteristics through influencing the amount of water and subsequent surface runoff**.** Lower temperatures are favorable for higher precipitations which increases the volume of water in the basin whereas higher temperatures decrease the volume of water through evapotranspiration. Ghana experiences relatively mild tropical climate with two (2) distinct seasons which are the rainy (wet) season, which starts from May to October and the dry season, which generally starts from November to April (Baffour *et al.*, 2021).

The wet season climate is the favourable season for recharge of water in the river that is used for irrigation during the dry season as well as domestic and industrial supply. Water flow drastically reduces in the river during the dry season due to cessation of rains and high temperatures. Smallholder irrigation farming in Ghana is done the most during the dry season where the levels of water in the White Volta River have gone down. Irrigation farming is done to supplement the yield harvested during the rainy season. Ghana has a tropical climate that is moderately slight for its latitude. Dry winds from the desert referred to as the harmattans, blows from the north to the east from December to March, which causes a drop in humidity which causes hot days in Ghana. Mean daily temperatures varies from thirty Degrees Celsius (30°C) during the daytime to twenty-four Degrees Celsius (24°C) during the night with an absolute humidity ranging from 77 percent (77%) to 85 percent (85%).

2.5.3. Human settlement

There are natural and human factors that affect river flow in many parts of the world but human activities in the river basins contribute to flow variability the most. Such activities include water abstraction, irrigation farming, animal grazing, river sand harvesting and bush clearing all of which change the dynamics and natural flow regime of water in rivers (Dutta *et al*., 2017). Besides changing the control, the continued period and duration and yearly regimes of important hydrological flow characteristics, these human activities also lead to both increase as well as decrease in quantity of water flowing in the river. Hydrological resources are affected by factors such as population growth, varying land use patterns and susceptibility of the hydrological system to variations triggered by the interaction of oceans and the atmosphere (Harley *et al*., 2017). Land use changes, use of water resources and water policies all have various impacts on the hydrological cycle.

Increase in human population causes the increase in demand for water for consumption and industrial use (Wang *et al.*, 2019). People settle within the catchment because it's a fertile ground for agriculture and for them to settle, they need space for building structures, farm land and roads. All these leads to cutting down of trees and other vegetation for various construction purposes. This problem will be worse with the increasing population growth in Ghana, which is now at 2.1% (GSS, 2021) which means that pressure on land within the basin and the river itself will continue posing a threat to the water in the river. Due to shortage of farmland, people practice streambank cultivation during the dry season where they grow crops in the banks which lie very close to where water is flowing (Kasei *et al*., 2013).

Most farmers depend on rainfall for their agricultural production and hence susceptible to the inconsistent and unreliable rainfall situations. This decreases the capacity to meet goals of food security and production. Despite the fact that water availability per capita in the basin is alleged as normal, increase in human population and climate variation will make water resource shortages to be a greater problem as water supplies become inadequate to meet people's requirements. Future forecasting of water crises and satisfying people's future water requirements in the basin is attached to the sympathetic understanding and growth of water resources. This helps in preventing depletion of hydrological resources (Ohemeng *et al*., 2017).

2.5.4. Anthropological Alteration of Streamflow

Anthropological alterations to streamflow change the behavioural pattern of natural hydrologic variations and streamflow dynamic forces (Zeiringer *et al*., 2018). There are several sources of alteration of streamflow such as dam construction, water diversions, urbanization, drainage and restoration of wetlands, groundwater pumping and surface water withdrawals, river flow regulation for hydropower, construction of storm water detention ponds and irrigation farming.

These human alterations alter rates of soil erosion, infiltration and overland flow which causes sedimentation of reservoirs and increases evapotranspiration which all have negative impacts on flow of water in rivers and other channels. Overland flow also causes floods in urban centers and people's homes that damages human life and property (Li *et al*., 2022). Damming of rivers for purposes such as hydropower generation, irrigation farming and domestic water supply is common in most rivers including the White Volta River.

A dam structure which is often constructed across a river is a clear and direct modifier of river discharge. A dam captures both low and high flow levels of water in a river and besides controlling floods, generation of hydropower, irrigation farming and supply of water to homes and industries, damming of rivers also helps in maintenance of the reservoir for levels of recreational and navigation. Damming of rivers as well causes disjoining in rivers which leads to loss of natural connectivity. All this affects availability of water for irrigation and aquatic farming (Zeiringer *et al*., 2018). Damming of rivers also lead to decrease in the quantity of water in rivers which leads to deposition sand particles and other deposits that lead to narrowing of river channels. Draining of land for agriculture and human settlement increase the probability of high flows which causes river flooding that destroy human lives and property.

Land compaction for human settlement also leads to reduced infiltration of catchment water into soil, an activity that reduces base flows in rivers. Creation of embankments and river canalization decrease overbank water flows, resulting to floodplain deposition. Channel restriction and limiting channel passage leads to creation of subordinate conduits along the river course. Humans also pump water from river catchment for various purposes ranging from irrigation farming to domestic and industrial water supply. Pumping water from the ground for various purposes lowers the water table which further decreases growth of plants.

The continued loss of plants due to reduced water table results into soil erosion and downcutting of river channels (Zeiringer *et al*., 2018). There has been a reduction in savannah vegetation due to the effects brought by changes on land, mainly caused by countless activities done by people, with crop and animal production being the dominant activity in the basin (Awotwi *et al*., 2015).

2.5.5. Agriculture

Agriculture is the practice of growing arable crops and raising farm animals for food and other economic uses. It is the main economic and employment activity in Ghana and rainfall has been the main source of water for the same. Agriculture in Ghana include crop production, livestock husbandry, fishing, forestry and plantations. People in the White Volta River basin grow both food and cash crops such as maize and rice, beans and peas, vegetables and oil trees, yams and casavas as well as forests and plantations. Furthermore, there is a lot of grass, shrubs and other foliage undergrowth that provides feed for various farm animals (Futukpor, 2022). The agricultural practices that dominate include single cropping, mixt cropping and mixed farming.

The recent unpredictable rainfall and climate variability have badly affected agricultural production and agriculture in the rainy season is not effective enough to support the growing population. Cultivation of arable crops such as maize and rice, and rearing of farm animals such as cattle and sheep are the most practiced agricultural activities in Ghana. Agriculture is the biggest employment sector, accounting for about 65 percent (%) and agricultural produce alone accounts for over forty (40) percent (%) of the country’s Gross Domestic Product (GDP). Agriculture also accounts for about forty (40) percent (%) of foreign currencies. White Volta River has the ability to have water in it throughout the year, a characteristic that provides a better pasture for animal grazing. If livestock are kept feeding in the catchment without control, they cause land along river banks to degrade, affecting the health status of any river in the process.

Continued land degradation due to animal grazing will as well lead to loss of vegetation within the catchment as a whole, all of which negatively affects the stability of, not only the river, but, other hydrological resources in the environment. Streambank cultivation and animal grazing are some of the factors that affect river health. Streamflow in areas with high degradation mostly results in overland flows that causes floods in most communities. These as well leads to the catchment losing more water during the rainy season, leading to dry season water shortages.

2.5.6. Vegetation

The existence of vegetation alters flow of water in river systems as well as modifying transport of sediments in silty canals. This all affects the life and the geomorphological growth of river systems in the globe. Vegetation increases the local coarseness in river channels, alter flow patterns and supply extra drag which all decreases the shear stress of river beds. Decreased stress in rivers enhances local sediment deposition. Vegetation also protects the soil from erosion due to rain water, preventing siltation of water bodies in the process (Li *et al*., 2022). Grassland such as star grass, provides a good ground cover, that protects soil from all forms of erosion.

The vegetation in the region where the White Volta River takes its path to Ghana is a Guinea Savanna grassland and it can be classified as the Coastal Swamplands, the Savannah Grassland and Woodland, the Mangrove Swamplands and the Deciduous Woodlands. The predominant vegetation is grassland of Savanna which have clusters of vegetation such as baobabs and acacias which are all resistant to drought. According to the report by Food and Agricultural Organization (FAO, 2010), a forest is an area whose coverage is greater than 0.5 hectares, and has ten (10) percent (%) or more tree top cover. Trees can be well-defined as having a solitary stem, truck or shoot and the possibility to reach a smallest height of 2 to 5 meters at maturity and it is probable to climb a tree at its maturity stage as compared to shrub vegetation (Biurrun *et al*., 2019).

2.5.7. Deforestation

Deforestation is the transformation of forested area to a non-forested area. This implies that if an area was formerly occupied by forest and now is cleared for other purposes, then deforestation would have occurred. Deforestation takes away the cover from the land which leaves it bare, exposing the soil to wind and rain erosion. This makes soil to be easily eroded away by all agents of soil erosion**.** Aside from their influence to flow of water in rivers, trees and other forms of vegetation support the terrain of the land and sustain the life of the forest (Borse, 2016).

Deforestation also affects the quality of water in neighbouring streams and other water sources. When nutrients from the earth are detached and dissolved, rainwater removes the soluble nutrients from the soil and transports them away. Water pools in bare areas generally have higher levels of nitrates. The population that is settled in forests and depend on forest resources for their survival faces direct impacts of deforestation. As their resources get disturbed, these people are forced to move away to elsewhere and find other means to sustain their lives.

The earth has lost an approximated 80 million hectares of vegetation since the year 1900 due to land clearing for human settlement, farming and industries (FAO, 2010). Deforestation is a worldwide hazard which has caught much public consideration. The international community, governments at national level and organizations are raising awareness about the hazardous sequences of loss of forests to the environment and humanity. The report by Food and Agricultural Organization exposed a disturbing rate of tree loss with a global loss of 13 million hectares each year between 2000 and 2010. This area alone is more than half the total area of Ghana. The report further indicates that Africa has the second highest rate of deforestation globally, with annual forest loss of 3.4 million hectares. This scenario is the same in Ghana where the vegetation has been under great pressure from activities done by man for his survival.

Despite the fact that fuelwood and charcoal burning are important source of income to humans, these practices have greatly contributed to the loss of hydrological resources in the savannah vegetation. They have led to the reduction in vegetative cover, putting the life of the White Volta River under threat in the process. Loss of vegetation also increases soil erosion that leads to the transportation various minerals and nutrients from the landmass into rivers and lakes. This has resulted into to eutrophication of streams, big rivers, lakes and other water pools. This has as well been accelerated in recent years due to agricultural growth in the basin (Nsor *et al*., 2019).

Ghana has a total surface area of approximately to 24 million hectares, of which forest areas covered about 8.2 million and savannah woodland covered about 15.7 million at the beginning of the last century. The forested areas with tall trees have considerably reduced, leaving only areas which are under government protection either as game reserves or government land. Records further demonstrate that at the beginning last century, Ghana had approximately nine (9) million hectares of primary forest which was undisturbed by humans (Awotwi *et al*., 2015).

The current trends as reported on www.mongabay.com, between 1990 and 2000, the average rate of deforestation per year was 1.82%, and between the year 2000 and 2005, this rate significantly increased. In Ghana, the 2010 Food and Agricultural Organization report (FAO, 2010) report has projected an annual loss of 135, 395 hectares of vegetation. This continuous deforestation will continue negatively affecting Ghana as a country. The main causes of deforestation are clearance of forest for production of cocoa and other food crop, uncontrolled cutting down of trees for fibre, shifting cultivation, uncontrolled burning of forests, fuelwood and charcoal burning, human settlements, overgrazing and clearing of forest areas for construction of industries, roads, mining, building of stadia and schools. Continued deforestation leads to overall loss in natures renewable resources which will affect future provision for the same (Souza *et al*., 2012).

2.5.8. Changes in Land Use and Land Cover in the Basin,

According to Bosompem *et al.*, (2017), all classes of land use and land cover happen in the White Volta River basin which includes agriculture, animal grazing, forestry, human settlements and wildlife preservations and all these categories of land use still occur in present times. Savannah shrublike vegetation with many mahogany-like plants is generally the main land cover type in the basin. Most of the population in the basin live on agriculture through rainfall, with a few continuing with dry season irrigation, mostly for rice and vegetables.

Remote sensing and GIS methods are used map and classify land, and these techniques are very useful as they help in providing comprehensive method of improving the selection of areas for purposes ranging from agriculture, industries and human settlement. The methods as well provide data about where, when and how the land use changes have happened including the forces that drive the changes (Bosompem *et al.*, 2017). Remote sensing is essential in analyzing changes in land use and land cover on both local and worldwide scales. Furthermore, remote sensing is significant because, it institutes the vital environmental and ecological statistics that are required for technical and scientific management of land and water resources and policy purposes.

There has been a significant loss of vegetative cover over the White Volta River basin over the past decades due to various economic activities (FAO, 2010). For example, Ghana has a total surface area of 23, 946, 000 hectares including water bodies and, in the beginning, about 23 million hectares of land was filled with vegetation (FAO, 2010). Within the 23 million hectares of land, high forests covered about 8 million hectares and savanna woodland covered about 16 million hectares. Current vegetative cover over the same land is 19.8 million hectares, representing a loss in vegetation of about 135, 395 hectares per year. This represents a mean deforestation rate of 1.82% per year during the same period.

Forests are cleared for various purposes such as human settlement, farming and creation of towns and cities. The continued loss of vegetation increases the volume of rainwater that runs over the surface during rainfall events. The increased surface runoff is what increases the discharge in the river whenever precipitation occurs and the continued loss of water through the same results in water shortages when the rains have stopped. Land cover change from the year 1990 indicates that thirty-seven (37) percent (%) of the entire land cover has been transformed from woodland to small shrub vegetation, 6 percent (%) from closed woodland to open woodland and 3 percent (%) has transformed from closed woodland to small herbaceous vegetation (FAO, 2010).

Increase in human population has contributed the most in the increase of agricultural land and the decrease in forests. An area with tree cover density of 50 percent and above is classified as a closed woodland where as an area of tree cover density of less than 50 percent is classified as open woodland. Changes in land use are very critical in determining the hydrological life of Volta basin Abungba *et al.*, (2022) and land use in the basin have continuously been changing, through anthropological activities, creating the variations in the hydrological cycle (Awotwi *et al.*, 2015).

2.5.9. Data and the Techniques Used in Land Use Analysis

Data on current land use and land cover are derived from analysis of satellite and aerial images. The imagery data from remote sensing, machine learning, and cutting-edge computer science technologies has sped up the incorporation of land use analysis into hydrological research too. Aerial photography shows changes in land usage, and the method is improved to carry out study on a larger scale. At increasingly finer resolutions, remote sensing offers synoptical views of rivers and their catchments. In order to generate landsite images that are utilized for land classification, the US Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) created the Landsat program for environmental monitoring in 1972.

Jannsendzimir, (2018) reported that this extensive data bank from USGS and NASA offers valuable resources for the classification of land uses and enables the monitoring of changes in land uses over time. A growing range of sensing technologies, such as optical sensors and light detectors, are being utilized to map the features of both the landscape and the water. As options to better synchronize time frames between data sources develop, the number and quality of such data are significantly rising in availability and accessibility. Geographic information systems (GIS) essentially made it possible to analyze patterns in the landscape. Calculating landscape composition metrics, or expressing the total number of different land use categories as a proportion of the region under examination, is the most used method.

The land use classification process is carried out over the entire study period, to detect the trends in land cover. Major focus is made on growth of land for agriculture, land for human settlement and expansion of industries and urban centers. These are the major land use classes that have detrimental effect to hydrological changes in the White Volta basin (Bosompem *et al.*, 2017). These changes in land use over the study period are compared to how stream flow and other hydrological systems have as well been progressing over the same period.

2.5.10. Natural Mechanisms that Alter Flow Regimes

Natural mechanisms that alter flow patterns in rivers includes surface runoff as a result of precipitation, water loss through evaporation from soil surface and groundwater bodies, transpiration by vegetation, groundwater release from aquifers and other underground water reserves, recharge of groundwater with water from streams, big rivers, and lakes as well as sedimentation of marshlands, lakes and wetlands. Humans can do little to stop natural mechanism that affect river flow from taking place but disasters from the same can be prevented by taking proper measures and warnings (Zeiringer *et al.*, 2018).

2.5.11. Environmental Feedbacks to Disturbed Streamflow Patterns

Zeiringer *et al*., (2018) wrote that most studies have revealed negative environmental changes in response to a diversity of flow disturbances due to various factors. Besides the decrease in flow magnitude in rivers, more prominently during the dry season, the negative changes to the ecological environment brings riverine floods that damages life and property in communities. Decrease in flow magnitude during the dry season affects irrigation farming and livestock grazing which all decreases country's output. All this has been summarized in Table 1.

Table 1:Environmental Feedbacks to Disturbed Streamflow Patterns

COMPONENT	**ECOLOGICAL RESPONSE**
Flow Magnitude	Loss of high and low flows leads to encroachment of vegetation into channels and increased riparian cover. Decreased flow magnitudes in rivers affects dry season irrigation and livestock rearing.
Flow Frequency	Decreased frequency of peak flows leads to shift in community composition and increase in wood production. Decreased flow frequency affects farmers that practice flood-based farming in the lower stream of rivers.
Flow Duration	Decreased duration of floodplain inundation decreases the area of plant that grow in river beds as well as general decrease in forest cover.
Flow Timing	Shifts in seasonality of peak flows leads to loss of accessibility to swamps and marshlands, reduced riparian vegetation
Rate of Change	Speedy changes in river leads to faster flood recession. It as well leads to poor seed establishment which leads to crop failure

Source; (Zeiringer *et al*., 2018)

2.5.12. Environmental Water Flow in Rivers

Environmental flow refers to the quantity of water that is needed over a particular duration to sustain river healthiness in a particular state (Zeiringer *et al.*, 2018). The flow variability in environmental flows is minimal when catchment activities are not posing any threat to the river. Environmental flows are an important characteristic in restoration of the natural river flow regime. River restoration is important in maintaining the environmental processes of surface andsubsurface water systems, floodplains, rivers and lakes (Zeiringer *et al*., 2018).

2.6.The Status and Growth of Irrigation Agriculture in the White Volta Basin

Irrigation is the precise artificial application of water to crops to ensure stable supply of water in areas with erratic precipitation (Hanafi, 2004) and rivers are the most common sources of water for irrigation in the world. Irrigation is important in that it helps to raise crops where they could have failed without it, grow crops of high economic value as well as increasing crop yield. Irrigation agriculture provide extra means of crop production in both subsistence and commercial agriculture (Adongo *et al*., 2016). The method of artificially adding water to the soil so as to assist crop growth is very crucial and significant contribution to agronomic production procedures as well as social and economic growth of nations in the world (Jain *et al.,* 2019). In the development and understanding of irrigation systems, it is essential to have strong ideas of the purposes for which these irrigation scheme developments were established including the goals that they want to attain. Irrigation is developed for reasons which are grouped into commercial production, social and political, environmental and agro - strategic reasons. Table 2 highlights irrigation objectives in some commonwealth countries. Kuscu & Demir, (2009) stated that irrigation is very important in the world in terms of crop production, food security, generation of human employment as well as providing the necessary income for the people in rural areas.

Table 2: Goals of Irrigation Farming in Some Selected Countries

Country	**Major Irrigation Goals**
Bangladesh	- Increasing production of food crops, reducing importation of food - Redistribution of income, employment and controlling floods,
Ghana	- Food Security, Income Generation
India	- Employment and Increase production of food crops, - Generation of foreign currency and equality in income distribution
Indonesia	- Increasing agricultural production, Promoting local farmers
Kenya	- Increasing agricultural production, reducing importation of goods, - Reducing failure of crops - Generating domestic employment and foreign currency,
Malawi	- Food Security, Reducing importation of agricultural products, Employment among the youths.
Malaysia	- Increase in production of rice, Income generation on local farmers,
Nigeria	- Food security, generation of foreign currency and employment - Local income redistribution
Sri Lanka	- Increasing the intensity and yield of crops, Food security

Source; Commonwealth Secretariate.

Irrigation records in Ghana shows that irrigation farming begun about a century ago and serious plans about irrigation development started about the year 1960. Even though irrigation farming in west Africa and in Ghana in particular is a response to a global irrigation savings outline, with a highest recorded in 1970, the growth scale is still very low (Namara *et al*., 2011).

Out of the approximated 3 million ha of land which has the potential for irrigation, only about two (2) percent (%) have been utilized. From the year 1960 to 1980, the developed land for irrigation in Ghana is about 19,000 ha, which was expanded to about to 33, 800 ha by the year 2007 (Namara *et al.*, 2011). Ghana has the irrigation water consumptive demand which is projected to expand between the year 2000 and 2025 from about 600 to about 4, 000 Mm^3/yr. The overall irrigation consumption is as to expand from 1,169 to 6,730 Mm^3/yr (Mul *et al.*, 2015)

Irrigation projects in Ghana are carried out by Ghana Irrigation Development Authority (GIDA) which is a government organization that came in 1977 under the authority of Ministry of Food and Agriculture. It was formed to map out the potential areas for irrigation agriculture, designing and constructing irrigation structures, management and supervision of irrigation projects and advocating new farming technologies amongst the local farmers (Takahiro, 2006).

Agricultural sector in Ghana is vulnerable because most people grow their crops for food and income during the rainy season which is unreliable (Dittoh, 2020). Long dry spells and unreliable weather all have great risks to farmers. With these stated risks and uncertainties and with the abundant water in White Volta River which flows all year round, irrigation development could therefore be maximized during the dry months of the year to supplement the yield harvested during the wet season months to increase country's agricultural outputs. Irrigation development therefore is critical and the solution to increased production and greater food security including development in local communities by ensuring yearlong agricultural production. For example, maize, a crop which is regarded as the most efficient grain and cereal crop in terms of water utilization (Plessis, 2003), can produce from 80 to 100 tonnes/ha of green material and 16 – 21 tonnes/ha as a dry material if grown under precisely designed irrigation system. This practice will surely ensure food security in Ghana as a country.

Irrigation buffer farmers against the effects of variability of weather and climate since irrigation systems are design to withstand the negative effects of weather. Irrigation systems also offsets the pressure from the increasing human populations. There are quite a lot of irrigation schemes in Ghana, both large- and small-scale, which directly uses water from surface flows of the White Volta River. Big irrigation schemes include the Tono scheme in Navrongo with a potential area for irrigation of about 2,500 hectares and the Vea scheme in Bongo district of the Upper East Region, which has an irrigable area of about 1000 hectares. Tono irrigation scheme in Kasena district and Vea irrigation scheme respectively requires 40 million cubic meters (Mm^3) and 8 million cubic meters (Mm^3) per year (Adongo *et al.*, 2016).

Another big scheme is the Bontanga irrigation scheme which is found in the Northern Region of Ghana, whose potential land for irrigation is 500 hectares with about 11 million cubic meters of water required on yearly basis (Mm^3). In Savelugu District, there is Integrated Tamale Fruit factory whose potential area for irrigation is 1,000 hectares with of 4 million cubic meters (Mm^3) of water required per year. All of the mentioned irrigation schemes gets water from the surface flows and tributaries of the White Volta River (Ofosu, 2011).

There are also industries that depend on agricultural produce within the basin. In Pwalugu, there is a Tomato Processing Factory that process tomatoes from Tono and Vea schemes, in Bolgatanga, there is a Meat Processing Factory and in Tamale, there is Ghana Cotton Company. There are also several facilities that process Shear Butter of which all benefit from the hydrological resources of the basin. Despite having the bigger potential for irrigation development and with much emphasis placed on it, only about two (2) percent (%) of agricultural land is used for irrigation agriculture in Ghana. Moreover, there has been no clear understanding on where Ghana is as far as use of different methods and irrigation infrastructure is concerned.

The estimated total land which can be used for irrigation in in Ghana which is one-third lies within 22 well-known public schemes. The location, expansion and organization plan for the schemes that covers the other two-thirds of potential land for irrigation is not known. The lack of reliable data on flow with the Volta River and its basin weakens the development needs and plans about how to expand on the schemes that are already present in the sector. From the Ghana report by Food and Agricultural Organization (FAO, 2010), it has been reported that only about 33, 000 hectares of land are used for irrigation agriculture out of 1.9 million hectares of potential land. This indicates that a lot of land is left unused for agricultural production.

Expanding irrigation farming is critical in realizing food security, reducing poverty and crating employment in rural areas but according to Ghana Irrigation Development Authority (GIDA), the land which has the potential for irrigation is still small despite the recent plans put on the same. Furthermore, the performance as well as the productivity of irrigation schemes that are in place, are generally low. All these are problems that needs a solution, if irrigation is to be maximized in Ghana. With the need for more irrigation farming in Ghana to supplement country's agricultural output, study about water and hydrological resources, is relevant.

There is slow growth rate in irrigation schemes in Ghana as compared to other countries attributed to unresolved challenges such as high initial costs of irrigation structures, poor access to farmer loans, poor agricultural marketplaces, ineffective private and public agricultural institutions, poor crop productivity and unsuitable agricultural technologies which are as well poorly managed with no maintenance (Ofosu, 2011). Securing access both to agricultural land and water resources, suitable agricultural technology, market availability, dependable farmer support, and effective private and government institutions with favourable strategies are some factors that can boost the development of irrigation farming in Ghana and in West Africa as a whole (Ofosu, 2011).

2.7.Planning for Irrigation Season

There are five major irrigation schemes that directly benefit from surface flows that recharges the White Volta River. Flows in the River were observed during the irrigation season and as indicated earlier, the White Volta River has its discharge drastically reduced during the period where water for irrigation is needed the most. In March, where most dry season crops reach maturity, most tributaries that are discharging water into the White Volta River dries up. The dry months of March and April recorded the lowest average flows of 21.89m^3/s and 24.97m^3/s respectively. This is where proper planning for the dry season irrigation farming is justified.

Annually, Tono irrigation facility as shown in Figure 1 and 2, requires 40 million cubic meters (Mm^3), Vea irrigation facility requires 8 million cubic meters (Mm^3), Bontanga irrigation facility requires 11 million cubic meters (Mm^3) and Integrated Tamale Fruit Factory requires 4 million cubic meters (Mm^3) which translates to 63 million cubic meters (Mm^3). All major irrigation reservoirs in the basin have a total storage volume of about 3,000 Mm^3. This amount of water could be used to irrigate approximately 30,000 ha of land. The small irrigation reservoirs have a total storage capacity of about 230 Mm^3. These irrigation reservoirs include the Tono irrigation dam across river Tono which has a maximum height of 179.22 meters and impounds 93 million cubic meters of water. 83 million cubic meters of water is used for irrigation in the Tono scheme where as 10 million cubic meters of water is used for domestic water supply. The surface area of the dam is 660 square meters (m^2). The dead storage, i.e., 10% of the dam reservoir water at full capacity, is not artificially used, so as to continue to support aquatic life and other biodiversity in the river downstream. The emergency spillway that discharges excess water during rainy season is 3 meters high and 165 meters long.

Figure 1: Tono Irrigation Dam

Figure 2: Rice Fields at Tono Irrigation Scheme

Table 3: Irrigation facilities and in their storage capacity.

	Command Area (Ha)			
Name	**Potential**	**Developed**	**Irrigated**	**Storage Capacity - Mm^3**
Golinga	100	40	40	1.23
Ligba	40	16	16	0.76
Bontanga	800	570	570	25.00
Tono	3, 860	2, 490	2, 033	92.60
Vea	1, 197	852	468	17.00

The IWAD irrigation scheme in Yagaba is 800 ha with maize, sugarcane and vegetables as dominant crops. The water source for the scheme is Kulpawn river, a tributary of the White Volta River, where there are three 75 Kilowatts pumps installed at their headworks to pump water from the river to the scheme. The pumps deliver 410 litters of water to the main conveyance per second. The storage reservoir keeps 18000 cubic meters (m3) of water for irrigation. In all these irrigation schemes, the dominant crop is rice, maize and vegetables which all have high seasonal water requirements. Rice is irrigated through flooding method which uses more water than any other method of crop irrigation. All of the mentioned irrigation systems gets their seasonal water requirements from water bodies which are mainly the tributaries of the White Volta. Decreasing trends of water in the river and its subsequent tributaries therefore calls for a proper planning of irrigation season so as to match the flow with the seasonal water requirement. Table 4 shows major irrigation schemes and their seasonal water requirement whereas Table 5 shows the proposed irrigation schemes that will need and depend on water from the surface flows from the White Volta River basin. Figure 3 shows graphical seasonal water requirements for the major irrigation schemes in the White Volta River basin.

Table 4: Irrigation facilities and their seasonal requirements

Scheme	**Area (Ha)** **Potential**	 **Developed**	 **Cultivated**	**Water Source**	**IR$_{Seasonal}$ (M^3/ha)**
Bontanga	800	570	570	Bontanga River	33506
Vea	1197	850	468	Yarigatanga River	95673
Tono	3860	2490	2033	Tono River	28907
IWAD	800	800	800	Kulpawn River	18000
Libga	40	16	16	Perusua River	19735
Golinga	100	40	40	Kornin	36655

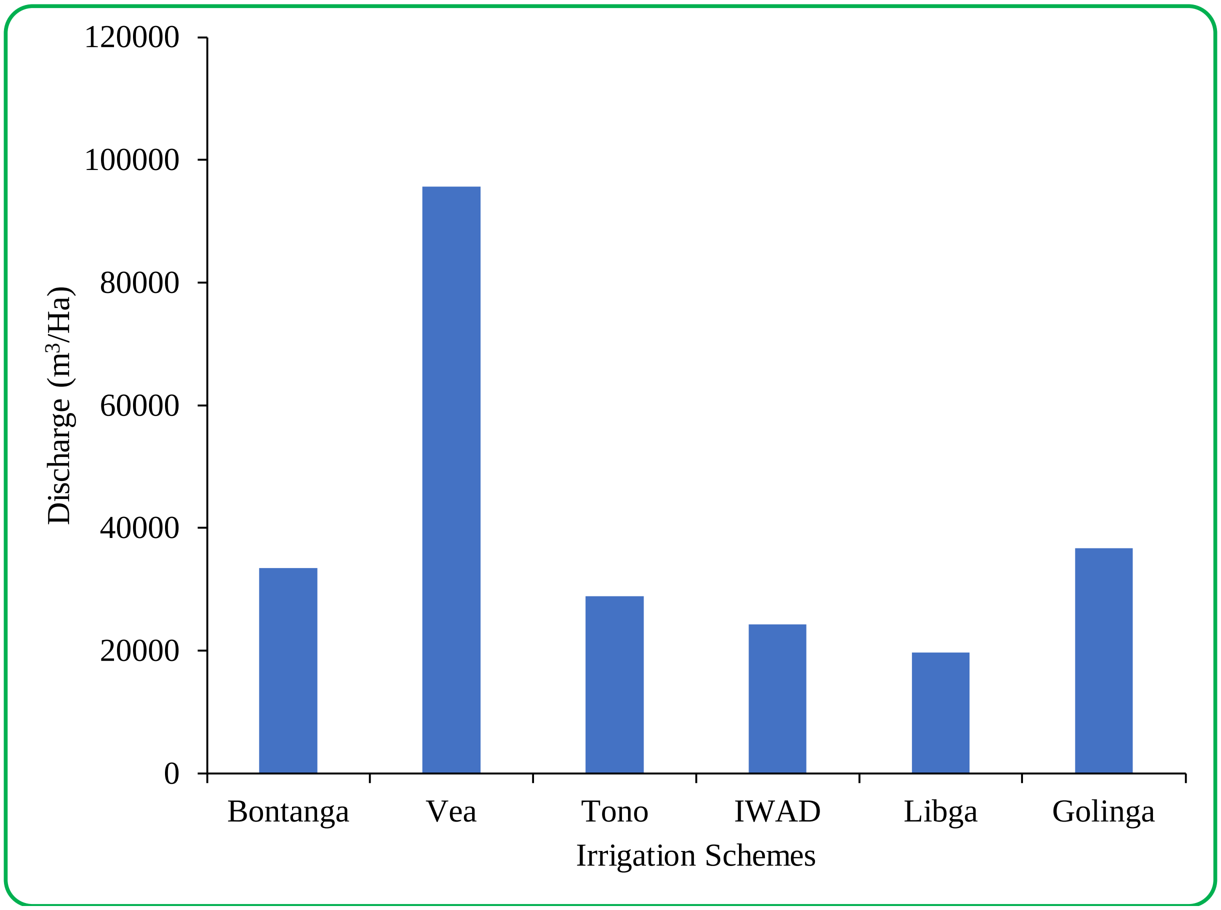


Figure 3: Average Seasonal Irrigation Requirement for selected irrigation schemes

Table 5: Irrigation schemes to be developed

Name	**Water Source**	**Potential Area (Ha)**	**IR$_{Seasonal}$ (M^3/ha)**
Buipe	White Volta River	200	11756.49
Mpaha	White Volta River	5440	319776.56
Dipala	White Volta River	100	5878.25
Tamne	White Volta River	1440	84646.74
Tiego Yarigu	White Volta River	200	11756.49
Sambolekuliga	White Volta River	200	11756.49
Lamassa	White Volta River	1280	75241.54
Accra Plains	White Volta River	11,000	646607.02

All these irrigation schemes that are proposed to be constructed in the White Volta River basin will get water from the surface flows that could have made their way into the ocean through the White Volta River. Irrigation systems have various effects on flow of water rivers including the White Volta River. Among other effects, irrigation systems result to the decrease in downriver water flow and increased loss of water through evaporation within the area under irrigated agriculture. Irrigation also results into the increase in water table within the irrigated fields since groundwater recharge in the same area is as well increased. Furthermore, irrigated agriculture leads to unexpected rises and falls in water levels in rivers. Sudden rise in water in rivers leads to river flooding that destroy human lives and their property whereas unexpected fall in water levels leads to water shortages for irrigation and domestic supply. Continued abstraction of water in rivers for irrigation purposes also have consequences on the stability of river banks, causing collapsing, loss of riparian vegetation, soil erosion and sedimentation of water reservoirs. This all justifies proper planning of irrigating farming along major rivers in the world.

2.8.The Status of Floods in the White Volta River,

Floods are the overflowing of the large amount of water over dry lands that are not usually waterlogged. They occur in various forms and in various systems such as rivers, urban areas, pluvial and sewer areas, coastal and glacial areas and lake outpourings (Ologhadien, 2021). Rainfall of high extremes are the common source of water that results into floods in large river basins. Flooding events in small catchments are mostly caused by rainfall of high intensity with short durations. According to Ologhadien, (2021), floods only are accountable for 20% to 30% of economic losses due to natural hazards in the world and they are also accountable for additional 50% of all mortalities due to natural tragedies. Ologhadien, (2021)similarly stated that the percentage of people in the world living in areas with flood problems has increased by 114%.

Floods generally makes worse the housing problems which increases the pressure on government and private sector to address the increasing housing demands (Ologhadien, 2021). Areas along large rivers including estuaries are continuously affected naturally by natural and human caused factors which add together to increase the pressure on the rivers and the seaside environments of which all contribute to the variability of flow in most rivers in the world.

According to Appeaning *et al*., (2020), coming up with approaches for disaster risk reduction for defenceless societies will need a critical understanding of the dimensions of susceptibility and the influences that increase the flood risks in the communities in the affected parts of the word. The approaches for disaster risk reduction reflects the organized development and administration of plans and practices to reduce vulnerabilities, risks and the recounting disaster effects in communities in the world. Appeaning *et al.*, (2020) further stated that studying the geometry of the estuarial oceanfront is vital to understanding the growth tendency in the estuarial oceanfront spots over time and how it effects the environment as far as flooding is concerned.

Urban area reduction through construction of infrastructure such as roads and railways increase surface runoff which increases water flow levels in rivers. Increased flows are what causes floods that destroy people and property. The practice of streambank cultivation as well accelerates river flooding in the sense that more quantities of soil are eroded and deposited in water bodies. Water bodies are silted, causing water to flow beyond boundary regions, causing river flooding in the process. Conversion of farmland and bare grounds to woodland and other vegetation upstream in the catchment therefore could decrease the instances of river flooding (Wang *et al*., 2019).

Flood routing is one among the various ways of predicting floods. In this process, hydrograph approximation is done about the increase and decrease of water in a river at any particular point during the progression of a flood occurrence. In this process, the routine of a flood water both in the up and down section of the river and of the entire flood course is followed. Flood routing is beneficial for it gives the estimates at a downriver site in actual time using the available water levels from the upstream positions. The upstream water levels should directly be from observations followed from the model about rainfall and runoff (Mosavi *et al*., 2018). The flood routing for the water waves downriver affect both the degree and timing of the peak flow.

Forecasts about the arrival of water of a particular level downstream are very important as far providing flood warnings to the general public is concerned. This provides room for arranging for brief flood defenses. A flood hydrograph is produced in two stages, and firstly, the time of the peak degree of discharge occurs later at downriver points. This stage is called as translation. Secondly, the degree of the peak discharge is reduced at downriver points, the outline of the hydrograph becomes flat. During this time, the quantity of flood water takes long time to channel into a lower point. This process is called attenuation and it helps to see the strength, value and effects of the storm water and the flood in general (Wang *et al*., 2019).

Another important parameter worth noting when it comes to shaping the degree and outline of the downriver hydrograph for flood forecast is the quantity of lateral water that flows into the river channel between two positions. The estimation of streamflow hydrographs from an upriver flood pattern which is already known is crucial for hydrologists who are deployed to perform flood prediction as well as projecting streamflow in the downriver. Hydrologists should as well have the ability to route flood hydrographs in evaluating the dimensions of reservoir spillways, in scheming flood protection structures or in gaging the extents, height and scopes of bridges, irrigation canals, curvets and other river structures (Hossain, 2015).

In any circumstances where planning for river channel modification is done, it is very critical to be aware of the likelihood effects on the outline of the flood hydrograph. Furthermore, the entire hydrograph of water moving on a section on the highest stage should be known. In order to make a functioning flood routing method for a major river like the White Volta, detailed streamflow records and their behaviour characteristics are required. In addition, the past understanding of the major flood occurrences within the river course with streamflow measurements completed at calculated positions on the river network and the statistics on the degree of floods which is available from reviews after historical occurrences is useful in flood predictions (Hossain, 2015)

Mousavi *et al.*, (2019) reported that floods are one of the major disasters that is resulting into enormous damages to infrastructure that negatively affects human and economic development. The study by (Komi *et al.*, 2016) reported that fatalities due to flooding have tremendously increased over the last 50 years, which calls for urgent and efficient flood management which includes estimation of flood magnitudes and their probability of occurrence. Xu *et al.*, (2022) reported that frequency, intensity and impacts of floods have shown substantial rising trends meaning that control and mitigating flood disasters is still a challenging task in the world.

Hu *et al.*, (2020) reported that land use connected to human caused activities on land is the chief cause of flooding and its associated risks. The study by Xu *et al.*, (2022) reported that urbanization and increase in frequency of extreme rainfall events are as well some factors that have increased the frequency of flooding whose damage has become one of the major hazards and stumbling block to human development in the world. Changes in land use types such as farm land, water bodies, urban land, grass and forests have hydrological significances and contributes the most to variations in the flood progressions that may result in various fatalities in the world.

Despite rainfall having a big impact on river flow Boateng *et al*., (2021), the study on the same by Baffour *et al*., (2021) found out that human practices on land and water resources have also altered stream flows more than variation in rainfall. Climate affects the river regime by influencing the volume of water in water pools. Jaafar *et al*., (2016) concluded that rainfall intensity, temperature, soil moisture and size of the watershed all influence runoff processes and their findings provided the recommendation on further research about these parameters.

Flood frequency analysis is essential in the maintenance and conservation the environment which is critical for human development and economic growth of countries (Huang *et al*., 2008). According to the study by (Grimaldi *et al*., 2013) flood prediction is complex and the risks are often correlated with subordinate incidents such as earth movements, landslides and erosion of soil. Grimaldi *et al*., (2013) further pointed out that flood prediction and flood risk management are vital for decreasing the damage and become accustomed with the effects of climate change. Flood problem in societies should therefore not be disregarded in sustainable development and flood frequency analysis including the reduction of flood risks should be done in flood prone areas so as to protect the lives and property of people including their crops and farm animals.

In the process of planning of water resources, hydrologists mostly focus on determination of the magnitude and frequency of floods (Bhagat, 2017) and (Acharya & Joshi, 2020) pointed out that design and construction of water systems also requires deep understanding of different flood occurrences and their return periods. Engineers needs to be able to route flood hydrographs in assessing size of water channels, in designing flood defense structures or in gauging the span of roads and bridges (Hossain, 2015). Flood frequency analysis clearly states the connection between the degree of flood and the frequency with which that flood is either equaled or surpassed (Hart & Stanley, 2020). It involves approximation of how frequent a quantified flow event will occur and streamflow analysis plays a vital role in obtaining a probability distribution of floods (Bhagat, 2017). A probability model is fitted to the dataset of yearly flood peaks measured over a certain long period of observation for a given river (Ganamala & Sundar Kumar, 2017).

Despite the fact that several studies have been done, there are still many problems regarding the space–time scale Hu *et al*., (2020), realistic flood events Parvaze *et al*., (2021), validation issues Grimaldi *et al*., (2013), regional parameterization Hu *et al.*, (2020), stream flow allocation issues Zhang *et al*., (2017), and connectivity issues Laganier *et al*., (2014). Understanding river flow and the impacts of land use is fundamental in addressing water issues but information about the same is limited in most countries (Faiilagi, 2015). According to the report by University of Mines and Technology in Ghana, floods affect humans in many ways. Destruction of life and property is one of the greatest effects and floods have continuously resulted in the devastation of structures making a lot of people homeless. Crops such as maize and farm animals such as cattle also die during the floods. The high velocity of the water dislodges plants which are then uprooted and carried away by the running water. Loss of crops and farm animals leads to reduced agricultural production which leads to insufficiency of food as well as increase in prices of food.

Flooding also results into erosion of soil, formation of gullies, siltation of water reservoirs and death of aquatic life such as fish which is important to the people. The high velocity of water on the surface is able to erode and transport away the fertile top layer of soil, decreasing soil fertility in the process. Soil erosion as well makes houses and roads weak, making them fall easily. Deep gullies also form in farmlands and roads, altering accessibility in the process. Flooding as well leads to waterlogging in arable lands as well as settlement lands. Waterlogging in agricultural lands leads to crop failure since most crops don't tolerate too much water.

There is high variability in seasonal rainfall in the Volta basin. Most areas are flooded during the rainy season and on the other hand, most rivers completely dry up when rains have stopped. In the White Volta River, records shows that heavy floods have occurred at least once every 10 years. In Ghana for example, notable and recent flood events include the 1989, the 1999 and the 2007 (Mul *et al*., 2015). All these flood events have been linked to rainfall of high extremes, with rainfall intensities exceeding 100 mm which easily increases the surface runoff that flood rivers.

Despite the negative effects, flooding in the White Volta River basin is also an important phenomenon to the small communities which are settled in the basin. On yearly basis, floods overflows into 51,830 ha of land creating a flood based productive land that is used by farmers for various farming practices in the flood plains. The practice is discouraged though because the practices followed worsens the problems brought about due to soil erosion in the river banks and sedimentation of downstream water bodies. This practice as well affecting the quality of water in the long run (Mul *et al.*, 2015). As shown in Figure 4, flooding has resulted into tremendous damage to buildings and other structures that have led to loss of livelihoods. Bridges, roads, buildings, dams and farms are some of the infrastructures that has been greatly affected and human lives are affected in each destruction, followed by mass displacement of people.

There has been loss of lives on each flood occurrence with several estimates made on the affected people. In 2007, floods took 61 lives in Ghana and about 300,000 people were in one way or the other affected. This flood was made worse by failure and uncontrolled water discharges from the spillway of the Bagré Dam in Burkina Faso (Mul *et al*., 2015). According to the report about floods in Ghana, DREF No. MDRGH0160, floods occurring in the Savannah region led to 500 and 200 displacements in 2020 in the Upper East and Accra, respectively.

Figure 4: Flooding in Bagre

(Source; The Final Report about Floods in Ghana, DREF No. MDRGH0160, 2020)

The White Volta River basin received heavy rains in October 2019 which forced the excess release of water from the Bagre Dam that caused floods as shown on Figure 1. These floods led to tremendous destruction to infrastructure including loss of human lives in the Upper East region of Ghana. When compared to the previous (2018) floods, the flood that happened in 2019 resulted into more destruction in terms of houses being ruined mixed with the loss of domestic items.

Few studies have been done in the White Volta River with a notable one by Komi *et al*., (2016), which aimed at identifying suitable flood frequency distributions. Other studies have made much of their emphasis on river response to climate change Awotwi *et al*., (2015), climate and land cover changes on water resources Oyebande & Odunuga, (2010) and Nsor *et al.*, (2019) did the collective effects of climate change, natural disturbances and social population on floodplain pressure, who as well recommended further the research on land use and land cover changes on frequency of flooding.

The Red Cross in Ghana and National Disaster Management Organization did joint rapid assessment in response to the same and reported that 26,083 people were affected and 19 fatalities were reported in the Upper East Region. Furthermore, 133 households were displaced and given temporally shelter in Manyoro Area Council. The report further indicates that over 116 societies from 13 districts were heavily affected. Facts and figures from the report confirms that over 2,218 houses were devastated with 3,743 others moderately affected. People who were displaced were temporarily sheltered in camps, prominently in neighboring schools. Figure 5 summarizes the displacements caused by the floods in Ghana in the year 2020.

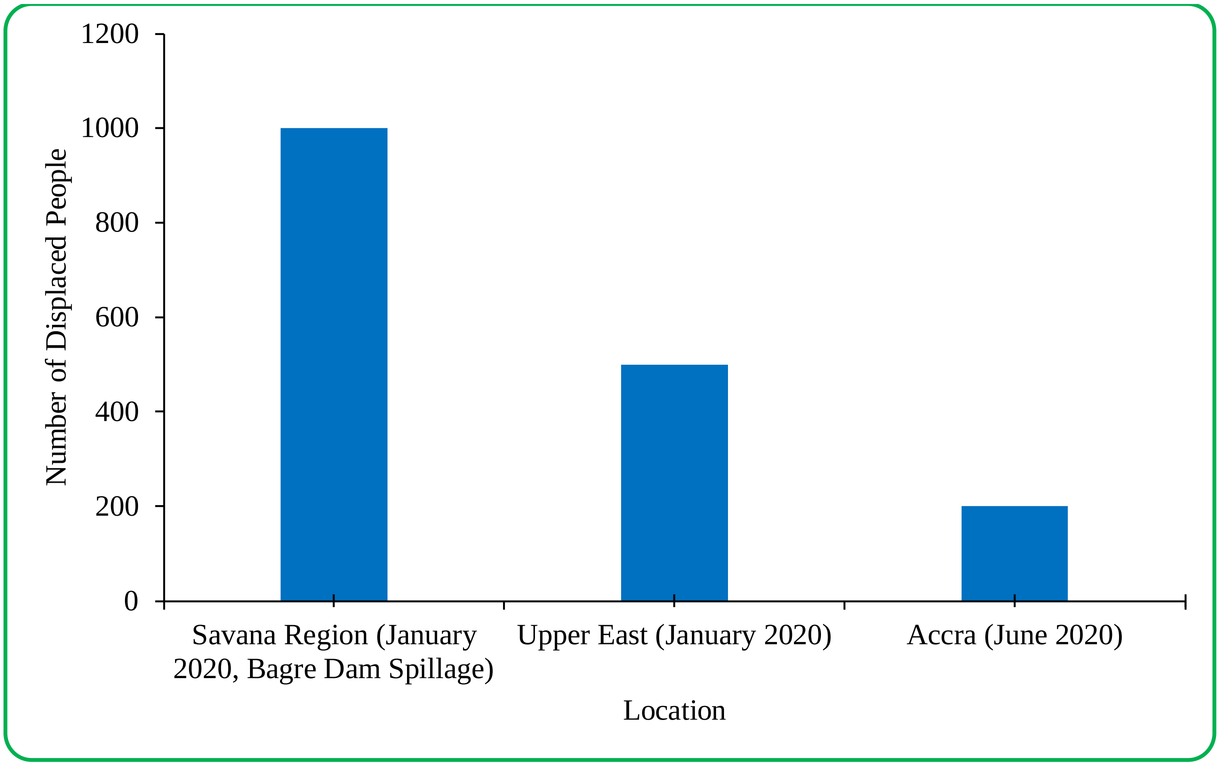


Figure 5: New people displacements caused by floods in Ghana in 2020, by area

Source; Ghana Floods Final Report DREF No. MDRGH0160, 2020

CHAPTER THREE

MATERIALS AND METHODS

3.1.Study Area

3.1.1. The Volta River Basin

The Volta River basin is between latitudes $8^0$50’N - $11^0$05’N and longitudes $0^0$06’E - $2^0$50’W in West Africa with the Oti and Black Volta sub basins lying to its eastern and western side respectively. The lower Volta sub basin drains the southern end. The basin is 400,000 km^2 big and shared by six states. It is forty percent (40%) in Ghana, forty-two percent (42%) in Burkina Faso, Six percent (6%) in Togo, five percent (5%) in Mali, four percent (4%) in Benin and three percent (3%) in Ivory Coast (Appeaning *et al.*, 2020).

Four (4) major sub basins make the Volta Basin with the first one being the Black Volta, whose total area is142,056 km^2. This sub basin starts in Burkina Faso as the Mouhoun river. It drains water out of some parts of Burkina Faso, Ghana, Ivory Coast and Mali. Second to it is the White Volta River basin whose total area 106,742 km^2. It starts from Burkina Faso and as well drains some parts of Burkina Faso and Ghana. It covers the whole Upper East Province of Ghana, approximately 70% of Upper West, and 50% of northern Ghana. Of the 44% of the area that is covered by this basin, 20% lies in Ghana alone with an area of approximately 47, 000 Km^2.

The third sub basin is the Oti, whose area is 72,778 km^2 and starts as Pendjari in Benin. It drains water from Benin and proceeds to Togo. The last one is the Lower Volta basin with an area of 71,608 km^2. This area is made up of sequences of seasonal streams that discharges straight into Lake Volta. This lake is formed by the Akosombo Dam, whose spillway discharges excess water downstream up to the Kpong Dam, and finally discharging into the Atlantic Ocean.

The elevation of the Volta River Basin ranges between zero (0) and nine hundred and twenty (920) meters. More than fifty percent (50%) of the basin has elevation ranging from two hundred (200) to three hundred (300) meters above sea level. The average elevation is approximately two hundred and fifty-seven (257) meters. There are several mountains in the basin such as Fazao, Akuapem, Togo and Kwahu Plateau. The most predominant relief feature in Benin and Burkina Faso is Atakora Ranges and Banfora Plateau respectively with the latter lying in the Black Volta. According to (Mul *et al.*, 2015), water and other hydrological resources are the main resources in the catchment that are used for the growth of humans through agriculture and industries through provision of hydro power. This clearly shows the reasons why there has been misunderstandings between different nations and stakeholders.

Water within the basin is used for irrigation farming, generation of hydropower, supply to homes, livestock and industries, fishing, mineral excavation and transportation. There has been a continued pressure on hydrological resources in the basin following the increasing need of water by the nations within the basin (Mul *et al.*, 2015). Increase in human population and settlements, expansion of towns, rise in industries and other commercial activities have all resulted into increased demand for building of water supply infrastructures and human development. Continued population growth will continue to exert pressure in the Volta Basin since humans settled within the basin live on resources that are slowly being depleted. Farming practices by the people involved in agriculture all accelerate soil erosion that silts surface water bodies. There are some big hydraulic facilities that have been built throughout the catchment, more specifically, big dams which are used for generation of hydropower and supply of water for irrigation farming, household and manufacturing schemes. Other numerous water storage facilities that are mainly for domestic and agricultural purposes on small scale have as well been constructed.

One of the extremely and well recognized construction project in Ghana and in Africa in particular is the the Akosombo Dam which forms the Volta Lake. It was built between 1961 and 1966 and considering its surface area of about eight thousand and five hundred square kilometers (8500 km^2), it is the largest artificial water reservoir. It has an estimated capacity of one hundred and fifty cubic kilometers of water (150 km^3). On average, the reservoir has a residence time of about of 3.7 years. The Akosombo dam is seven hundred meters (700 m) long and one hundred and thirty-four meters (134 m) high. The observed rainfall variations and river discharge records in the periods both before and after building the dam have exposed the effects of the project which have all resulted in the inconsistency of hydrological processes in the basin. The lake serves people in the form of fishing and generation of hydropower among other uses. The reservoir, which takes almost four (4) percent (%) of the total mainland of Ghana, and the hydroelectric power plant installed on it with a capacity of about 912 MW remain to be the most significant man-made hydraulic structures in Ghana. On the downstream of the reservoir, there is Kpong Dam, and the area covered by the reservoir is about 38 km^2. The total volume of water that can be stored by this reservoir is 2.5 Mm^3 and produces 160 MW of electricity for Ghana.

Some other significant features on the Volta Basin include the Bui Dam which has a storage capacity of 13,000 Mm^3 lying on an area of 440 km^2. The dam has the capacity to produce 400 Mega Watts (MW) of electricity. The Kompienga powerplant which was constructed on River Ouale in Burkina Faso generates 14 MW of electricity. The Kompienga lake has a storage capacity of 2,025 Mm^3. The total water storage of Bagre Dam is about 1,700 Mm^3 and it generates 16 Mega Watts (MW) of electricity for Burkina Faso. The Batchanga Dam on the Oti River in Benin stores about of 350 Mm^3 of water. This reservoir produces 15 Mega Watts (MW) of hydroelectric power for Benin (Mul *et al.*, 2015).

Agriculture in Ghana is mainly through rainfed and irrigation farming could only be traced to about a century ago. Big irrigation incentives started around 1960s and since then, the land which has been developed for irrigation is about 19,000 ha. From the year 2007, irrigation schemes have extended to about 33,800 ha, the area which has been the same up to the year 2020. The government of Ghana has developed about 9,000 ha and the private sector has developed about 20, 000 ha. There are about 20 major irrigation systems in Ghana benefiting directly from the surface flows in the Volta catchment. The potential of irrigation development in Ghana ranges from 1.0 to 3.0 million hectares with the ability of water control and distribution being the major factor (Mul *et al*., 2015). Other irrigation schemes with estimated area of over 43,000 ha are still on idea stage. This includes the Accra Plains Project which has a potential area of 11,000 ha.

In Burkina Faso, about 25,000 hectares of land are irrigated and ideas are still ongoing to add 13,000 hectares to it. In Togo, plans are underway to put two (2) irrigation structures on River Oti which will put 2, 600 hectares of land under irrigation. The maximum profits of the major developed irrigation schemes are yet to be realized. This has been attributed to improper management of the irrigation schemes. Aside from the irrigation schemes that have been developed by the government, there are other private irrigation schemes in the basin which are mostly used on small scale. the exact number of the same are not available. Within the catchment, the water storage reservoirs in the upper region as well as the northern end are mostly used for rearing of domesticated farm animals. Very few reservoirs are used for irrigation farming of small sized schemes of between 0.4 to 1 ha, primarily for vegetable gardens (Mul *et al*., 2015). Burkina Faso has the uppermost percentage of small reservoirs for irrigation. The demand for building bigger storage reservoirs is high in this region. Following the 1970 and 1980 droughts, a number of small irrigation reservoirs were constructed between 1970 and 1990.

After realizing that all countries depend much on hydrological resources for growth of their economies, the Volta Basin Authority (VBA) was instituted and commissioned to handle the administrative tasks related to water resources, construction projects and water over exploitation. Analysis of previous hydroclimatic conditions in the catchment have shown that great variations have occurred in total quantities of water and their determinants such as rainfall, stream flow and evaporation coupled with water transpiration from plants (Ndehedehe *et al.*, 2017). The variations that influence the environment, macro and microclimate and the atmospheric mechanisms have all the potential to limit hydrological systems of the Volta River Basin.

The basin further covers some societies that are so vulnerable such that water supply for household use is a vital prerequisite for sustainable growth as well as the overall welfare of the people within the same. The research study done by Dakpalah *et al*., (2018) concluded that there is a shortfall in the supply scenario of water in the basin such that the supply is so low as compared to the need for drinking water in a considerably number of people in the basin. Over the past years, rainfall has been the main source of water for the big employment sector of agriculture.

Agriculture in the rainy season has not been effective due to unpredictable rainfall variations. There have been instances of delayed rainfall season, as well as wet season floods that have led to crop failures and loss of harvests. Most economic activities in the basin centers around crop and animal production and there are some smallholder irrigation activities that benefits directly form on subsurface water tapped from both shallow and deep wells. Kasei *et al.,* (2013) discovered that the water resources situation of the basin with surface flows included respond sensitively to changes in climate and climate variability. Temperatures on yearly basis have as well been projected to rise by one (1) °C in the dry months and two (2) °C in the wet months. Temperature variability causes variability in rainfall too that recharges the Volta River system.

3.1.2. The White Volta River

The Volta drainage system has three major tributaries; the Black Volta, the Oti and the White Volta which has the Red Volta as its main tributary. Among the mentioned rivers, the White Volta is the biggest and longest waterway that passes through Ghana and it covers a distance of approximately eight hundred and eighty-five (885) kilometers between the source and its mouth. The river emerges in the northern Burkina Faso as Nakambe River, and streams its way into Ghana through the north and discharges its contents into Volta Lake. The river has a drainage basin which cover an area of 106,742 km^2. Out of this, 49,225.5 km^2 lies in Ghana alone. The main tributaries of this basin include Mole, Sissili, Kulpawn, Asibilika, Red Volta, Nasia, Agrumatue, Tamne, Morago and Nabogo rivers. All these tributaries join the Black Volta at Nkamandei in Ghana (Mohammed *et al*., 2013).

Variations in the availability of water and other hydrological resources across the White Volta River basin have social economic and cultural impacts among the population settled within the basin (Mul *et al.*, 2015). Most of the rivers in the basin have several variations in response to both human and natural factors. Most of the rivers stays dry for longer periods, and flooding generally occur in the short rainy season. There have been observable changes in the river in terms of the volume of available water including the changes in the short period, current seasonal and future distribution and availability of water across the basin. Observations have been made on the changes due to overpopulation, agricultural production, supply of water to homes and industries and hydroelectric power production. According the report by (Mul *et al*., 2015), water shortages have started becoming a big problem, with less predictability. Climate change is anticipated and projected to worsen the situation and will continue to affect the amount of rainfall and temperatures which all affects water resources in the long run.

The river has two tributaries in the northern part of the basin, the Nazinon and the Sissili that drains the central and eastern parts of Burkina Faso. From there, the river flows into Ghana through the north and turns westwards where it meets by the Red Volta. The river proceeds to the Upper East Region of Ghana where it then meets with the Nasia river as the main tributary. The river proceeds southwards to Nawuni and meets the Mole River and flows past Daboya and finally enters the Lake Volta in southern Ghana. All rivers in the basin are crucial as far as provision of water for the economies of most societies in Burkina Faso and Ghana is concerned. The network of streams in basin arises the most in the rainy seasons and usually dry out in the dry season. All these streams provide water that is used for irrigation, livestock farms and supply to homes and industries in their various proximities (Darko, 2015).

There are several stream gauge stations that are installed within the river and its tributaries to record and make available daily discharge readings about water flow. On seasonal basis, more water flow is concentrated in wet months, that is, between July to September. On annual basis, the average water flow is 300 m^3/s, and out this, 36.5% is drained from Burkina Faso alone. Some other gauging stations within the basin include the Nangodi on Red Volta and Yarugu hydrological stations and they respectively measure mean discharge of 30 m^3/s and 80 m^3/s. At Yarugu hydrological station, the total mean annual discharge is 80 m^3/s whereas at Nawuni hydrological station, the total annual discharge is 230 m^3/s. Using previous monitored and evaluated stream discharges as well as trends in climate change, Li *et al*., (2018) predicted a future increase in the occurrences of stream discharges of low returns. Despite being the most important source of water that is supplied to irrigation farms, homes and industries in the basin, the White Volta also causes some serious problems like river flooding, more specifically in the wet season, that have catastrophic effects to the people settled along its banks (Barnabas, 2018).

Flooding occurs on each occasion when there is excess discharge of water from the Bagre Dam. Annual events of flooding have always resulted in loss of lives and property. Water flows in the river at all times of the year making it suitable for agriculture through irrigation, water supply for homes and industries, aquatic farming, recreation, water transport, livestock ranching and hydroelectric power generation but declining levels of its flow over the last few years due to climate change and other river flow variability factors have severely brought some negative effects in its course over time (Ndehedehe *et al.*, 2017). Despite the White Volta being a perennial river, water shortages have been a big problem because of drying up of its main tributaries, specifically during the high temperatures of dry season. Even in the perennial rivers, the flow regimes have started becoming irregular, affecting the process of planning for dry season irrigation farming and water supply for homes, farm animals and industries.

Ghana receives rains between May and October each year and the levels of water in the river goes beyond its banks, causing floods that damages people and property. Human activities along the banks of White Volta River such as dam construction, streambank cultivation, brick making, aquatic farming, soil and water conservation measures along its course, water transport together with other anthropogenic factors have so far hampered its flow patterns that flow levels have been so irregular in the past decades (Ndehedehe *et al.*, 2017). Being one of the biggest water ways in Ghana, the river as well plays a critical role in water cycle, sediment transport, energy balance, climate change and ecological development. The various factors including human activities along river banks that usually affect the flow pattern of water in rivers have long term negative impacts that will affect any society in the world as a whole if such problems are let to stand for long. Negative effects includes river flooding that brings loss of life and property and siltation of water bodies that brings water shortage challenges (Atubiga *et al.*, 2023).

Furthermore, with the increasing growth of population, pressure on the river and its catchment will continue posing a threat to the behavioral characteristics of water flow of the river. The continued variation in flow regimes negatively affect the river which will cause it to fail to support the people who're benefiting from water, fish and hydrological resources from the river. The river finally discharges its contents into water reservoir created by the Akosombo dam in Ghana. The reservoir behind Akosombo dam is recharged from the flows from the basin through the White Volta and the variability of flows in the river have consequences on the communities as well as national economy. The stability of the dam structure and the sustainability of the stored water is the function of the energy from accumulated water in the reservoir and flow behaviour of the White Volta River as a whole. During the dry spells in the years of 1983, 1998, and 2006, Ghana suffered limitations in power production which led to decline in manufacturing of goods and services, loss of jobs, and reduction in overall Gross Domestic Product (GDP). All this supports the idea of the study of the flow of the river since it is critical as far as electricity generation at the Akosombo dam and other economic activities is concerned in Ghana.

After the lake, the river discharges into Atlantic Ocean at Ada in Ghana. The outlet channel to the ocean is accompanied with a comparatively huge spit which has been formed due to extension of natural modifications of the mouth of the river. Before the construction of the Akosombo Dam, discharge in the river use to average about 1000 m^3/s in the dry months to about 6000 m^3/s in the wet months (Codjoe *et al.*, 2019). On annual basis, discharge was about 87.5 mm/yr, which is higher compared to the discharge of 73.5 mm/yr after the dam project. Peaks in discharge during the rainy season and the transport of sediments have as well been reduced after the dam project. Two more dams have since then been built, the Kpong and Bui dams in 1982 and 2013 respectively, which have also affected the rate of streamflow.

Following the controlled streamflow in the river, the flow and sedimentation dynamics in the estuary has change as well. The Volta delta is located at Accra-Ho-Keta Plains in the lower portion of the basin. The geological feature of the Volta Delta comprises of quaternary alluvial deposits of sand, silt and clay particles (Appeaning *et al*., 2020). The width of the boundary of the delta at the shore is about 15 to 33 km with the shoreface which is generally uniform and moderately steep. This end is considered to be the depth that is substantial for wave induced sediment transport on the shoreline. The Volta River usually transports huge amount of sediment, more prominently the sand which is coarse grained and other particles, to the sea where they have been depositing themselves at the river mouth, forming the delta which is there today.

Throughout its path, the river passes through a serious of earth media ranging from sandstones, mudstones, shales, gneisses, granites, to schists just to mention a few. These are the particles that are deposited at the shore at Ada Foah in Ghana, forming a delta in the process. There has also been a problem of soil erosion of various rates at the shoreline. The incoming water quality, the supply of sand and other beach nutrients determines the predominant plant and animal life near the mouth of the river that helps the population settled in the delta end. Mul *et al.*, (2015) reported that as these inputs have continuously been changing as a result of the disturbances in the natural ecosystem brought about primarily because of human activities, such as the creation of the water reservoir due to the Akosombo Dam project, the plant and animal life has also significantly changed over time. Due to the effect of this changing characteristics, Ghana and Togo have been facing serious problems directly relating to soil erosion at various points. The most severe affected areas are at Ada and Keta in the Volta Estuary Basin. Annually, the sea takes away about one (1) to two (2) meters of land from the Ghana coastline which is about 560 km. These two areas have recorded an annual loss of about four (4) meters (Appeaning *et al.*, 2020).

The White Volta River is located within the Volta River basin which is shared between six (6) countries as shown in Table 6 and Figure 6. This work used the flow data collected in the White Volta River from Pwalugu, Nawuni and Daboya and all these hydrological stations are in Ghana. The satellite image of the Volta River system was obtained from NOAA-AVHRR as presented in Figure 5. The shapefile for the White Volta River and its basin were obtained from USGS and it was processed using Arc GIS. The path and elevation profile of the river was processed using Google Earth Pro software.

Table 6: Volta Basin Distribution

State	**Approximate Area (Km^2)**	**Percentage Area**
Benin	14, 000	3.50
Burkina Faso	172, 000	43.10
Ghana	166, 000	41.60
Ivory Coast	9, 000	2.30
Mali	12, 000	3.00
Togo	26, 000	6.50
Total	**399, 000**	**100.00**

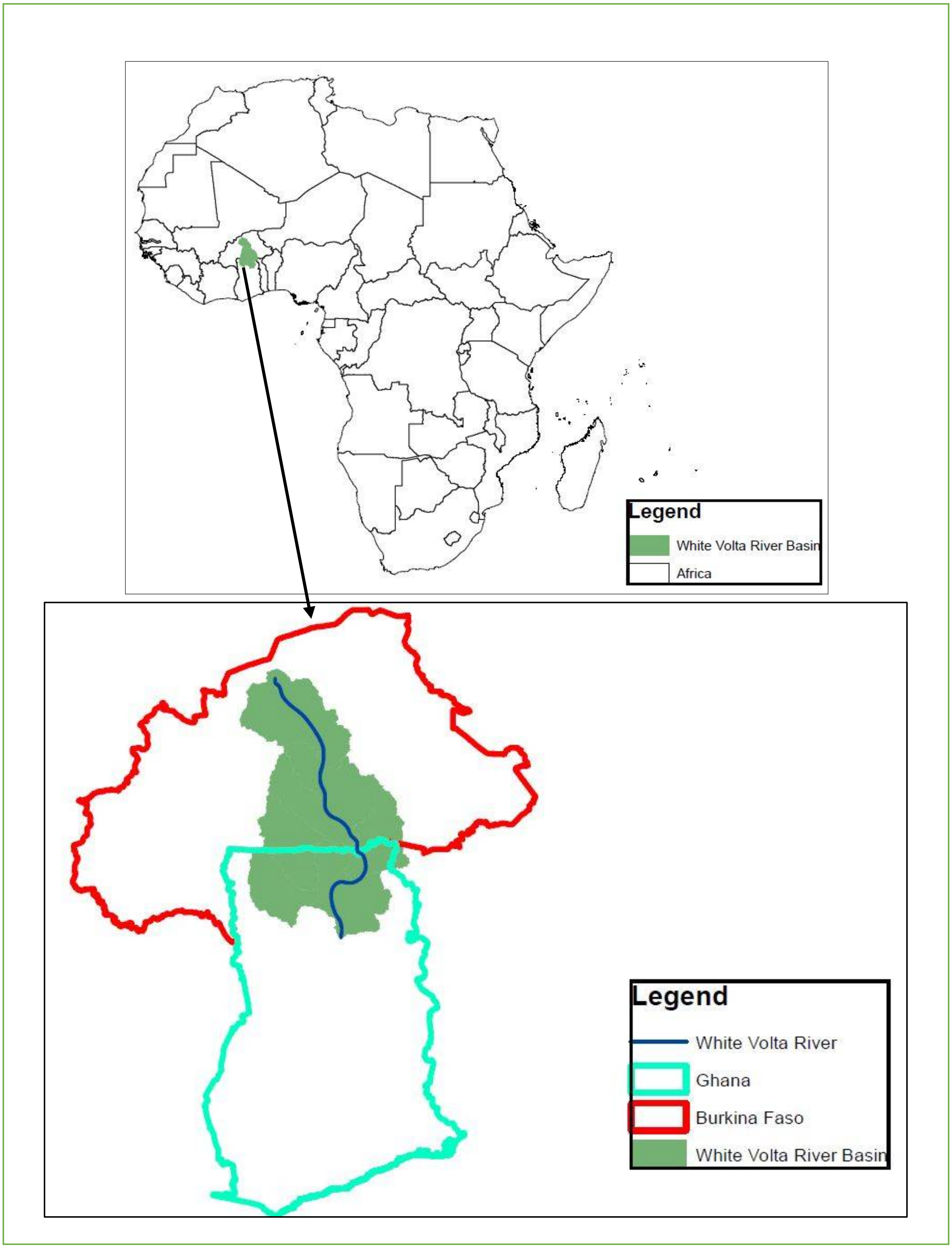


Figure 6: Map showing the study area

3.2.Theoretical Framework

Most theoretical methods in studying water flow have relied on Duration - Averaged Momentum Equation and the Energy Balance Equation for the average flow and turbulence. In these equations, the statistics are presented in a different way, stressing particular sides of water flows in rivers. Most studies have relied on one specific equation on the purposes of the study and data availability, ignoring combined attention of more than one equation. Such a scarcely focused method could be a cause for inconsistencies in the identification and explanation of the physical mechanisms accountable for sustaining flows in rivers including their variability over time. It is therefore instructive to consider other methods and equations which could make available some additional understanding into the mechanisms of water flow in rivers.

In this review, the statistical Man Kendal Trend test and the Sens Slope is used which provide significant values such as the mean flow, peak flow and base flow which are critical values in explaining river flows for irrigation farming and predicting floods (John *et al*., 2018). The Mann Kendal test also considers rainfall which is a key parameter in flow of water in rivers and other water ways (Pirnia *et al*., 2019). This study uses the recorded streamflow data of three gauging stations in the White Volta River, perform a statistical investigation and puts forward a new calculation method of flow analysis and flood frequency analysis. On this foundation, we provide a technical and realistic river flow analysis technique and estimate the river flow status in the White Volta River. We substantiate the reasonableness of the technique from various viewpoints and discuss the application of the technique in irrigation water management and flood prediction.

3.3.Conceptual Framework

The conceptual framework presented here provides a foundation for planning, implementation, monitoring and evaluating the potential contributions, productions, consequences, and influences from assessment of flow variability of the White Volta River. This conceptual framework was developed based on the literature about flow of the White Volta River, reports on irrigation and floods in Ghana, existing case studies about the White Volta River and the prior knowledge from the flow behaviour of rivers in Ghana, particularly the White Volta. In addition, the framework draws from the global action plan for water and other hydrological resources.

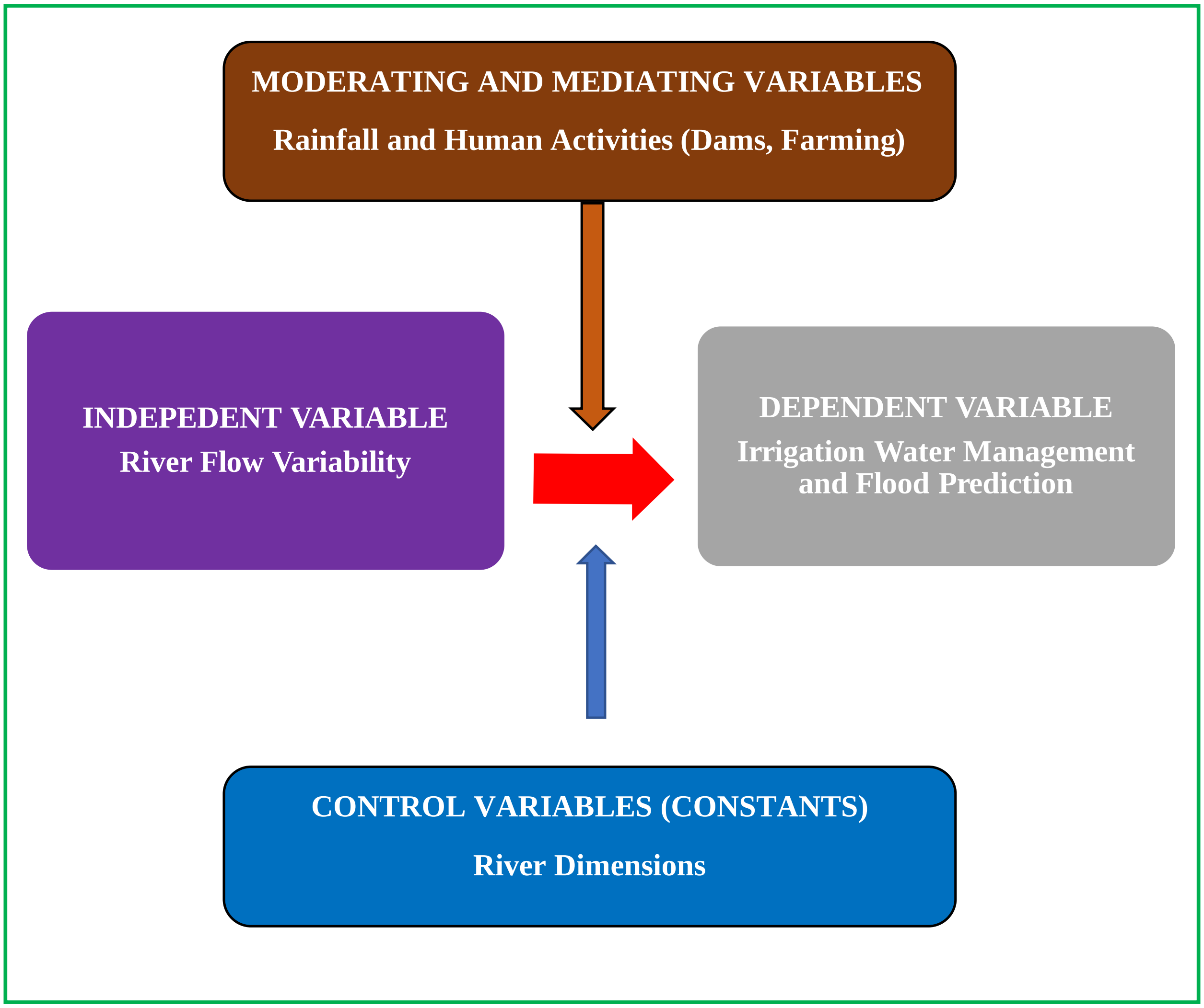
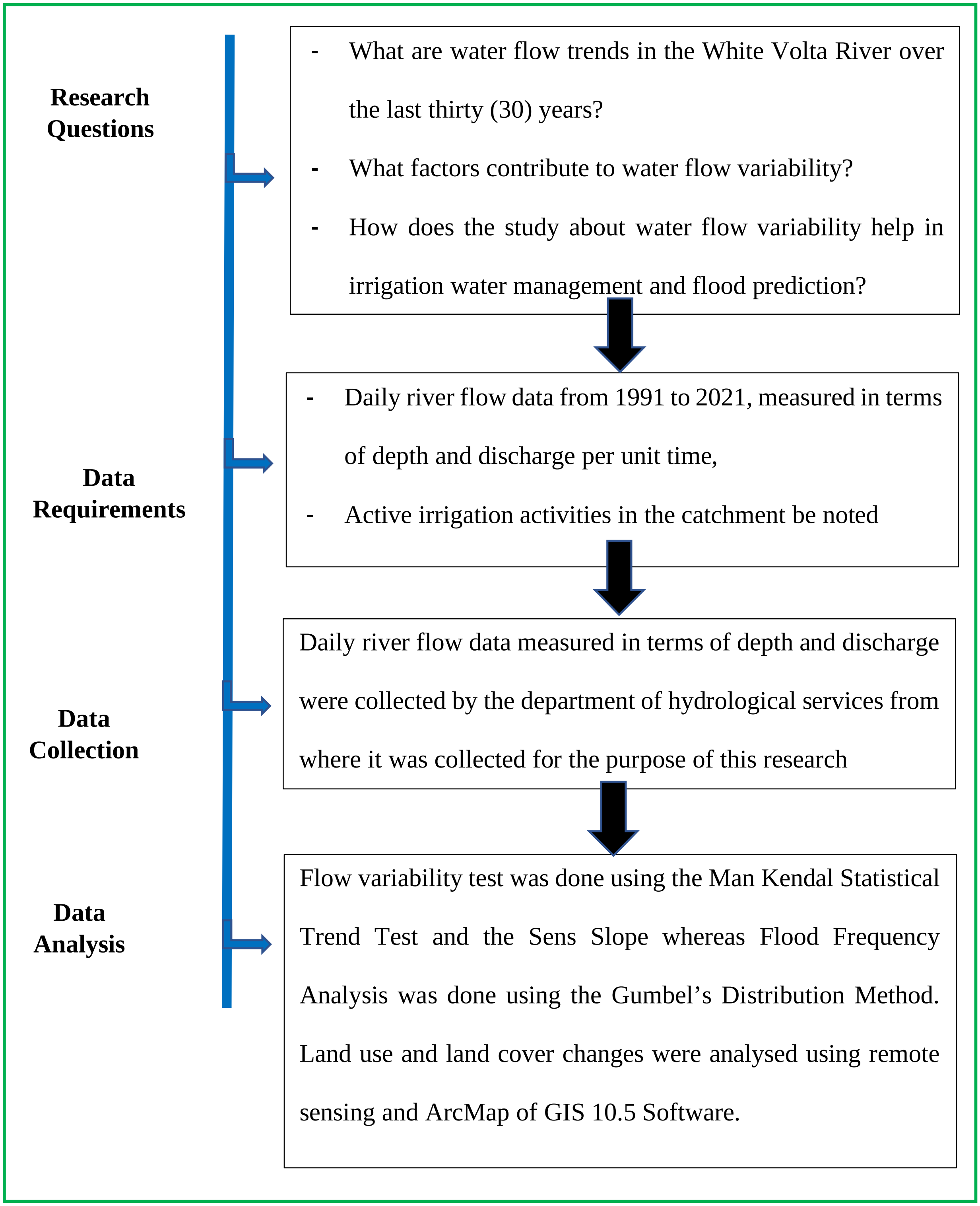


Figure 7: Conceptual Framework

3.4.Research Design,

The following figure summarizes the study design used.



- What are water flow trends in the White Volta River over the last thirty (30) years?
- What factors contribute to water flow variability?
- How does the study about water flow variability help in irrigation water management and flood prediction?

- Daily river flow data from 1991 to 2021, measured in terms of depth and discharge per unit time,
- Active irrigation activities in the catchment be noted

Daily river flow data measured in terms of depth and discharge were collected by the department of hydrological services from where it was collected for the purpose of this research

Flow variability test was done using the Man Kendal Statistical Trend Test and the Sens Slope whereas Flood Frequency Analysis was done using the Gumbel's Distribution Method. Land use and land cover changes were analysed using remote sensing and ArcMap of GIS 10.5 Software.

Figure 8: Research Design

3.5.Data Collection

3.5.1. River Discharge (Flow) Data

Data was collected from three hydrological stations within the White Volta River namely, Pwalugu, Nawuni and Daboya. These stations had no missing data over the thirty (30) year(s) study period between 1991 and 2021. A minimum of thirty (30) years of streamflow data permits for an accurate long-term trend investigation (Asfaw *et al.*, 2017). Additionally, a period of thirty (30) years is characteristically selected as reference point for most climatic studies for the reason that it is long and sufficient to capture variations between decadal periods as well as short enough to capture fluctuations within decadal decades (Zaghloul *et al.*, 2022).

3.5.2. Flow Rate and Magnitude (Q)

This is the quantity of water moving in a river or another water way per unit time. Flow magnitude has been calculated by multiplying the area of the channel and the velocity of water moving through it as given by the following equation.

$Q = (A) \times (V)$ ……………………………………………………………………… Eqn 1.

Equation 1: Flowrate Equation

Where A is the cross-sectional area of the river channel and V is the flow velocity. Units are cubic meters per second (m^3/s) (Othman *et al.*, 2017).

3.5.3. Base Flow

Base flow is the dry weather flow in a stream or river (Othman *et al.*, 2017). From the day-to-day river flow data, minimum flow for the river have been worked out using the spreadsheet (Excel) minimum function.

3.5.4. Peak Flow

The peak flow is the extreme rate of flow through the historical datasets of runoff which is usually caused by an extreme precipitation (Othman *et al.*, 2017). From the everyday river flow data, peak stream flows have been worked out using the spreadsheet (Excel) maximum function.

3.5.5. Mean Flow

This is the average discharge of water that is passing through a river. It has been worked out by finding the average flow from the discharge values recorded during the study period. The mean flow can also be worked out from a hydrograph, which is a diagram showing the degree of discharge against time past a definite point in a water way. Monthly average flows are worked out using daily flows whereas yearly average flows are worked using monthly flows. Five-year average flows are worked out using yearly flows form the years in question.

3.5.6. Flow Frequency

This is the number of recorded flow regimes of a given quantity per given unit time and it describes the return duration and period for the flow of that magnitude to occur and at what time. The quantity of flows passing through the river over time are used to work out flow frequency within that waterway in question. The parameters involved to work out flow frequency are the discharge and the period of time recorded using a clock.

3.5.7. Flow Predictability

This is the ability to predict the occurrence of stream flows of a specified quantity and magnitude returning on either an annual basis or any other specified period. Daily discharge data of thirty (30) years has been used to work out predictability and graphs have plotted to predict flow in preceding years as shown in the results section.

3.5.8. Rate of Change

This is the measure, quantity or frequency at which the quantity and magnitude of streamflow changes (Wiyo, 2015). It is an important parameter for dam releases Flow change rates has been worked out from discharge relationships worked out using existing historical river flow data of thirty (30) years. This work has used the daily discharge data recorded at Pwalugu, Nawuni and Daboya hydrological stations on the White Volta River from 1991 to 2021.

3.5.9. Flow Timing

These are the approximate dates when stream flows a particular quantity and magnitude might start. Projections are made from graphs that are produced from the current existing data.

3.5.10. Flow Duration

This is the total length or period of time of stream flow of a particular quantity and magnitude to flow within a waterway. Flow duration considers the daily discharge values measured on daily basis over a specified time interval. Daily discharge data has been used to plot flow duration curves that characterize the flow of White Volta River. The flow duration curve has been plotted with the discharge and their probability of occurrence or exceedance and shows streamflow rates, often daily average discharge applying to the hydrological stations on the river representing flow through the study period. Probability of occurrence or exceeded is the period of time when a particular flow in a river will either be equaled or exceeded. It has been estimated using various reoccurrence periods of five (5), ten (10), twenty-five (25), fifty (50) years or one hundred (100) years. From the graph which have been plotted, exceedance probabilities for both high discharge values and low discharge values are extrapolated. In the flow datasets, high discharge values have low exceedance probability and low discharge values have high exceedance probabilities within a particular year.

3.5.11. Seasonal Distribution of Flows

This is the distribution of water flow within one year. The daily discharge data are added on monthly basis to find the total discharge for each month throughout the study. The daily flow data are also used to find the mean, maximum and the minimum discharge for every month throughout the study period. Graphs are plotted in excel to see the season flow distribution.

3.5.12. Annual Distribution of Flows

The monthly discharge data during the study period were added to work out the total discharge for each year from 1987 to 2017. These annual totals were graphed to see the distribution for each year during the study period. The monthly discharge data were also used to calculate the mean, maximum and minimum discharge for that year, and presented in graphs plotted in excel.

3.5.13. Trends in Maximum Annual Flow and Minimum Annual Flow

The excel maximum and minimum function were used to respectively work out the peak (maximum) flow and the base (minimum) flow for every year. The maximum and minimum flow graph were plotted in excel to see the variability in maximum and minimum discharge over the entire study period.

3.5.14. Flow Variability

This is the change in either daily, annual or longer behaviour of stream flow characteristics. The Mann Kendal trend test is applied to see the variability in the flow of the river whereas the Sen's slope is performed to see the degree of the variation in the trends. In this work, they have applied on annual basis between 1991 and 2021 to see the variability during the study period and on seasonal basis as to see the variability in a year, from January to December.

3.5.15. Future Forecast of Flow Trends

The annual flow trends were forecasted to the next decade from the last year (2021) of study period. The forecasted discharge graph helps to forecast future flows of the river, putting climatic and other anthropogenic factors constant. Depending on the quality and reliability of the data, flow in a river can forecasted up to fifty (50) years, but this research has forecasted the flow in White Volta River to the year 2031, which is ten (10) years from the last year (2021) of the study period. Equation 2.1 provides the procedure for future forecast of river flows. Graphs are plotted in Microsoft Excel. The forecast function uses the following arguments:

=FORECAST (x, known_y's, known_x's)

Where x is a numeric x-value for which we want to forecast a new y-value. The Known_y's is the dependent array or range of data and the Known_x's is the independent array or range of data that is known to us.

$$y = a + bx \quad \text{……………… Eqn 2.1}$$

$$a = \bar{y} - b\,\bar{x} \quad \text{……………… Eqn 2.2}$$

$$b = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sum(x - \bar{x})^2} \quad \text{……………… Eqn 2.3}$$

Equation 2: Future Forecast Function

3.5.16. Land Cover and Land Use

Records about land use and land cover changes in the basin were obtained through remote sensing and satellite images. The satellite images were processed in ArcMap, a component of ArcGIS 10.4. LANDSAT images with spatial resolution 30 m were acquired from United States Geological Survey (USGS) earth explorer on UTM zone of 30 in the Northern projection.

The reference datum on World Geodetic Survey (WGS) was 84. Supervised land classification was then caried on the acquired LANDSAT images using ArcGIS and ArcMap 10.4. For the images downloaded between 1990 and 2000, LANDSAT images of bands between 1 and 5 were used to classify land use and land cover changes. This was due to availability of the images from the explorer for the required period. For the last decade of the study period, LANDSAT images of bands between 1 and 7 were used for classification. All the downloaded images were from the dry season, that is, in the months between December and March. This was done so as to download clear images with low cloud cover for easy classification. Land use and land cover maps were prepared using the image analysis tool of ArcGIS. The training sample manager was used to extract the exact land uses which were assigned to each pixel on the image. Data about irrigation activities in active irrigation schemes that are in the White River Volta basin was obtained through field visits and from the Ghana Irrigation Development Authority (GIDA).

3.5.17. Soil

Soil formation and characteristics was determined from soil maps and digitized using GIS. Textural characteristics of the soil was determined through direct observation and matching the properties on the soil triangle provided by USDA System.

3.5.18. Rainfall Variability

Rainfall data over the study period was obtained from the weather stations that have rainfall measuring devices installed in the basin. Rainfall and any other form of precipitation is measured by rain gauges. A rain gauge is installed within the basin to collect rain water through is container, and the depth in it is recorded as the total rain for that rainfall event.

3.5.19. The Basin Size and Geographical Location

The size of the drainage area was worked out using geographic information system and verified with the information in Ghana topographic maps. The geographical location was worked out using coordinates collected through GPS referencing and digitized images from Google Earth Pro software. All the maps describing the size of the drainage area including size of the river were plotted using ArcMap, a component of Arc GIS computer program.

3.5.20. Elevation

The elevation profile for the path taken by the White Volta River was worked out by Google Earth Pro computer program. The terrain of the path taken by the river and its basin was determined using digital elevation model (DEM). A digital elevation model (DEM) is a three (3) dimensional computer graphics illustration of elevation data to represent topography or overlaying objects, commonly of the earth, moon, or asteroid. Images of higher resolution are used for better analysis of land characteristics. The DEM was then processed using ArcMap, a component of Arc GIS computer program.

3.6. River Stage Data

A river has three stages; the upper stage, the middle stage and the lower stage where the river empties its contents, either into a lake, ocean or another river and the three hydrological stations namely; Pwalugu, Nawuni and Daboya, were selected based on the same. River stage dataset is presented in the arrangement of a graphical plot of phase against sequential time referred to as phase hydrograph. The phase hydrograph is used to determine the stream discharge and the data is also helpful in design of hydraulic infrastructures such as bridges, dams, inland waterways, dams, dykes as well as flood warning and flood protection works.

3.7. The Relationship Between River Stage and Discharge

The measured river discharge data is used to plot the relationship between the stage of a river and its discharge. The measured discharge values are plotted against the equivalent river stages. The plotted relationship is called rating curve. The joint effect of discharge and stage is referred to as a control, and if the relationship does not vary with time (constant), the control is said to be permanent or stable whereas if it varies with time, the control is referred to as a shifting control. The stream rating equation that describes stage (G) and discharge (Q) relationship is given as;

$Q = C_r (G - a)^{\beta}$………………………………………………………………………… Eqn 3.1

Equation 3: Stream Rating Equation (Subramanya, 2008).

In the equation; Q = The discharge in m3/s, G = Gauge stage (height) in meters (m), a = gauge reading constant, Cr and β are curve rating constants (Subramanya, 2008).

In a logarithmic plot, the stream rating equation is represented as;

$\text{Log } Q = \beta \log (G - a) + \text{Log } Cr$ ………………………...………………………………… Eqn 3.2

Or,

$Y = \beta X + b$, ……………………...……………………………………………………… Eqn 3.3

where $Y = \text{Log } Q$

And

$X = \text{Log } (G - a)$ and $b = \text{Log } Cr$.

The parameters from the same are used to plot the stream rating curve for both permanent and shifting control in a stream (Subramanya, 2008).

3.8. The Mann Kendall Variability Test

The Mann Kendall Trend Test and the Sen’s Slope Estimator are mathematical models used to analyse historical river flow data collected over a long duration for constantly increasing or decreasing trends in water flow. They’re non parametric tests which can be applied to all distributions and the datasets should not necessarily have to meet the hypothesis of normality (John *et al*., 2018). The World Meteorological Organization indorses this test to capture the tendencies in a set of hydrological data such as rainfall and river flow data.

Investigation of trends in daily flows is vital for improved management and planning of water resources and in this study, trends of flow of the White Volta River will be studied on periodic time series using the Mann-Kendall (MK) test and Sen's slope estimator. That is the reason why, the daily, monthly and annual flow data were gathered from the gauging stations that are in the White Volta River. The established charts of spatiotemporal variability of flow may support hydrologists and other river engineers to map out the hazards and the vulnerabilities associated with climate change and flow variability of the river and the data and results which will be made available will help in predicting flood events and planning for dry season irrigation farming.

Hydrological models are developed for research with the aim of prediction hydrological problems so as to improve decision-making about a practical hydrological problem. The Mann–Kendall rank trend test statistic Z is built on the principle as presented in Equation One (1). In equation, x_j and x_i are the logic and sequence datasets, n represents length of dataset, m represents number of series with at least one recurrent dataset, t represents the range of any given tie. Σ represents the addition over all dataset ties. A positive Z indicates increasing trend and negative Z indicates a decreasing trend in the time series. In the event of absolute, $|Z| > 1.96$ and $|Z| > 2.575$, it means a substantial trend at the confidence levels of 0.05 and 0.01 respectively (Aditya *et al*., 2021).

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}}, if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{Var\ (S)}}, if\ S < 0 \end{cases} \quad \text{……………………………………………......………. Eqn 4.1}$$

Where;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\ (x_j - x_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 4.2}$$

$$Sgn\ (\theta) \begin{cases} +1\ \theta > 0 \\ 0\ \theta = 0 \\ -1\theta < 0 \end{cases} \quad \text{…………………………………………………..………. Eqn 4.3}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 4.4}$$

Equation 4: The Mann Kendall flow variability Test.

According to (Odiyo, 2014), positive (+) and negative (-) z values designate the direction of the trend in a time series. The Mann Kendal trend test is constructed on two hypotheses;

Null Hypothesis (H_0) = There is no trends or variability in the series

Alternative Hypothesis (H_a) = There is a trend or variability in the series.

The Null Hypothesis is rejected when the calculated (p) value is greater than the Alpha value of 0.05. This means that a p value greater than 0.05 supports the hypothesis that there is trend in the river in question, and, the Sens slope is used to see the magnitude or the degree the of the trends as presented by the Mann Kendal test.

3.9. Hydrological Drought Indices

3.9.1. Standardized Precipitation Index (SPI)

The standardized precipitation index contains an intensity scale with estimated positive and negative values that directly connect to wet and dry episodes. When the SPI findings are consistently negative and reach a value of -1, drought events are indicated. Up until SPI hits a value of 0, the drought event is thought to be continuous. Precipitation data is the main input to the SPI. It is calculated using the following formula.

$H(x) = q + (1-q)\, G(x)$ …………………………………………………………. Eqn 5.

Equation 5: Standardized Precipitation Index

Where q is the probability of zero, calculated from the frequency of zero precipitation observations in the time series, and G(x) is the cumulative probability calculated from the gamma distribution for non-zero observations. The value of the SPI gives a measure of the severity of a wet or dry event as summarised in Table 7.

Table 7: SPI Classification

SPI Value	**Class**
$SPI \geq 2$	Extremely Wet
$1.5 < SPI \leq 2$	Severe Wet
$1 < SPI \leq 1.5$	Moderate Wet
$-1 < SPI \leq 1$	Near Normal
$-1.5 < SPI \leq -1$	Moderate Dry
$-2 < SPI \leq -1.5$	Severe Dry
$SPI < -2$	Extremely Dry

(Svoboda & Fuchs, 2016)

3.9.2. The Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) is a simplified water balance calculation that takes precipitation and potential evapotranspiration into account. The initial value, the normalized value, and the standardized value are determined using monthly temperature and precipitation information. It is calculated using the following formula.

$$\text{RDI} = \frac{y - \hat{y}}{\sigma} \quad \text{Eqn 6}$$

Equation 6: The Reconnaissance Drought Index

Where y is the natural logarithm; ŷ is the arithmetic mean and $\boldsymbol{\sigma}$ is the standard deviation. In describing drought conditions using the RDI method, moderate drought is characterized by -0.5 > -1.0 > -0.7 > where as a severe drought is characterized by -1.0 > -2.0 > -1.5 >

3.9.3. The Agricultural Reference Index (ARID)

The Agricultural Reference Index makes predictions about the soil's moisture availability and for it to determine the effect of water stress on plant growth, development, and production for particular crops, it combines crop models and estimates for water stress. Data on daily precipitation and temperature are used in its calculation. In situations when agricultural effects are the main concern, this score is used to detect and forecast drought. ARID values range from 0 to 1 and it is calculated using the following formula.

$$\text{ARID} = 1 - \frac{T}{ET} \quad \text{Eqn 7}$$

Equation 7: The Agricultural Reference Index

Where T is the transpiration from plants and ET is the reference transpiration.

3.9.4. Streamflow Drought Index (SDI)

The Streamflow Drought Index creates a drought index based on streamflow data by using monthly streamflow values and the normalization techniques associated with the SPI. As shown in Table 8, both wet and dry periods, as well as the severity of these events, can be explored with an output comparable to the SPI. The monthly streamflow measurements and the streamflow gauge's historical time series are the major pieces of data needed and the in the formula below, Where Vik is the cumulative streamflow volume, Vkm is the mean and Sk is the standard deviation of cumulative streamflow volumes.

$$\mathrm{SDI} = \frac{\mathrm{Vik} - \mathrm{Vkm}}{\mathrm{Sk}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 8}$$

Equation 8: Streamflow Drought Index

Table 8: Drought classification according to the SDI values.

SDI Value	Category
≤ 2	Extremely Wet
1.5 to 1.99	Severy Wet
1 to 1.49	Moderately Wet
0.5 to 0.99	Slightly Wet
-0.49 to +0.49	Normal
-0.5 to -0.99	Mild Drought
-1 to -1.49	Moderately Drought
-1.5 to - 1.99	Severely Drought
≤ -2	Extremely Drought

(Tareke & Awoke, 2022)

3.10. Flood Frequency Analysis

Flood frequency is the probability (P) for a flood to be corresponded or surpassed in any given year (Hart & Stanley, 2020). Various methods are used for the same and this work used the Gumbel's method to predict the future occurrence of flood in the river. Flood frequency is represented in terms of the return period (T) as given in the following equation.

$T = \frac{1}{p}$ and $P = \frac{m}{n+1}$……………………………..……………………………………. Eqn 9

Equation 9: Flood Return Period

Where T is the return period, P is the flood frequency, m is the rank of discharge and n is the number of years for the recorded dataset (Hart & Stanley, 2020).

3.10.1. Gumbel's Method

This is also called extreme value distribution and it defines a flood as the biggest flow out of the everyday flows and the yearly series of floods flows consists of a series of biggest flow values. The likelihood of occurrence of an event equivalent to or greater than a value X is calculated as;

$P (X \geq X_0) = 1 - e^{-e^{-y}}$…………………………………………………………………… Eqn 5.1

Where, $Y = \alpha (x - a)$ and $a = \bar{x} - 0.45005\sigma_x$, $\alpha = 1.2825/\sigma_x$……………………………. Eqn 5.2

Where $\bar{x}$ is the average and σ is the standard deviation of the variate.

Rearranging equation 5.1, we obtain;

y = $\frac{1.285(x - \bar{x})}{\sigma x}$ + 0.577, and for a given probability, y becomes y_p = -ln (ln (1 – P) .... Eqn 5.3

and the return period (T = 1/P) designated by Y_T = - [ln. ln$\frac{T}{T-1}$] ………………………. Eqn 5.4

The value of variate X with return period is $X_T = \bar{x} + K\sigma_x$, ……………………………. Eqn 5.5

where the constant K = $\frac{YT - 0.577}{1.2825}$ …………………………………………….…………... Eqn 5.6

Equation 10: Gumbel's Method

The theoretical plotting by Gumbel (1945) is used in estimation of floods and the whole process of rate of flood recurrence analysis is based on extreme value distribution and uses rate of recurrence factors established for hypothetical distribution. By using the number of years and Gumbel's correction, the Return period is calculated the equations as presented in the equation 5 above. The recurrence interval by Gumbel’s method is given by;

Tr = $\frac{N}{m+c-1}$ ……………………………………………………………………………… Eqn 6

Equation 11: Recurrence interval using Gumbel’s Method.

N = Number of years, m = flood rank, c = Gumbel’s correlation

3.11. Data Analysis

Streamflow data was collected to describe the flow behavior of the White Volta River which is the first objective of this research work. Various statistics are calculated from the streamflow data collected so as to characterize the flow pattern of the White Volta River. These statistics includes flow rate and flow magnitude, base and peak flow, mean and flow frequency, flow predictability, rate of change, flow timing and flow duration flow distribution. The procedures for all these have been explained in the above section.

The Mann Kendal trend test and the Sen’s slope was applied to calculated the significant trends and variability in the river flow. The key data used in this procedure was the streamflow records between 1990 and 2021 which was collected from the three hydrological stations within the river. The Mann Kendal trend test to test the variability in flow whereas the Sen’s slope was used to calculate the magnitude of flow trends.

To achieve the second objective, three key factors that affect river flow were investigated and the effect of rainfall and temperature on streamflow was the first to be studied using the rainfall and climatic data which was collected from the Hydrological stations in Tamale and Navrongo. The rainfall and climatic data collected for this analysis was from the year 1991 to 2021. The effect of rainfall and temperature on streamflow of the White Volta River has been presented in the section of results and discussion. Data about land use and land cover changes between the study period was acquired as images downloaded from USGS and classified using ArcMap, a component withing ArcGIS 10.4 computer programme.

Five irrigation schemes that are benefiting from the surface flows of the White Volta River were visited to acquire the data about how water is used by the crops per each cropping system. These irrigation schemes include Bontanga, Golinga, IWAD, Tono and Vea. This was done to achieve the third objective of this study.

To achieve the last specific objective, peak streamflow for each year between 1991 and 2021 were used to analyze the frequency of flooding in the river. The Gumbel’s method was used to predict future flooding in the river at return periods between 5 and 150 years. The linear regression for the streamflow and the Gumbel’s probability curve were done and plotted in Microsoft excel from which discharge of various magnitudes have been plotted against their probability of recurrence.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1.Analysis of Flow Patterns and its Characteristics

4.1.1. Flow Duration

Flow duration is the average discharge values measured on daily basis over a specified time interval. Daily discharge data is used to plot flow duration curves that characterize the flow of streams. As shown in Figure 9, the flow duration curve below has been plotted with the discharge and their probability of occurrence or exceedance. It has been used to compare streamflow data over the study period. The curve as well shows streamflow rates, often daily average discharge applying to the three hydrological stations on the White Volta River representing flow through the study duration. From the graph, high discharge values have low exceedance probability and low discharge values have high exceedance probabilities.

This flow duration curve will be used to evaluate low-level stream flows in the White Volta River, a process that is critical in water management for irrigation and domestic as well as industrial supply. The curve has indicated an increase in probability of low streamflow during the dry season. Increase in probability of low flows means an increase in probability water shortage problems within the river this was also reported by Dakpalah *et al*., (2018)

The curve will also be used for other purposes such as measuring the total amount of sediment carried by a river during which the sediment load and other load of dissolved solids of the stream are calculated. As part of flood management and flood control research, this streamflow duration curve will be used in the design of drainage systems, water control structures and calculating the probability of high flows during the rainy season.

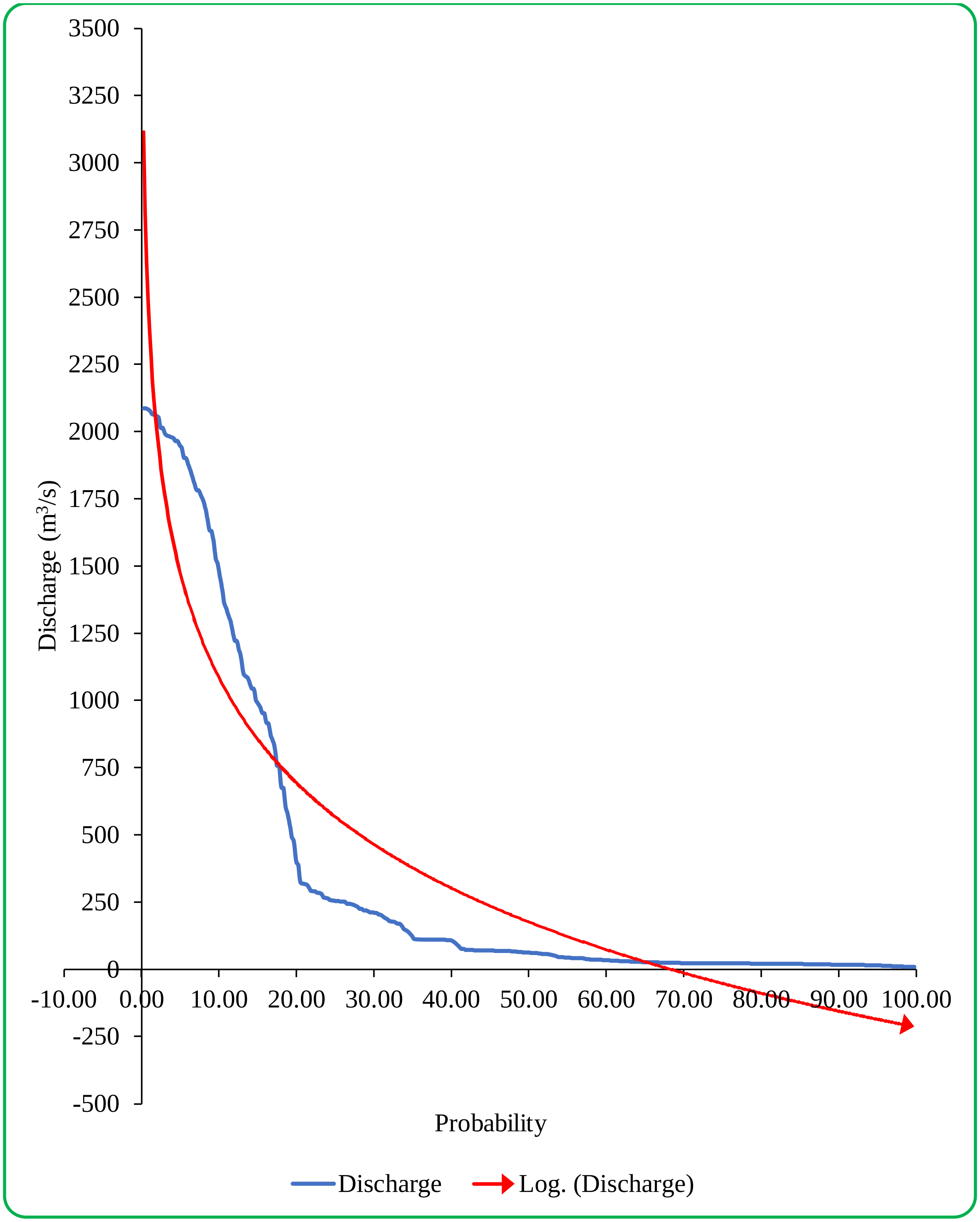


Figure 9: Flow Duration Curve

4.1.2. Seasonal Flow Distribution for Pwalugu, Nawuni and Daboya Stations

The maximum daily discharges recorded over the study period were 1425.19 m^3/s, 1644.25 m^3/s and 2086.95 m^3/s from Pwalugu, Nawuni and Daboya stations respectively, all in September. The lowest discharges were 0.33 m^3/s, 0.85 m^3/s and 1.42 m^3/s from the three respective stations in the month of March. The overall highest average discharge of the river was 941.23 m^3/s recorded in September and the overall lowest average discharge was 30.08 m^3/s recorded in March. Figure (s) 10, 11 and 12 respectively presents the seasonal flow characteristics for Pwalugu, Nawuni and Daboya hydrological stations. Figure 13 shows the average distribution.

Between December and April, analysis of flow characteristics from the three stations will help in management of water for irrigation farming as well as supply to homes and industries. The average amount of water in the river will determine how much should be abstracted from the same for irrigation purposes. During the rainy season, the flow distribution curve helps calculating annual peak flows which are used in analysis of floods that are common in the river.

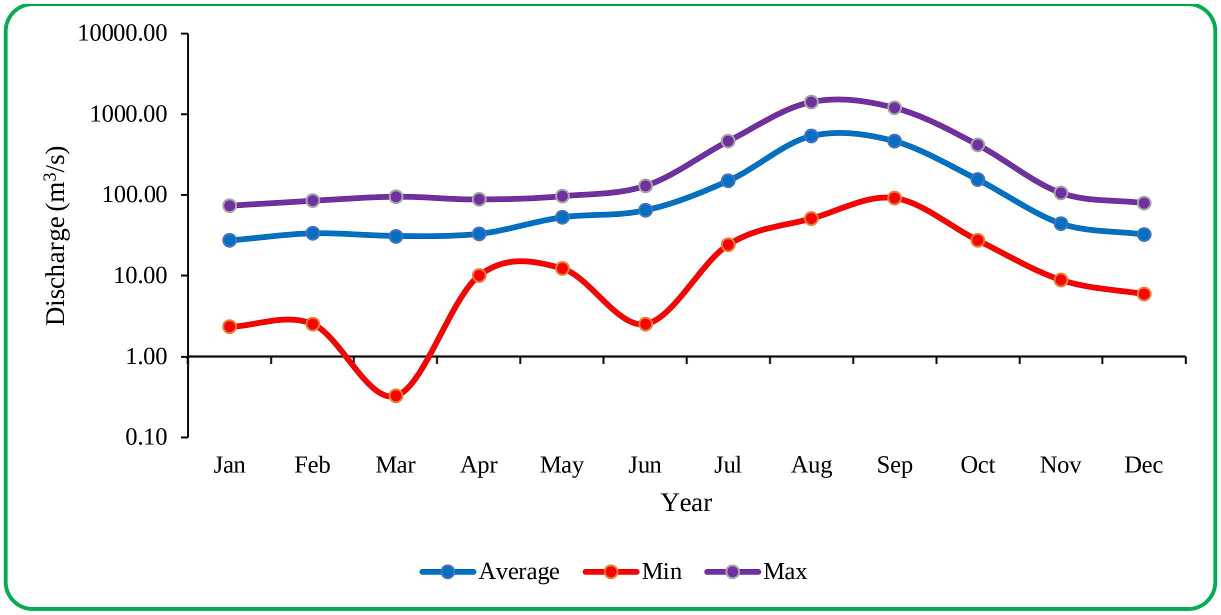


Figure 10: Seasonal Flow Distribution for Pwalugu Station

Analysis also shows that water spillage from the Bagre Dam in Burkina Faso has a bearing in the shape and peak flows that have been recorded over the study period, with a notable discharge of 2087 m^3/s in 2020 at Daboya hydrological. This was also reported by Mul *et al*., (2015).

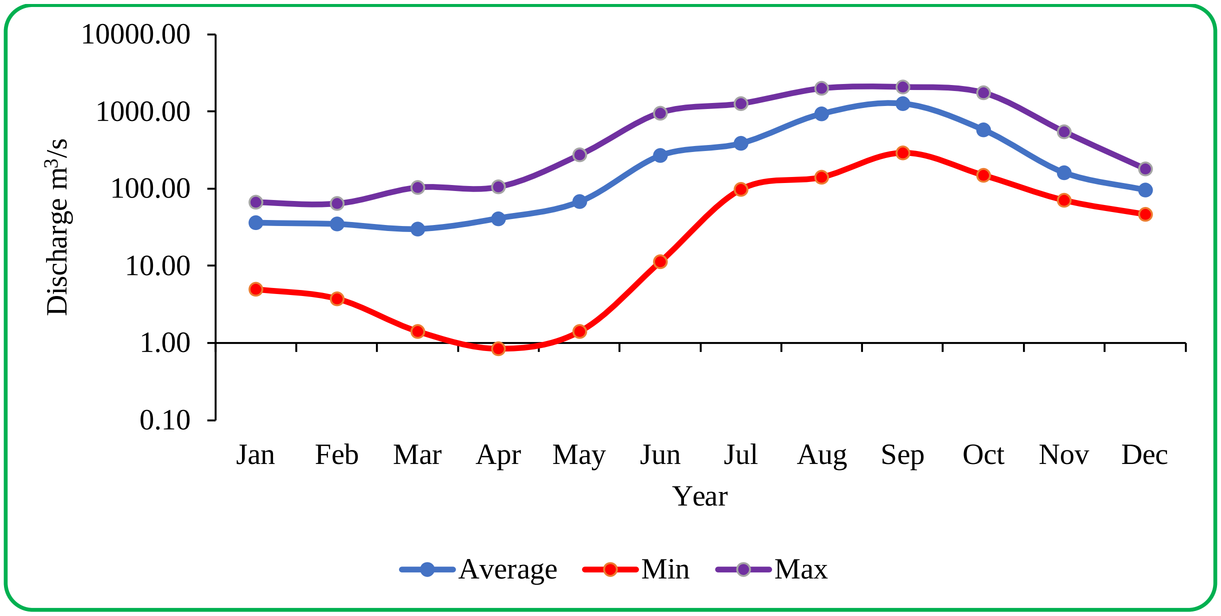


Figure 11: Seasonal Flow Distribution for Nawuni Station

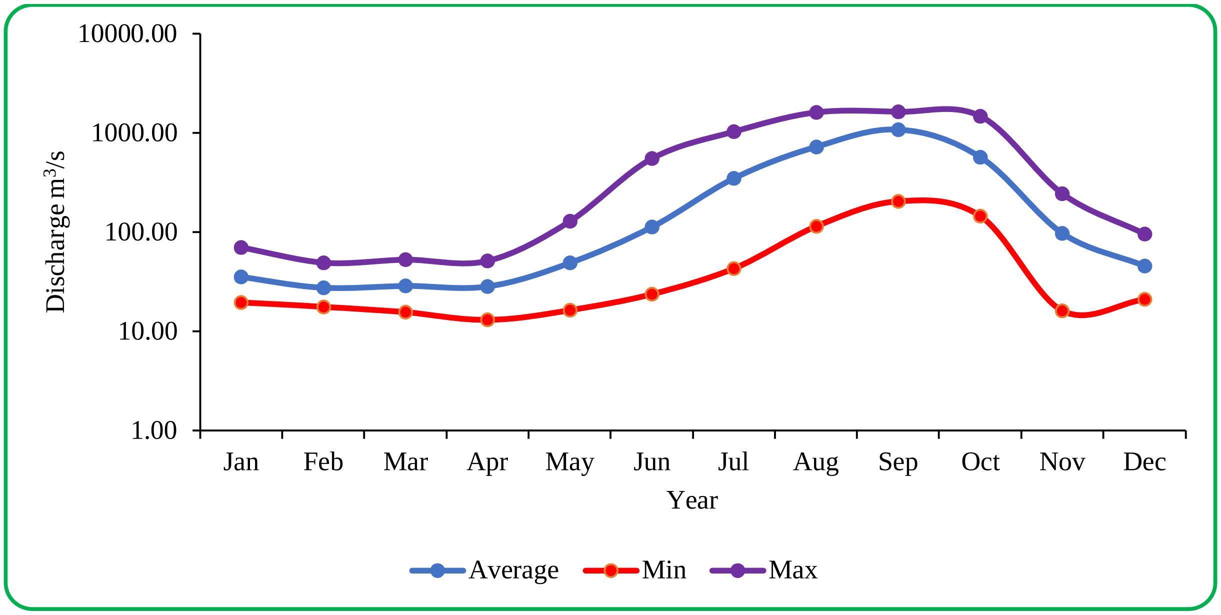


Figure 12: Seasonal Flow Distribution for Daboya Station

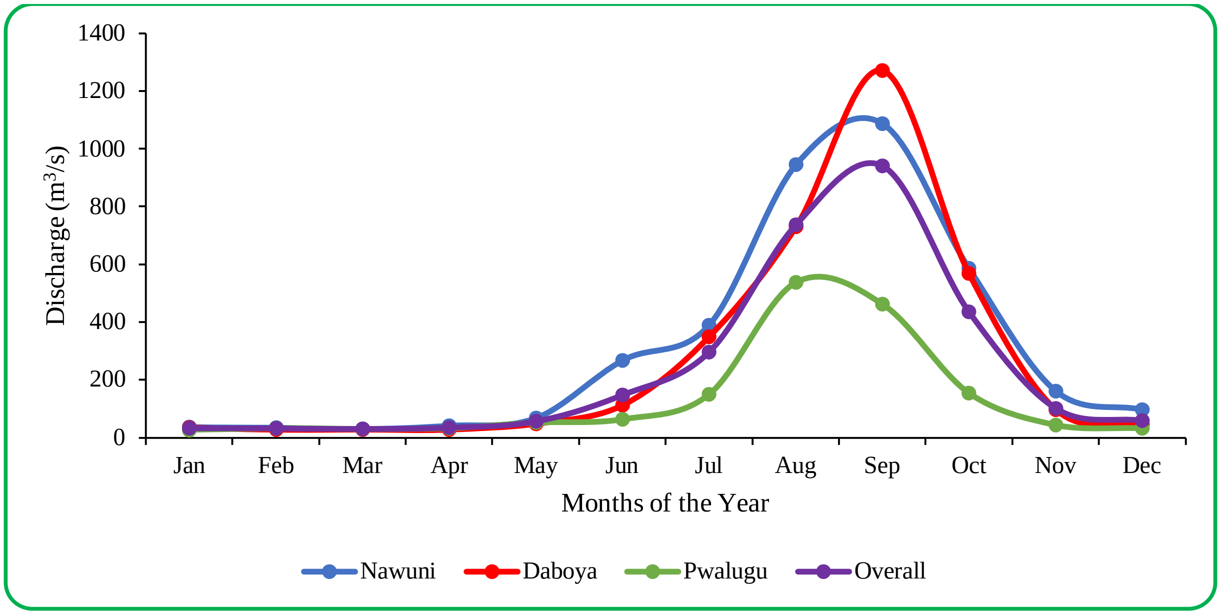


Figure 13:Average Seasonal Flow Distribution for Pwalugu, Nawuni and Daboya Stations

4.1.3. Overall Seasonal Flow Distribution

This was worked out from daily discharge flows from the three hydrological stations. On seasonal basis, flows were high in the months between July and November and moderately low in the dry months between December and June. The uppermost flow was observed in the wet month of September with the bottommost flow observed in the dry month of March as illustrated in Figure 14. The month of September showed an average daily flow of about 1818.26 m^3/sec whereas the average daily flow was about 16.29 m^3/sec in June.

Flow of the river improved from June to October and then began to decrease in January. This change from upsurge to decline and the vice versa is in response to the onset of rainfall over the region during the stated period. This was also reported by Kasei *et al*., (2013). The relationship between rainfall and flow of the White Volta River has been well illustrated in Figure 20 and 23. The overall flow distribution was used to work out the flow trends in the river using.

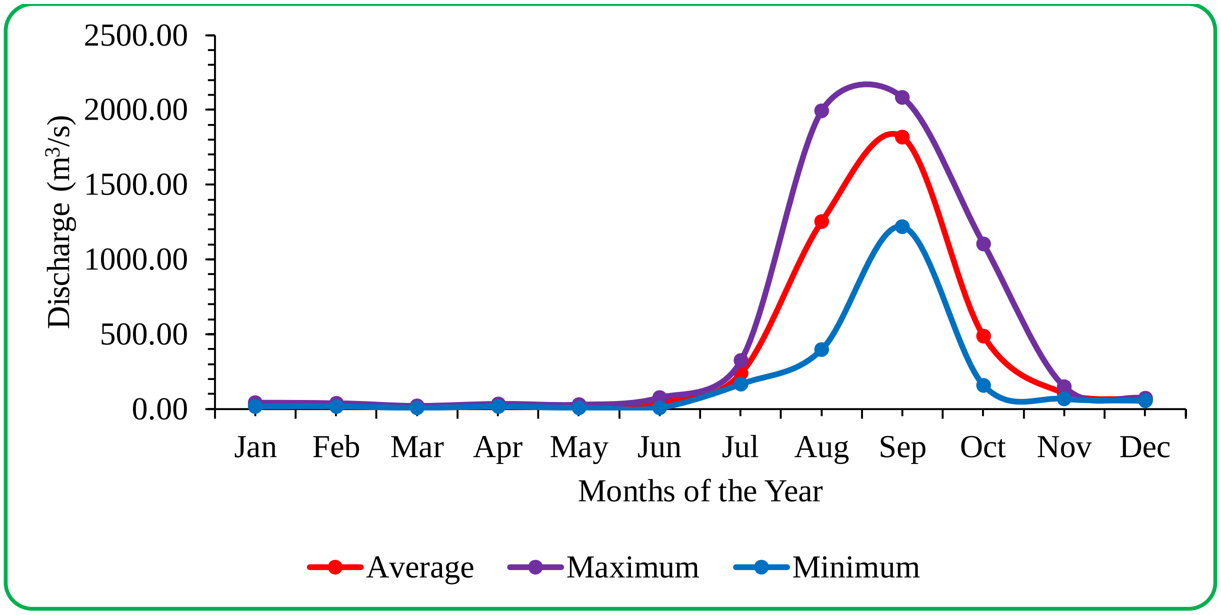


Figure 14: Average Seasonal Flow Distribution

4.1.4. Mann Kendal Trend Test for Seasonal Distribution Of Flows

The Mann Kendal trend test was performed to see the seasonal variability in the flow of the river whereas the Sen's slope was performed to see the extent of the change in the variations as presented in Table 9 and 10. On monthly basis, the flow in the river increases starting from June each year and decreases starting from December each year. The increasing trends in June were significant at the 95% level of confidence. The seasonal statistic had 365 observations with a minimum of 8.25 m^3/s, a maximum of 522.57 m^3/s, an average of 83.03 m^3/s and a standard deviation of 100.12 m^3/s. The magnitude of change as provided by the Sen's Slope was 0.21 with a Mann Kendal's Tau of 0.42.

Seasonal flow variability in the White Volta River were also reported by Barnabas, (2018) who modelled the flow using data driven frameworks. Figure 15 shows the graphical representation of flow between January and December, as provided by the Mann Kendal Trend Test. The flow variability data will be used to characterize the flow over the entire season for water management.

Table 9: Summary Statistics for Seasonal Mann - Kendal Trend Test

Variable	**Observations**	**Confidence Level**	**Sens Slope**
Flow	365	95%	0.207
Minimum	**Maximum**	**Mean**	**Std. deviation**
8.253	522.570	83.027	100.117
Kendall's tau	**S**	**Var(S)**	**p-value (Two-tailed)**
0.416456544	27665	5425115.67	0.0001

Table 10: Trends in monthly flow

		Kendall's			**P-Value**		**Sen's**	
Month	**n**	**Tau**	**S**	**Var(S)**	**(Two-Tailed)**	**Alpha**	**Slope**	**Trend**
Jan	31	-0.88	-410	3461	0.0001	0.05	-0.92	Yes
Feb	28	-0.11	-53	3460	0.3767	0.05	-0.06	No
Mar	31	-0.17	-81	3462	0.1739	0.05	-0.14	No
Apr	30	0.31	143	3449	0.0156	0.05	0.25	Yes
May	31	0.22	101	3457	0.0890	0.05	0.15	No
Jun	30	-0.42	-193	3462	0.0011	0.05	-1.50	Yes
Jul	31	-0.37	-171	3462	0.0039	0.05	-2.80	Yes
Aug	31	1.00	465	3462	0.0001	0.05	53.29	Yes
Sep	30	-0.94	-435	3462	0.0001	0.05	-25.66	Yes
Oct	31	-0.93	-431	3462	0.0001	0.05	-32.36	Yes
Nov	30	-0.71	-301	3193	0.0001	0.05	-1.72	Yes
Dec	31	-0.68	-316	3461	0.0001	0.05	-0.53	Yes

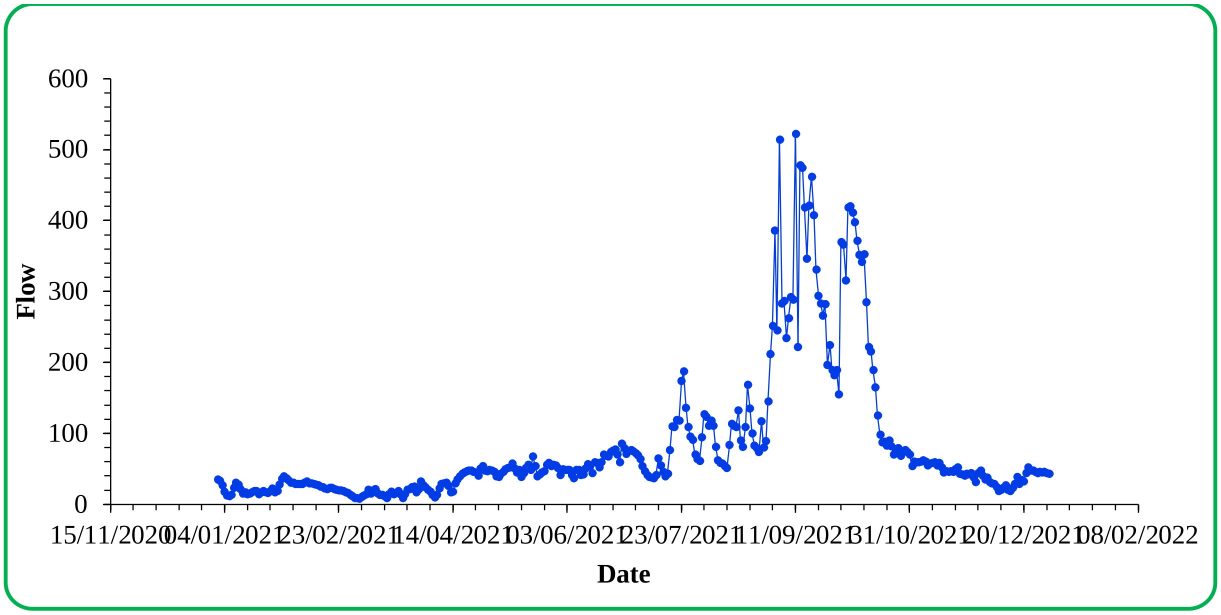


Figure 15: Trends in monthly flow

4.1.5. Annual Flow Distribution

Daily discharge data was used to calculate annual means which were used to graph the annual flow distribution as shown Figure 16. The year 2021 had average discharge of 446.84 m^3/s, the highest discharge on average basis during the study period whereas on daily basis, the year 2020 recording the highest flow of 2086.95 m^3/s at Daboya station. A plot of annual flow distribution of the daily flow data from the three hydrological stations showed an increase in short duration flows of high magnitudes in rainy season months and decreasing low flows in the dry months. The total annual flow calculated from the total inflow from the basin showed a decreasing trend. This trend agrees with Ganiyu *et al.*, (2011), the research work that was done on its sub catchment. During the rainy season, Pwalugu station recorded an average discharge of 83.03 m^3/s in 2006 and 132.87 m^3/s in 2021 and Nawuni station recorded an average discharge of 138.10 m^3/s in 2006 and 248.23 m^3/s in 2021. Daboya station recorded an average of 202.25 m^3/s in 2006 and 345.46 in 2021. The annual peak data have been used for flood analysis.

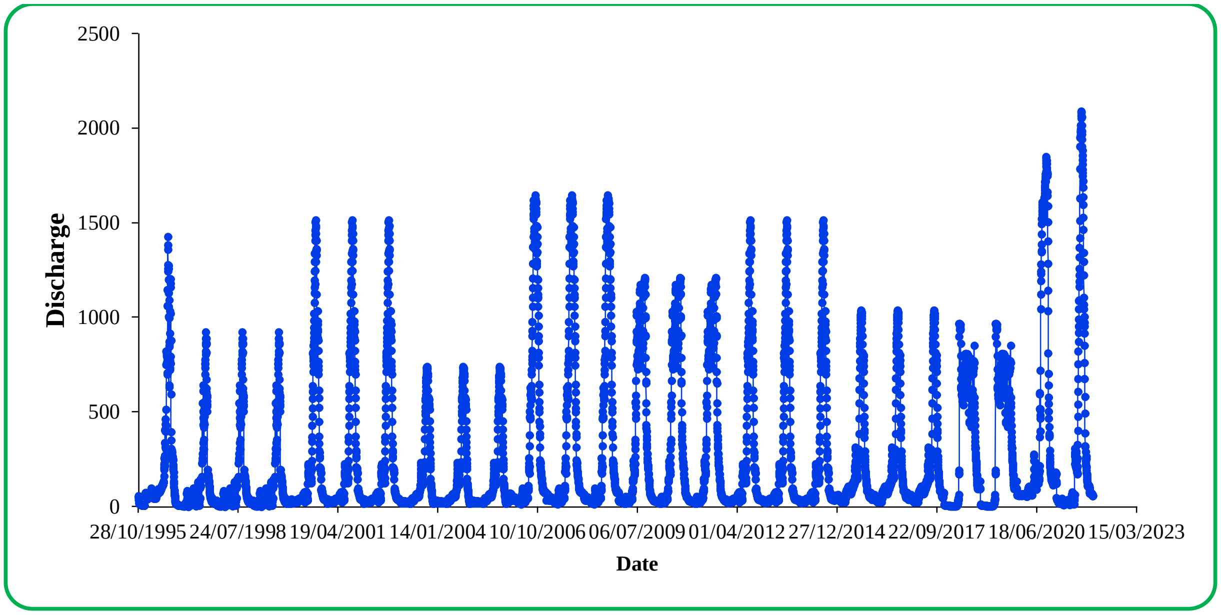


Figure 16: Annual Flow Distribution

4.1.6. Mann Kendal Trend Test for Annual Distribution of Flows

The Mann Kendal trend test was performed to see the annual variability in the flow of the river whereas the Sen's slope was performed to see the extent of the change in the trends as presented in Table 11 and 12. On annual basis, there are some years where the flow has been lower than the preceding year, a trendline line as presented in Figure 17 shows that there is a decrease in total flow in the river from 1990 through each year to 2021. This variation of flow trend was also reported by Ndehedehe *et al.*, (2017) who did the analysis of hydrological variability over the same basin. The test results were significant at the 95% level of confidence. The annual statistic had 11323 observations with a minimum of 0.328 m^3/s, a maximum of 2086.95 m^3/s, with 233.03 m^3/s as average and 365.30 m^3/s as standard deviation. The magnitude of change as provided by the Sen's Slope was 0.003 with a Mann Kendal's Tau of 0.114. Figure 17 shows the graphical representation of flow between 1991 and 2021, as provided by the Mann Kendal Trend Test.

Table 11: Summary Statistics for Annual Mann Kendal Trend Test

Variable	**Observations**	**Confidence Level**	**Sens Slope**
Flow	11323	95%	0.003
Minimum	**Maximum**	**Mean**	**Std. deviation**
0.328	2086.95	233.03	365.30
Kendall's tau	**S**	**Var(S)**	**p-value (Two-tailed)**
0.114	7278935	161324112523.66	0.0001

Table 12: Trends in Annual flow

		Kendall's					**Sen's**	
Year	**n**	**Tau**	**S**	**Var(S)**	**P-Value**	**Alpha**	**Slope**	**Trend**
1991	365	0.42	27665	5425116	0.0001	0.05	0.21	Yes
1994	365	0.09	6290	5424586	0.0069	0.05	0.14	Yes
1997	365	0.30	19636	5424854	0.0001	0.05	0.17	Yes
2000	365	0.41	27371	5425050	0.0001	0.05	0.33	Yes
2003	365	0.42	28100	5425104	0.0001	0.05	0.34	Yes
2006	365	0.38	25043	5425088	0.0001	0.05	0.41	Yes
2009	365	0.35	23026	5424832	0.0001	0.05	0.52	Yes
2012	365	0.40	26683	5425050	0.0001	0.05	0.32	Yes
2015	365	0.46	30518	5424868	0.0001	0.05	0.52	Yes
2018	365	0.22	14389	5422321	0.0001	0.05	0.42	Yes
2021	365	0.50	33471	5424838	0.0001	0.05	0.55	Yes

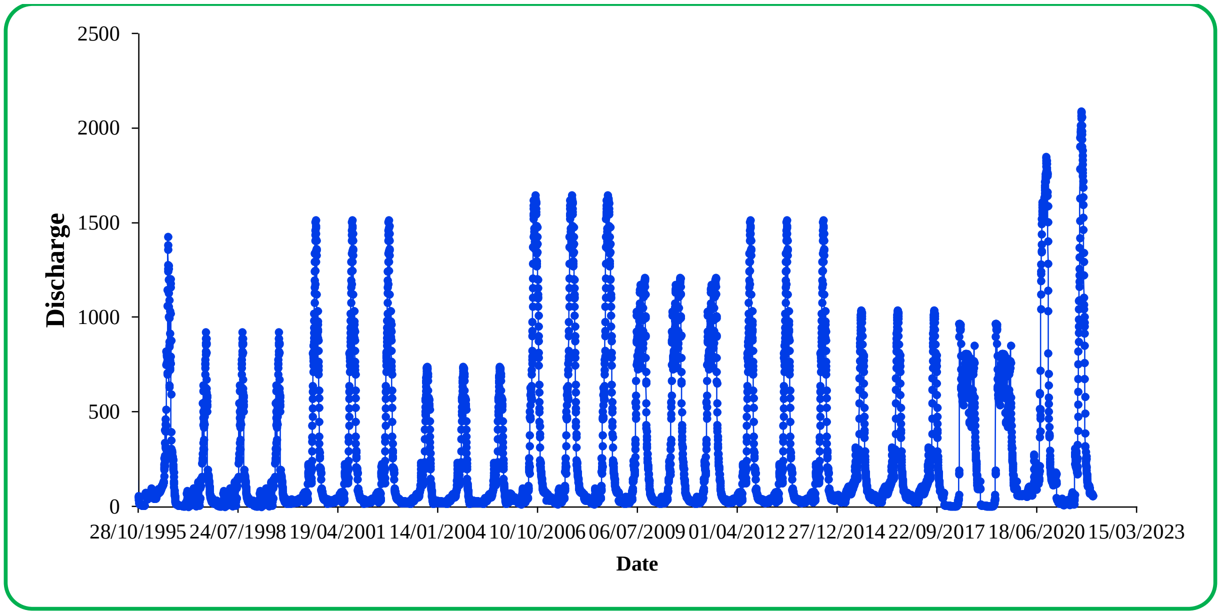


Figure 17: Trends in annual flow

4.1.1. Mann Kendal Trend Test Interpretation

The Mann Kendal test is a nonparametric test that is distribution free and able to detect the trend in hydrologic time series data. It is less influenced by outliers in a dataset and able to detect the trend in a dataset that are not normally distributed. It is test is constructed on two hypotheses;

Null Hypothesis (H_0) = There is no trends in the series

Alternative Hypothesis (H_a) = There is a trend in the series.

The Null Hypothesis is rejected when the calculated (p) value is greater than the Alpha value of 0.05. From the analysis, the overall computed value (p) is lower than the significance level alpha = 0.05 which supports the alternative hypothesis (Ha) that there is trend in the river discharge in the White Volta River over the study period. The graphical presentation of the trend and the magnitude provided by the Sen's Slope have indicated an increasing trend in rainy season flows and a decreasing trend in total annual flows, as shown in and Figure 17.

4.1.2. Future Forecast of Annual Flow Distribution

The flow trends were forecasted to the next decade (10 years) from the last year (2021) of study period as shown in Table 13. As show in Figure 18 and 19, the forecasted discharge graph helps to forecast future flows of the White Volta River.

Table 13: Future Forecast of Annual Flow Distribution

Year	Lower Confidence Bound	Upper Confidence Bound
2021	446.84	446.84
2022	354.89	534.35
2023	330.90	572.47
2024	313.35	604.14
2025	299.36	632.26
2026	287.71	658.04
2027	277.75	682.12
2028	269.08	704.92
2029	261.44	726.68
2030	254.64	747.60
2031	248.56	767.81
2032	243.08	787.41
2033	238.14	806.49
2034	233.65	825.10
2035	229.57	843.30
2036	225.87	861.13

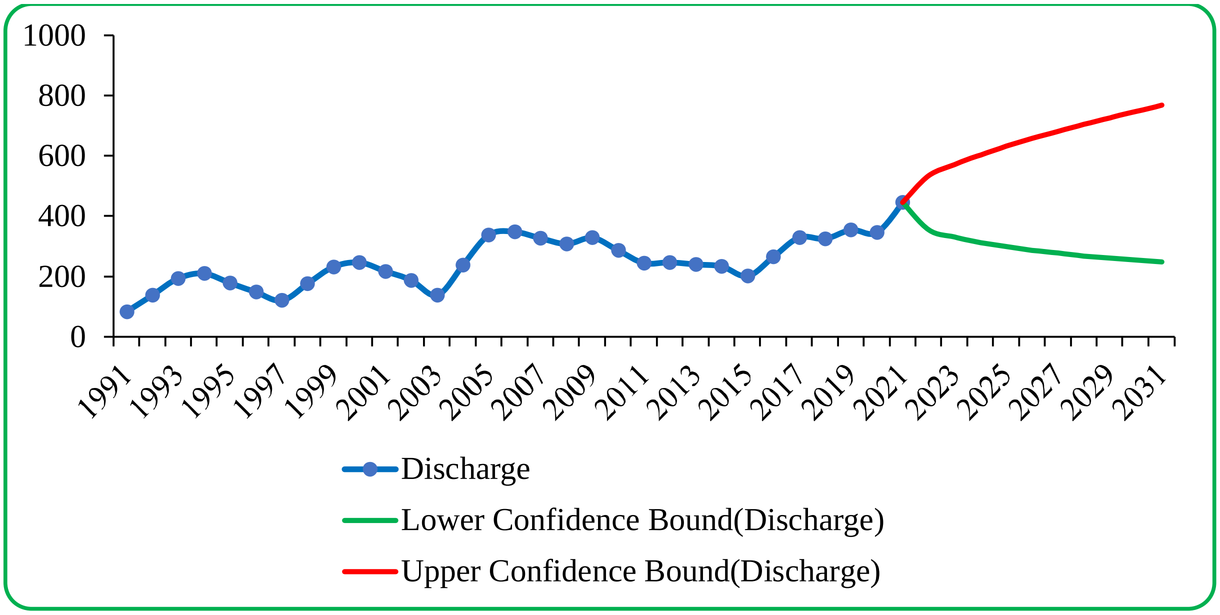


Figure 18: Future Forecast of Annual Flow Distribution (2021 – 2031)

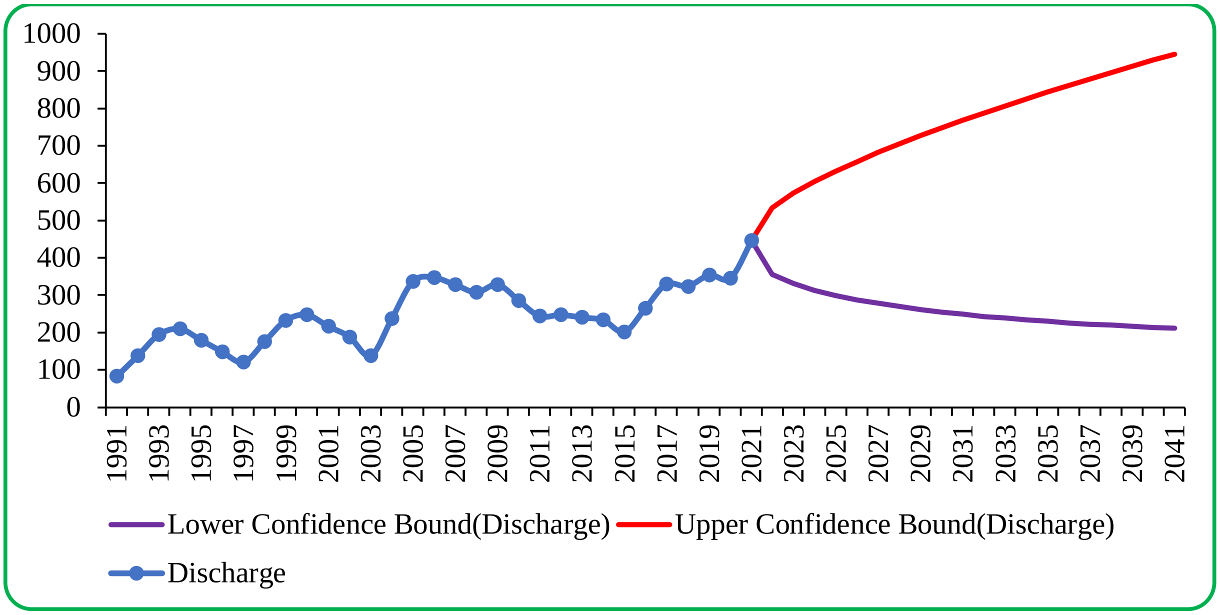


Figure 19: Future Forecast of Annual Flow Distribution (2021 – 2041)

4.2.Applications of Streamflow Characteristics and Flow Distribution

The curve about seasonal distribution of flows as shown in Figure 14 will help in quantifying the amount of water required for irrigation water required during the dry season.

The forecasted flows as shown in 18 and 19 will help policy makers to set specifications and illustrate the field management practices to be undertaken by farmers. This helps to sustain water for downstream users and other ecosystems. Future forecast of the streamflow will help stakeholders in developing long-term water resource management plans for the basin.

Additionally, flow distribution curves provide an outline of how irrigation can be scheduled, the procedures on how water should be conveyed to the field and from which sources should the irrigation water be abstracted. Irrigation scheduling is helpful in saving costs of operations on irrigation schemes as well reducing overall irrigation water consumption.

Streamflow characteristics as indicated in Figure 16 helps in identifying peak flows during the rainy season, a component of the stream that is critical in managements of floods in a river basin. This has been well presented in section 4.5 of this work. The annual flow distribution as indicated in Figure 17 helps in calculation of historical droughts, that are key in predicting future drought events. This has been well presented in section 4.4 of this work.

The calculated streamflow curve and flow characteristics will also be used in characterizing and assessing in-stream circumstances, water habitation assessments, in-stream flow supplies and recreations. The analysis was required to determine the amount and timing of streamflow to assess habitats and to develop in-stream flow requirements for agriculture, more especially flood-based irrigation systems that are common the White Volta basin. This was as well reported by (Dittoh, 2020) and (Mohammed *et al.*, 2013).

4.3.Analysis of Factors that Affect River Flow

4.3.1. Rainfall and Other Climatic Conditions

The analysis of streamflow data and rainfall data showed a direct relationship between the two parameters in the White Volta River. The months of July, August and September recorded the highest average rainfall of 188.80 mm, 184.70 mm and 188.30 mm respectively. These are the same months that the three selected hydrological stations on the White Volta River recorded higher discharge values on average basis. The average discharge recorded during these months are 296.76 m^3/s, 738.5 m^3/s and 941.23 m^3/s respectively. The driest months were from November to April, where the White Volta River basin experiences few or no (0) rains. During the study period, the discharge during these dry season months were 58.50 m^3/s, 33.06 m^3/s, 32.04 m^3/s, 30.08 m^3/s and 34.41 m^3/s in December, January, February, March and April respectively. The White Volta River have its low flows recorded during this time of the year. Throughout the White Volta River basin, the year 2016 recorded the highest total rainfall of 1128.3 mm whereas 2006 recorded the lowest with a total of 817.3 mm. The relationship of rainfall and streamflow in the basin agrees with a similar work by Kasei *et al*., (2013).

Pwalugu hydrological station which is located in the northern part of Ghana of recorded the lowest average discharge over the study period. On annual basis, it recorded an average maximum discharge of 538.69 m^3/s in the rainy season month of August and minimum average of 27.5 m^3/s in the dry season month of January. The annual overall average discharge for Pwalugu hydrological station during the study period was 135.74 m^3/s. Nawuni hydrological station recorded an average maximum discharge of 1271.76 m^3/s in during the rainy season month of September and minimum average of 30.33 m^3/s in the dry season month of March. The annual overall average discharge for Nawuni station during the study period was 327.82 m^3/s.

Daboya hydrological station recorded an average maximum discharge of 1088.39 m^3/s in September and minimum average of 27.6 m^3/s in February. The annual overall average discharge for Daboya station during the study period was 263.66 m^3/s. Table 14 and 15 summarize monthly and yearly rainfall records where has Table 16 summarizes temperature and humidity. The relationship between discharge in the White Volta River and rainfall in the White Volta River basin on seasonal basis and over the study period has been presented in the Figures 20 and 23.

Table 14: Mean Monthly Distribution of Rainfall - mm (1991 - 2021)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Navrongo Metrological Station												
1	4	15	55	100	132	189	278	165	74	8	2	1023.0
Tamale Metrological Station												
0	4.3	12.2	70.8	92.2	163.5	188.8	184.7	188.3	83.2	4.5	10.9	1003.4

Table 15: Annual Distribution of Rainfall - mm (1991 - 2021)

1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
886.9	1456.7	745.2	922.7	1155.1	1021.9	1044.1	846.7	1889.2	1065.3
2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
844.5	836.7	922.7	1033.5	769.5	817.4	1031.9	1307.1	1357.6	1332.8
2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1076.7	1030.3	1079.0	1002.5	1013.2	1123.6	877.3	1057.0	998.0	1418.3

Table 16: Mean Monthly Temperature, Humidity and Sunshine (1991 – 2021)

Month	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
T_{Max} (^{0}C)	30	31	31	31	30	28	27	26	27	28	30	29
T_{Min} (^{0}C)	24	26	26	26	25	25	23	23	23	24	24	24
Humidity (%)	79	77	77	80	82	85	85	83	82	83	80	79
Sunshine Hours	214	204	223	213	211	144	142	155	171	220	240	235

Figure 18 summarizes rainfall during peak precipitation. The relationship between discharge in the White Volta River and temperature and relative humidity in its basin on seasonal basis and over the study period has been presented in the Figures 21 and 22.

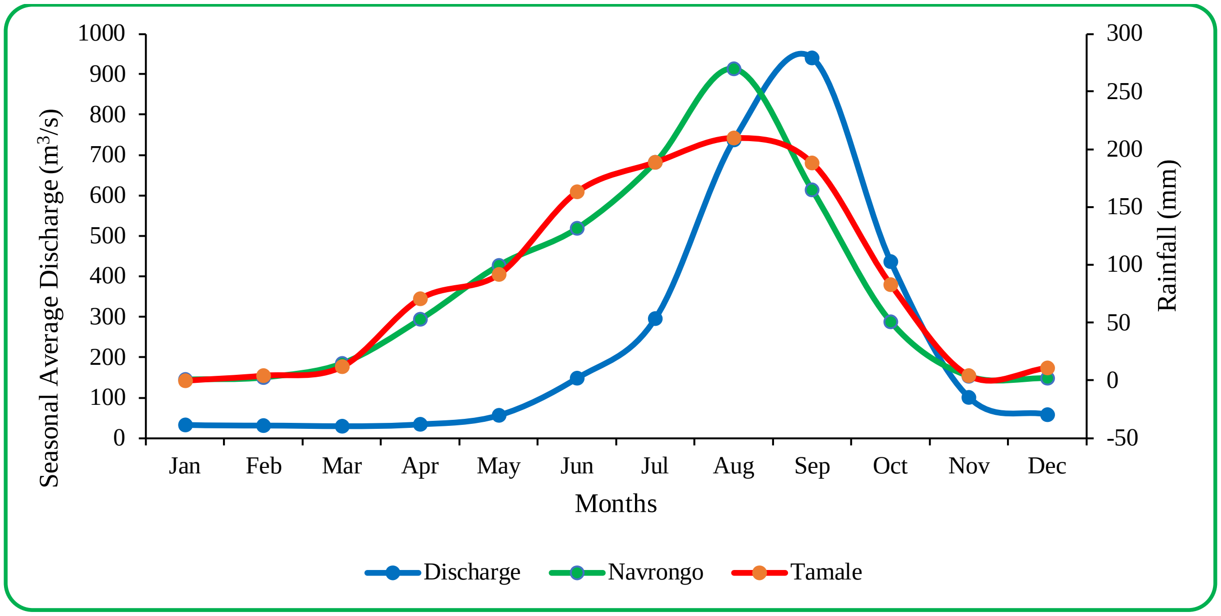


Figure 20: Monthly Average Discharge Response to Rainfall from Navrongo and Tamale Metrological Stations

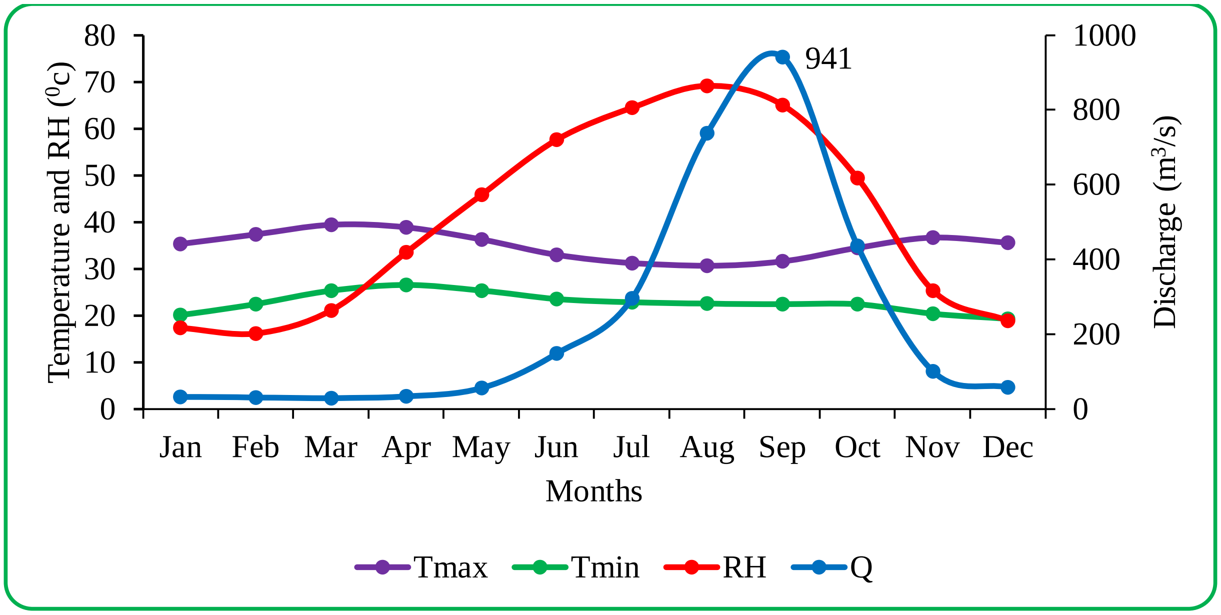


Figure 21: Monthly Average Discharge (Q) Response to Maximum (TMax) and Minimum (TMin) Temperature and Relative Humidity (RH).

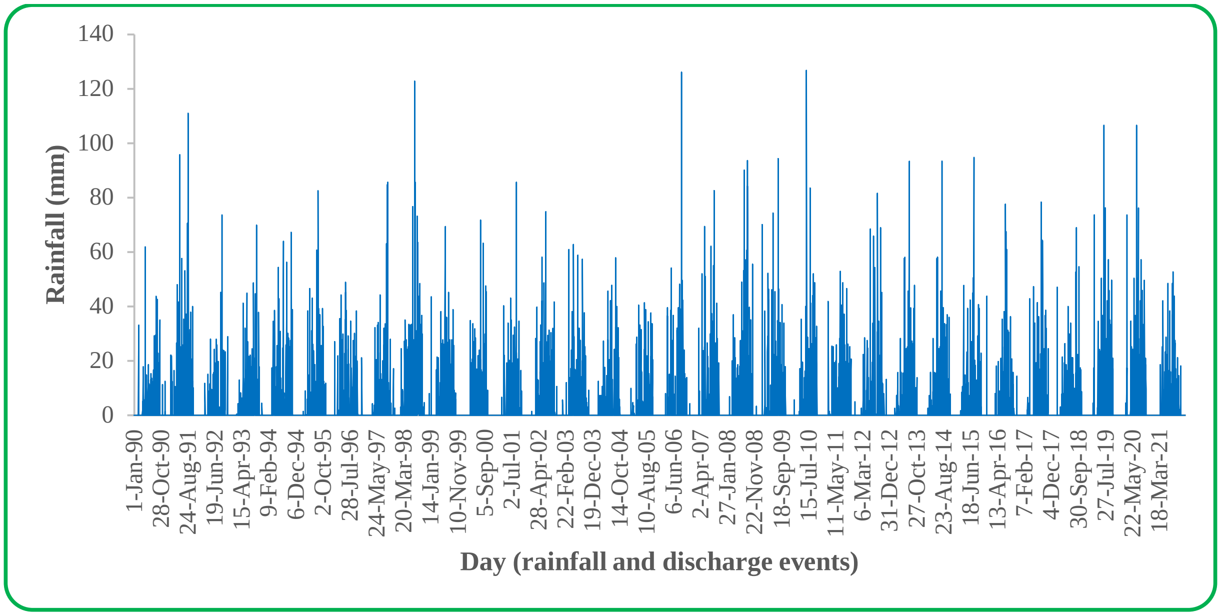


Figure 22: Rainfall Distribution over the study period

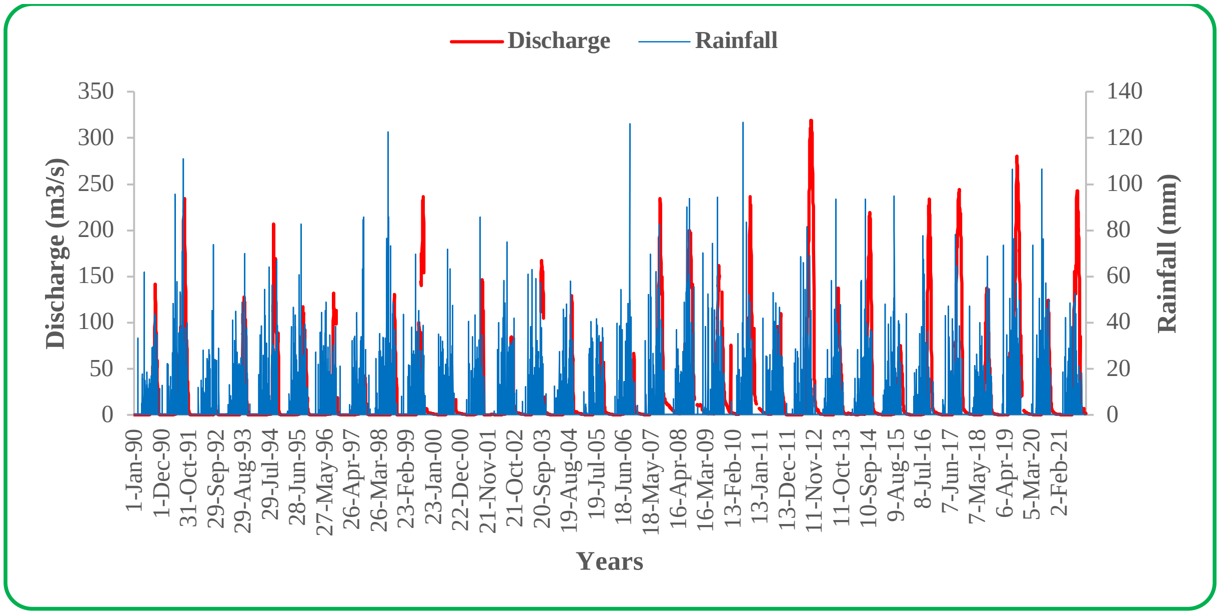


Figure 23: Daily Average Discharge Response to Daily Rainfall (1991 – 2021)

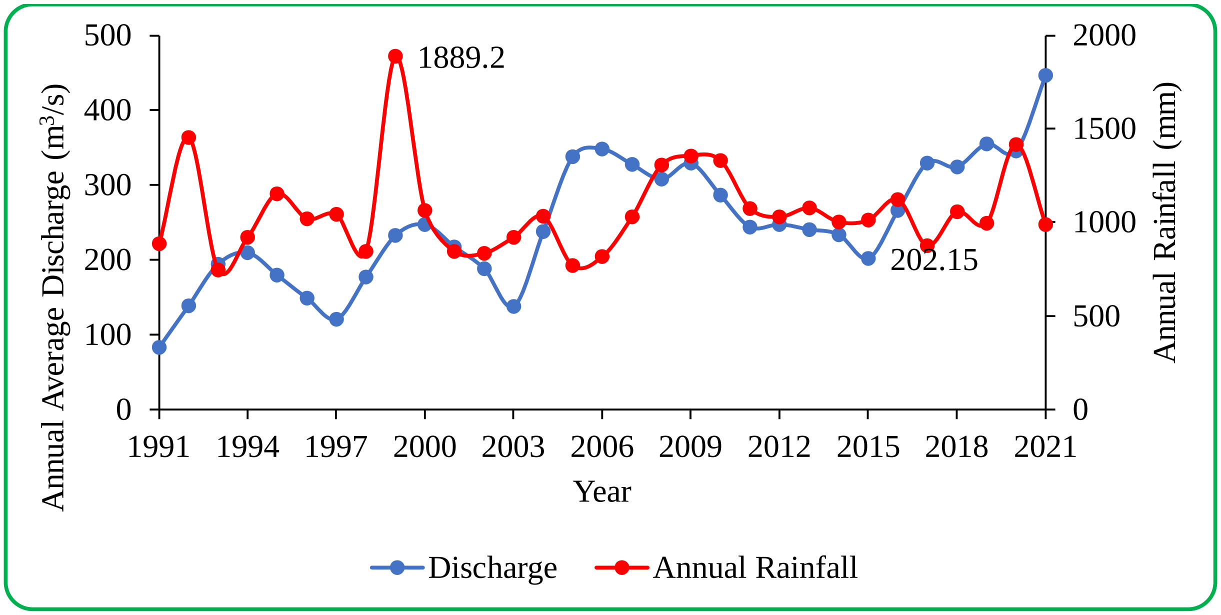


Figure 24: Mean Annual Discharge Response to Mean Annual Rainfall (1991 – 2021)

4.3.2. Changes in Land Use and Land Cover

In this work, land use and land cover changes were analysed using the data captured between 1990 and 2020 using Digital Elevation Model (DEM). The total calculated area of the White Volta River basin which has been used in this work is 107, 000 km². Soil type and its distribution was worked out from soil maps using GIS and there are various soil types ranging from savannah ochrosols to sandy coastal soils as presented in Table 17 and Figure 25.

The main geological formations are the rocks ranging from volcanic, sedimentary, granites as well as metamorphic rocks.

Table 17: Distribution of Soil Types

Soil Type	Area Within the Basin (Km^2)	Area Expressed in Percentage
Luvisols	54	50.5
Regosols	18	16.8
Vertisol	08	7.5
Lithosols	15	14.0
Gleysol	04	3.7
Plinthosol	03	2.8
Acrisol	02	1.9
Cambisol	03	2.8

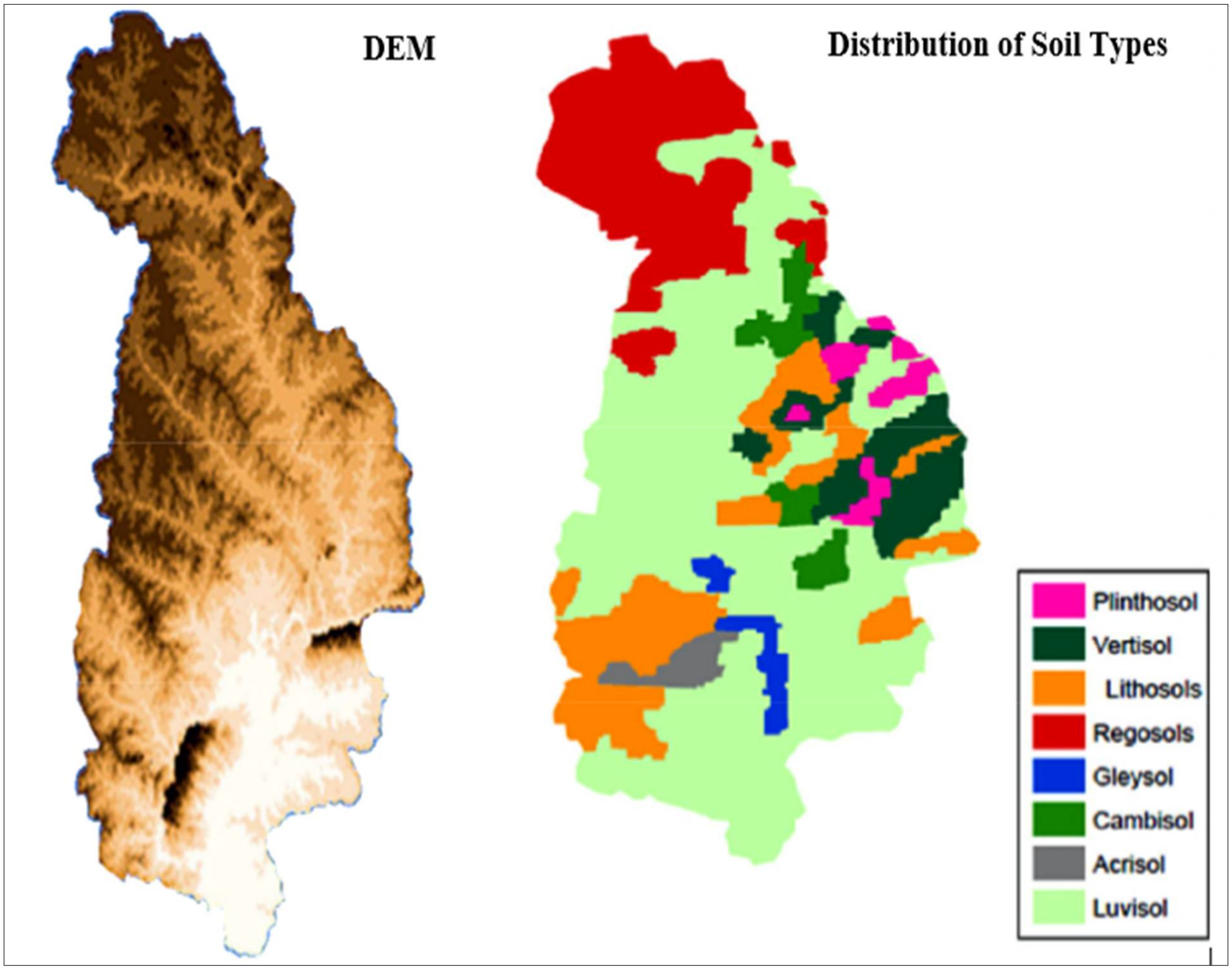


Figure 25: The Digital Elevation Model (DEM) and the Soil map of White Volta Basin (Source; NOAA-AVHRR, GIS)

Using the Digital Elevation Model, the classes of land use and land cover changes were assessed starting from the year 1991 to the year 2021 to see the how land use and land cover has changed through the study period. During the analysis, focus was made on human settlement, agricultural land, savannah vegetation, grasslands and bare lands as illustrated in Figure 26. Besides agricultural land, vegetation is the predominant feature in the basin and it comprises of savannah vegetation and grassland. The current average coverage of each land use class in the basin has been summarized in Table 18.

Table 18: Land use and land coverage in the White Volta basin

Land Cover	**Area (km^2)**	**Percentage Area (%)**
Cropland	72, 000	67.2
Grassland	7, 000	6.5
Savannah	23, 000	21.5
Urban	5, 000	4.8
Total	107, 000	100

There has been changes in land use and land cover between 1990 and 2021 evidenced by the decrease in savannah and grassland and the increase in agricultural land and human settlement. Agricultural land has increased by 56.5%, with a decrease in savannah vegetation and grassland to 46.5% and 56.25%, respectively.

Analysis of the hydrological flow data of the White Volta River collected from Pwalugu, Nawuni and Daboya and climatic data from Navrongo and Tamale stations from 1991 to 2021 indicates that as land cover changes from 1990 to 2021, there has been an increase in flow of high magnitudes in the rainy season and a drastic decrease in the dry season with a general decrease in total annual flow.

The general decrease in dry season flow and total annual flow is attributed to the reduction of grassland and savannah vegetation that is responsible for reduction in water loss through surface runoff and water retention. This general decrease in total annual flow could lead to future water shortages during the dry season, putting dry season irrigation under threat within the basin. Changes in land use and land cover over the same basin are as well in line with a similar study by Awotwi *et al*., (2015) who assessed the same on water balance components.

Analysis further indicates that more land is converted to arable land in the catchment in the White Volta River, projecting potential future water problems. The general increase of flow in the river during the rainy season increases the frequency of floods which damages life and property.

Change in water flow characteristics in the river can easily be linked to the outcome of land use and land cover changes, which are exacerbated by various anthropological activities such as crop and animal production, settlement and expansion of industries, which are all dominant in the basin. As indicated in Table 19 and in Figure 25, the savanna vegetation and coverage by grassland decreased by 20 and 9 km^2, respectively, and cropland increased by 26 km^2.

Table 19: Land use and land cover trends from 1991 to 2021 (Km^2)

Land Cover	**1991 – 1999**	**2000 - 2009**	**2010 - 2020**	**% Change**
Cropland	46, 000	66, 000	72, 000	56.5
Savannah	43, 000	30, 000	23, 000	-46.5
Grassland	16, 000	9, 000	7, 000	-56.25
Urban	1, 900	2, 100	5, 000	163
Total	107, 000	107, 000	107, 000	

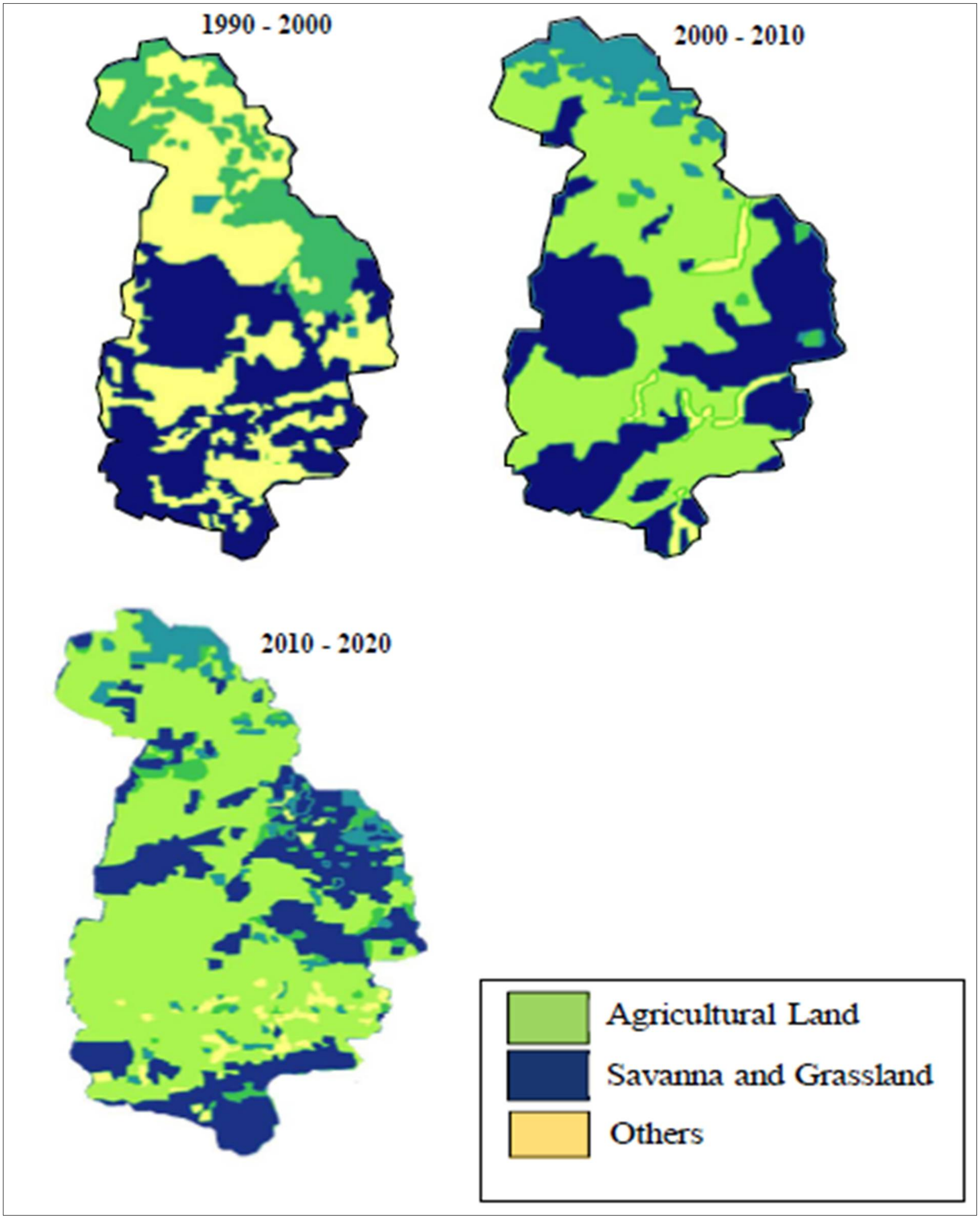


Figure 26: Land use and land cover trends from 1990 to 2021

(Source; NOAA-AVHRR and GIS)

4.4. Analysis of Hydrological Droughts for Irrigation Water Management,

4.4.1. Standardized Precipitation Index, Streamflow Drought Index (SDI) and The Agricultural Reference Index (ARID)

Monthly datasets of precipitation, streamflow and temperature were prepared form daily datasets from which the SPI, SDI and ARID were calculated as shown in Figure 28. In the White Volta basin, dry season runs between November and April, during which streamflow volume in most streams in the basin decreases. Analysis shows that droughts are common during this time of the year, and Figure 27 provides a summary of the various categories of droughts that have happened between 1991 and 2021. Using the indices as provided, the analysis has identified the most severe and extreme drought years over the river basin. Figure 28 shows the response of ARID to SDI and SPI.

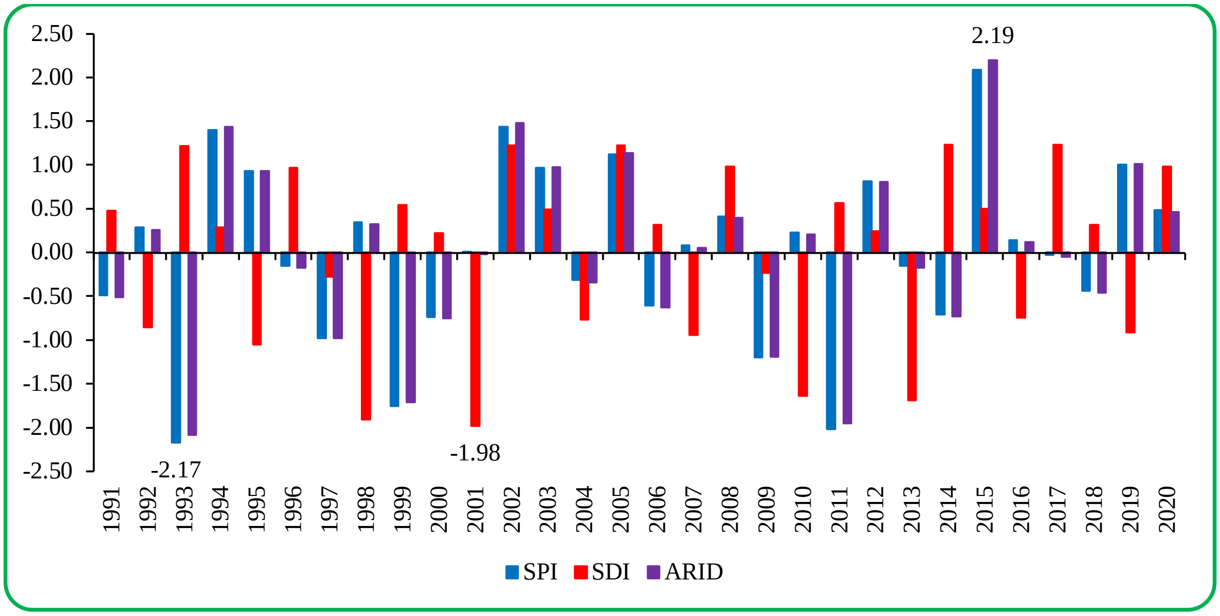


Figure 27: The Standardized Precipitation Index, Streamflow Drought Index and The Agricultural Reference Index.

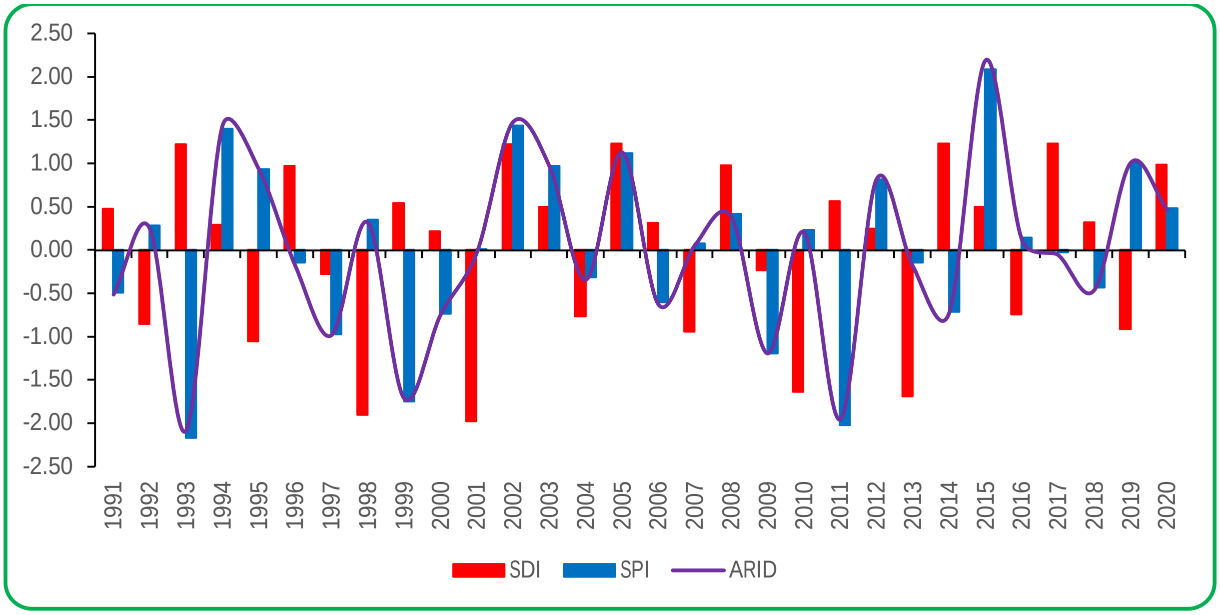


Figure 28: The Response of ARID to SPI and SDI.

4.4.2. The Reconnaissance Drought Index (RDI)

The RDI has calculated a simplified water balance scenario using precipitation and potential evapotranspiration data from the basin. The initial value, the normalized value, and the standardized value have been presented in the Figure 29.

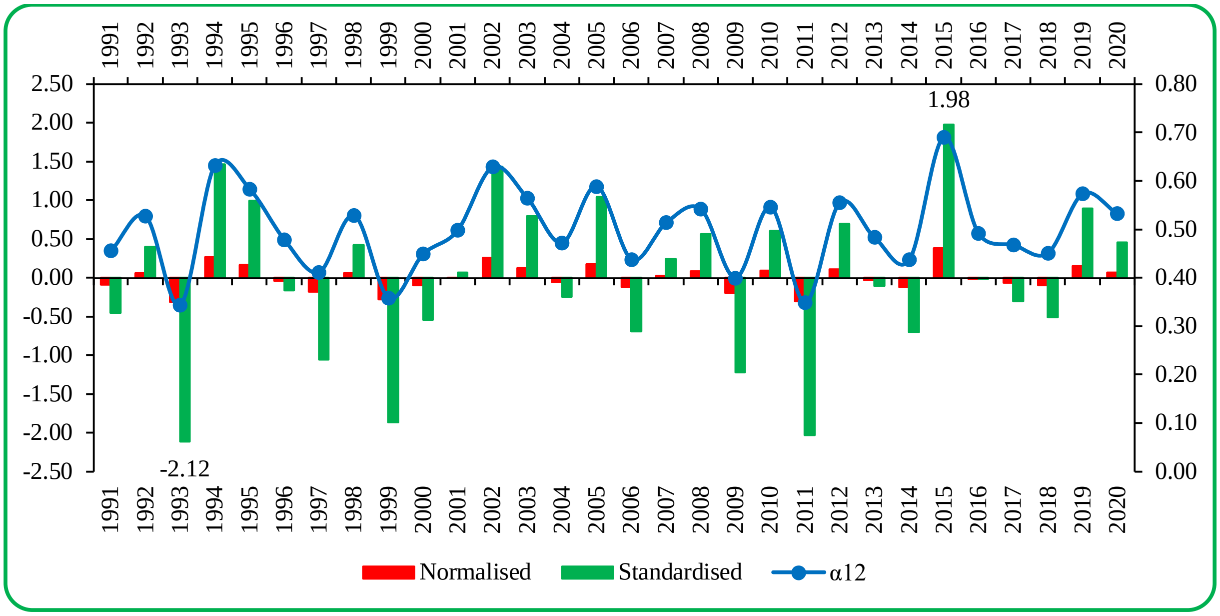


Figure 29: Reconnaissance Drought Index (RDI)

4.4.3. Future Forecast of the Streamflow Drought Index (SDI)

The streamflow records were forecasted from the last year of dataset to a further ten years, to see the streamflow trend in the river. As presented in Figure 30, the SID curve has shown future streamflow scenarios, which are critical in planning for dry season water management in the White Volta River basin. Figure 30 has also presented the years where streamflow is expected to increase, a scenario which is critical in flood prediction.

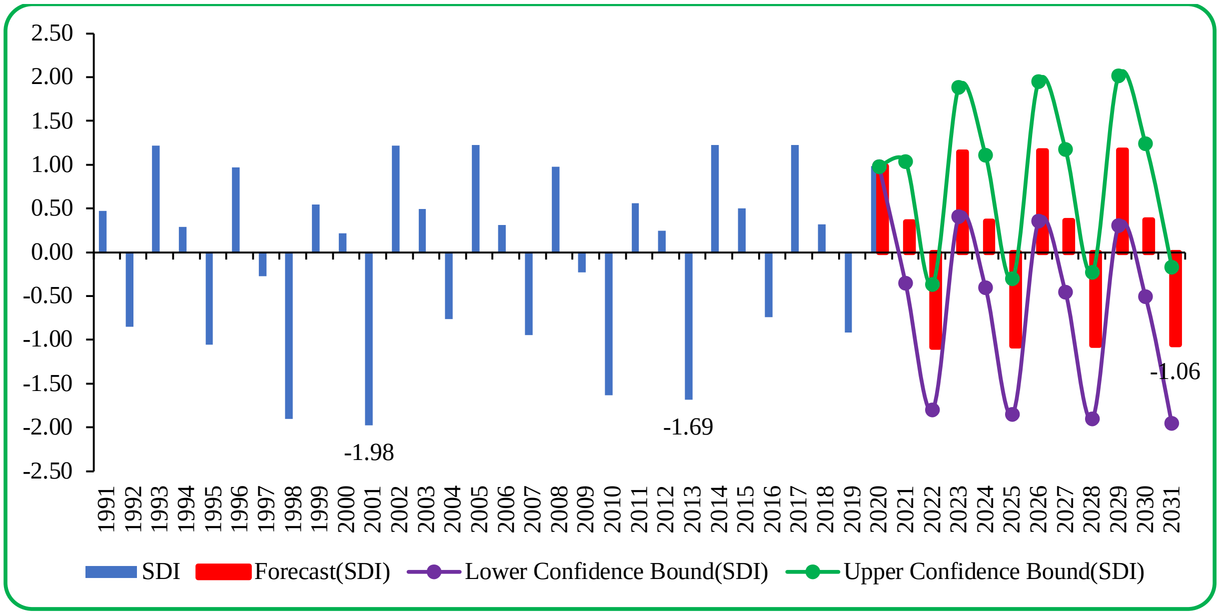


Figure 30: Forecast of the Streamflow Drought Index (SDI)

4.5.Flood Frequency Analysis,

This technique is appropriate for forecasting flood recurrence interval and the analysis provides the probability to the yearly extreme floods which are documented for a duration of thirty (30) between 1991 and 2021. There are other different types of approaches for flood frequency analysis including calculating the return period and flood recurrence interval and this in this work, the Gumbel's method has been used for the same.

4.5.1. Gumbel’s Method

Through this method, the list of annual floods for each year were organized in the descending order and the ranks (m) were allocated to each flood from the uppermost value. Bearing in mind the values, the recurrence interval and probability positions were calculated. The calculated mean value was 519.64, squared mean was 269921.81, mean of squares was 1259.86, and standard deviation was 314.72. Using standard deviation and frequency factors, the expected amounts of floods discharge were then calculated. Table 21 gives the recurrence interval; Table 22 gives the probability positions and Table 23 gives return periods.

From the same analysis, the flood of over 2000 m^3/s have less than 10% chances of occurrence and floods with average of 300 m^3/s and below have over 80% chances of occurrence in the next 20 years from 2021. Specifically, a flood of 2500 m^3/s has the likelihood of happening only once in the next 100 years form 2021 in the White Volta River.

Table 20: Recurrence Intervals for Gumbel's Method

Year	Peak Discharge	Rank	Sorted Discharge	Gumbel's Method
1991	522.57	1	2086.95	107.14
1992	924.97	2	1848.96	23.44
1993	1327.38	3	1644.25	13.16
1994	1425.19	4	1547.74	9.15
1995	1229.56	5	1525.71	7.01
1996	1033.93	6	1514.37	5.68
1997	921.46	7	1514.37	4.78
1998	1146.4	8	1451.23	4.12
1999	1371.35	9	1425.19	3.62
2000	1514.37	10	1408.31	3.23
2001	1228.32	11	1371.35	2.92
2002	942.27	12	1327.38	2.66
2003	740.45	13	1308.24	2.44
2004	1144.1	14	1302.24	2.26
2005	1547.74	15	1258.21	2.10
2006	1644.25	16	1245.09	1.96
2007	1451.23	17	1229.56	1.84
2008	1258.21	18	1228.32	1.74
2009	1208.18	19	1208.18	1.64
2010	1308.24	20	1146.40	1.56
2011	1408.31	21	1144.10	1.48
2012	1514.37	22	1140.77	1.41
2013	1302.24	23	1090.11	1.35
2014	1090.11	24	1038.45	1.29
2015	1038.45	25	1033.93	1.24
2016	1140.77	26	964.47	1.19
2017	1245.09	27	942.27	1.14
2018	964.47	28	924.97	1.10
2019	1525.71	29	921.46	1.06
2020	2086.95	30	740.45	1.02
2021	1848.96	31	522.57	0.99

Table 21: Calculation of Probability Positions

Rank (m)	**Sorted Discharge**	**Plotting** **[T = $\frac{N+1}{m}$]**	**Probability Position** **[Q = $\frac{m}{N+1}$]**	**Q^2**
1	2086.95	31.00	3.23	4355360.30
2	1848.96	15.50	6.45	3418653.08
3	1644.25	10.33	9.68	2703558.06
4	1547.74	7.75	12.90	2395499.11
5	1525.71	6.20	16.13	2327791.00
6	1514.37	5.17	19.35	2293316.50
7	1514.37	4.43	22.58	2293316.50
8	1451.23	3.88	25.81	2106068.51
9	1425.19	3.44	29.03	2031166.54
10	1408.31	3.10	32.26	1983337.06
11	1371.35	2.82	35.48	1880600.82
12	1327.38	2.58	38.71	1761937.66
13	1308.24	2.38	41.94	1711491.90
14	1302.24	2.21	45.16	1695829.02
15	1258.21	2.07	48.39	1583092.40
16	1245.09	1.94	51.61	1550249.11
17	1229.56	1.82	54.84	1511817.79
18	1228.32	1.72	58.06	1508770.02
19	1208.18	1.63	61.29	1459698.91
20	1146.40	1.55	64.52	1314232.96
21	1144.10	1.48	67.74	1308964.81
22	1140.77	1.41	70.97	1301356.19
23	1090.11	1.35	74.19	1188339.81
24	1038.45	1.29	77.42	1078378.40
25	1033.93	1.24	80.65	1069011.24
26	964.47	1.19	83.87	930202.38
27	942.27	1.15	87.10	887872.75
28	924.97	1.11	90.32	855569.50
29	921.46	1.07	93.55	849088.53
30	740.45	1.03	96.77	548266.20
31	522.57	1.00	100.00	273079.40

Table 22: Expected Discharge and their Various Return Periods

Return Period, T (Years)	Mean (ϙ̄)	Standard Deviation (S)	Frequency Factor (K)	K * S	Expected Discharge (X) X = ϙ̄ + K * S
5	1259.86	314.72	0.87	272.66	1532.52
10	1259.86	314.72	1.54	484.97	1744.83
20	1259.86	314.72	2.19	688.62	1948.48
50	1259.86	314.72	3.03	952.23	2212.08
100	1259.86	314.72	3.65	1149.76	2409.62
150	1259.86	314.72	4.02	1264.95	2524.81

4.5.2. Gumbel's Probability Curve

This is the curve of expected stream flow versus recurrence intervals plotted from the results obtained from flood frequency analysis using the Gumbel's method. It is plotted on a log probability paper and a smooth curve is fitted covering all points from where extreme future values could be extrapolated. It is fitted such that any flood or stream peak flow has its corresponding return year which could be easily read from the x – axis (series) of the graph. In this way, future occurrence could be predicted, and proper warnings be placed in advance. The Gumbel's probability curve has a trend line is with a R^2 regression of 0.85. From a sample of the five given return periods (x – values) in years of 5, 10, 20, 50, 100 and their corresponding discharge (y – values) of 1532.52, 1744.82, 22, 1948.47, 2212.08 and 2409.62 (m^3/s) respectively, a logarithmic equation has been developed that can be used to calculate the return period given the observed discharge. The equation is;

$$Y = 290.83 \ln X + 1072 \quad \text{Eqn 8}$$

Equation 12: Log Equation for Return Period Calculation

Where ln is the natural logarithm, X is the return period and Y is the corresponding discharge

For example, to calculate the return period of a discharge of 2115.58 m3/s, the procedure is; 2115.58 = 1290 ln(X) + 1072; which gives X (Return period) of 61 years. This value can as well be easily extrapolated from the Gumbel's curve as provided in the Figure 31 and 32. The linear regression that supports the plotting of flood prediction curve using Gumbel's method has been calculated and represented as shown in Figure 33.

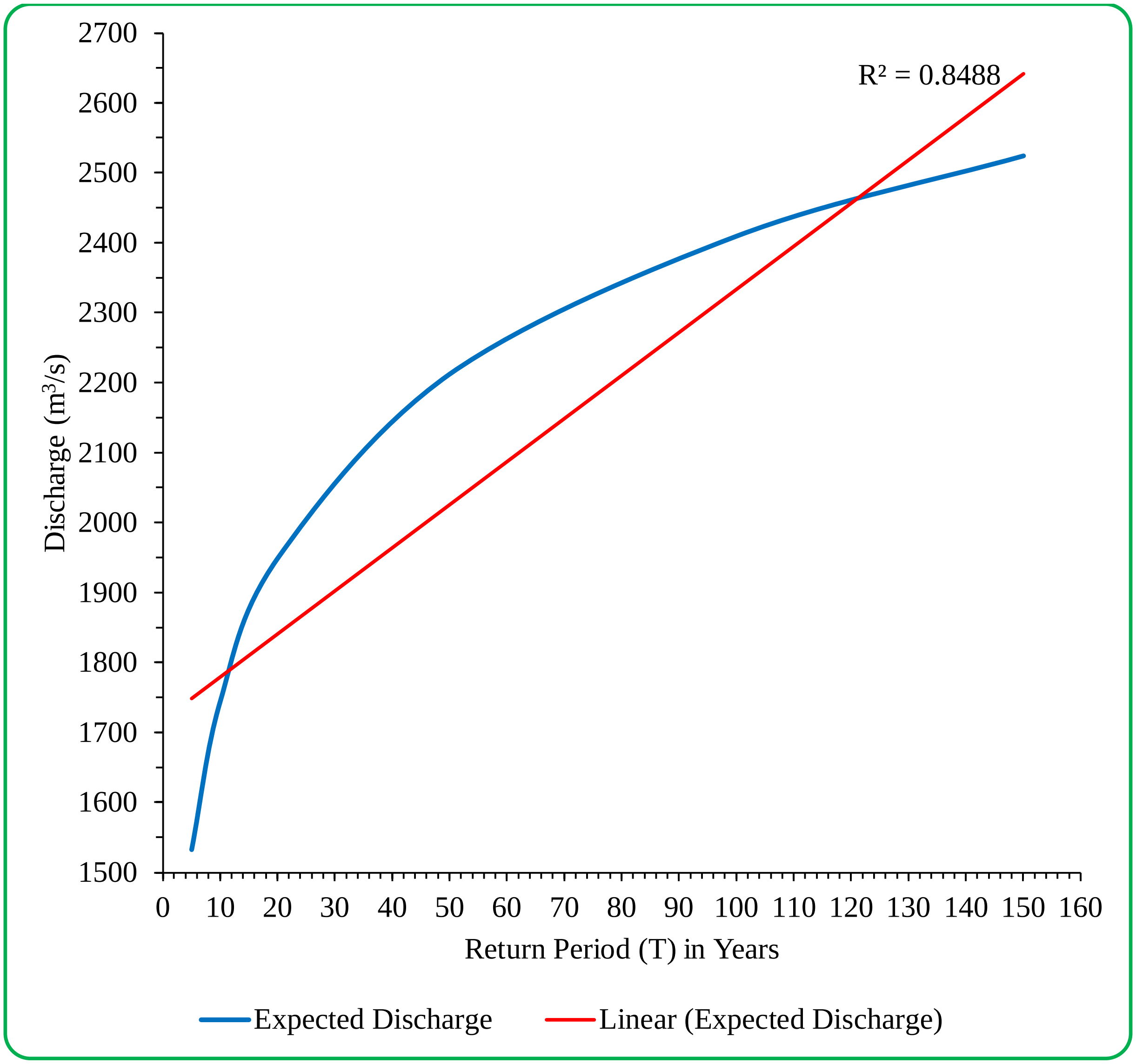


Figure 31: Gumbel's Probability Curve

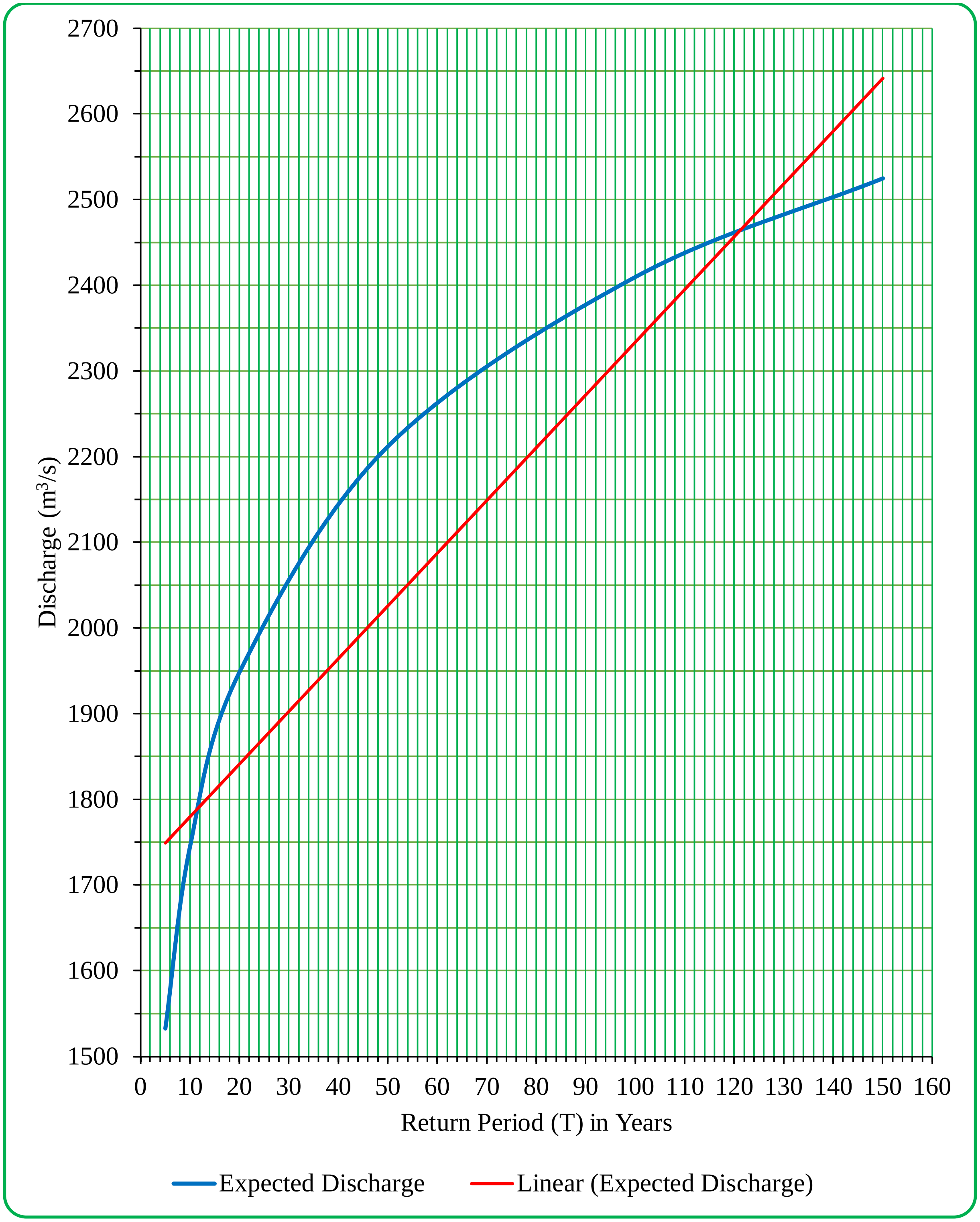


Figure 32: Gumbel’s Curve.

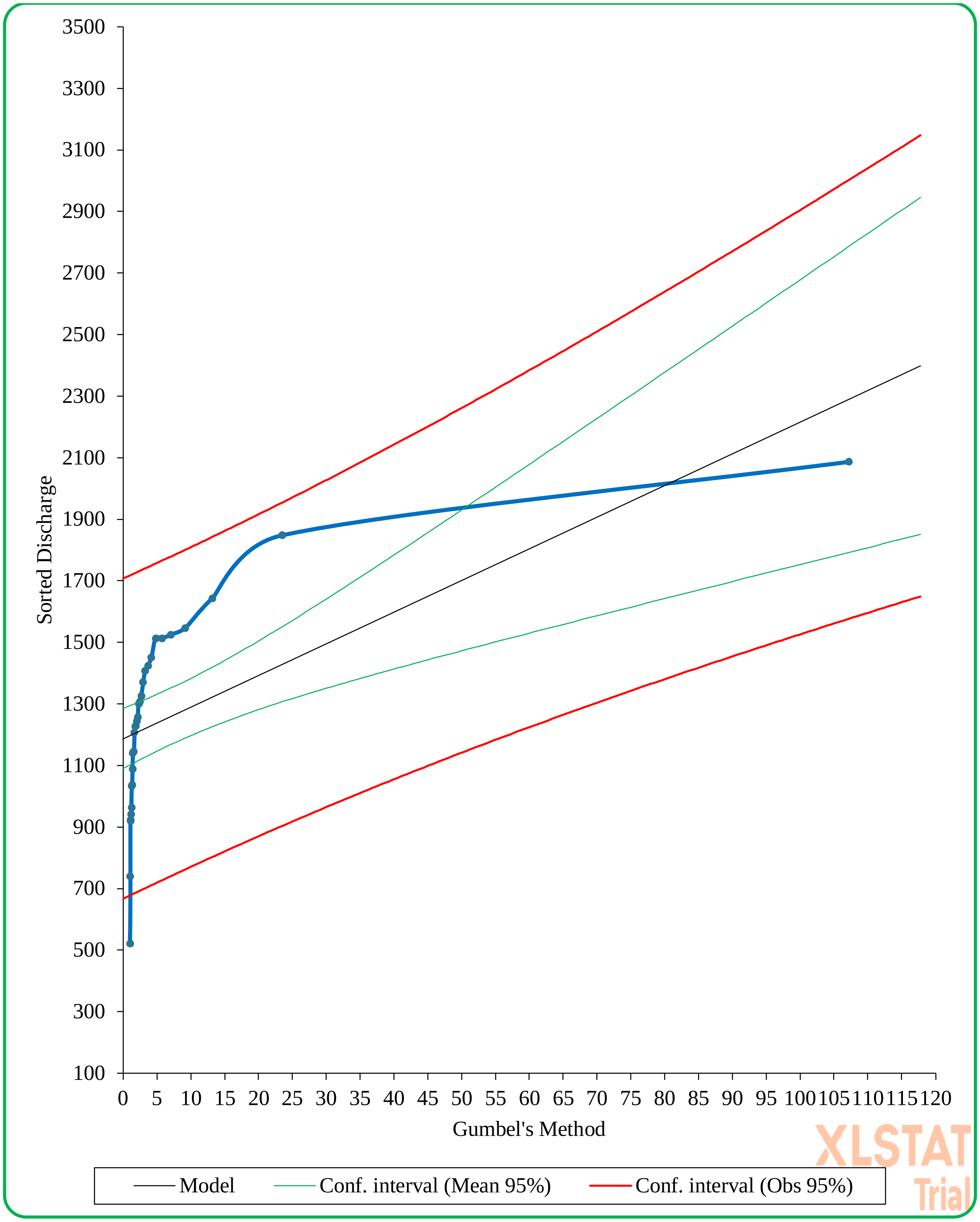


Figure 33: Regression of Sorted Discharge by Gumbel's Method

CHAPTER FIVE

CONCLUSIONS

Analysis showed that high magnitude discharges in the river has low probability of exceedance than those of low magnitudes. For example, a discharge of 2052.5 m^3/s has 5% probability of exceedance in the preceding year whereas a discharge of 20 m^3/s has 80% probability of exceedance. The Mann Kendall variability test shows that there is a decrease in the total discharge in the White Volta River. This trend agrees with a study by Dakpalah *et al*., (2018) who analysed water trends for irrigation development in Upper West Region of Ghana and Abdul-Ganiyu *et al*., (2011) who analysed hydrological parameters in its sub basin.

Rainfall, changes in land use and land cover and growth of irrigation farming are the main factors that affects the flow of the river. Over the study period, agricultural land expanded by 47.8% and savannah and grassland decreased by 30.2 and 56.2%, respectively. Analysis shows increase in surface runoff during the rainy season, which is attributed to decrease in vegetative cover in the basin. This agrees to a similar study by Awotwi *et al*., (2015) and Kasei *et al*., (2013).

Hydrological droughts have also been common in the basin, which has affected planning of irrigation season in the basin. Irrigation agriculture is expanding in the region, agreeing with the study by Dittoh, (2020)and Namara *et al*., (2011). This includes flood-based irrigation farming.

Finally, there is an increase in floods in the river and this work has calculated the value for the future forecasting of flood that might happen in the river. According to the analysis, a flood of 1644.25 m^3/s that happened in 2006 has a return period of 20 years, and, a flood of over 2086.95 m^3/s that happened in 2020 has a return period of 50 years and more. Increase in flood scenarios were also reported by Atubiga *et al*., (2023).

CHAPTER SIX

RECOMMENDATIONS

This research recommends re - afforesting bare lands, reduced farming practices in streambanks and proper drainage in cities might help in balancing the hydrological cycle that is key in flow of rivers. The research work further recommends on proper planning for dry season agriculture, following the calculated hydrological droughts to prevent future water shortages. Dams should also be constructed in the basin, to accommodate excess flows during the rainy season. This will prevent floods that destroy lives and property.

There are several key drivers to change in flow regimes and this study therefore recommends further research on all the factors that affect the flow in the White Volta River so as to come up with proper procedures on the activities in the river so as to accommodate future flows. People that are living in flood prone areas should as well be sensitized on how to cope with the increasing flows of the White Volta River so as to stay safe from flood events.

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