UNIVERSITY OF CAPE COAST

HYDROLOGICAL RESPONSE OF OTI RIVER TO CLIMATE AND LAND USE LAND COVER (LULC) DYNAMICS, GHANA.

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By

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DECLARATION

Candidate's Declaration

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

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

Name: Nathaniel Lewuyagane

Supervisors' Declaration

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

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

Prof. Benjamin Kofi Nyarko

ABSTRACT

Climate and LULC dynamics are the main factors impacting the life of water bodies, especially rivers. As a result, numerous studies are turning to issues revolving climate, LULC, and water supply. This thesis did a 30-year investigation into the hydrological response of Oti River to climate and LULC dynamics, Ghana. Specifically, the study evaluated the trends of change in the Oti River basin as a result of climate and LULC dynamics between 1990-2020 using the Mann-Kendall test tool and ArcGIS respectively. The SWAT model further examined the combined impact of Climate and LULC dynamics on inflows and outflows. Results from the Mann-Kendall test indicates that, annual temperature has consistently been high over the years. A computed p value of 0.106, signifies that, there are no significant trends in temperature, however, there is a rise in general annual temperatures in the area leading to increased evaporation rates in the river, more inflows and less outflows. The computed p-values (0.388, 0.320) for the two weather stations indicated that there are no significant trends in rainfall but rainfall is generally decreasing in the Oti Catchment. Results from the change detection analysis indicated that, farmlands, water and the closed forest are being lost to open forest, built-up and bare lands. Due to the recent bareness of the lands, runoffs during rainstorms are made easier and there has been significant sedimentation. The Oti River's inflows and outflows are subsequently impacted by this. The SWAT model's calibration and validation confirms this by showing a good correlation between the simulated and actual flows.

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DEDICATION

To my family and Love ones

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CHAPTER ONE

INTRODUCTION

Background to the Study

The provision of water for both domestic and industrial purposes is greatly influenced by water bodies; especially rivers. However, dynamics in natural processes and the numerous activities of man continue to have long-term negative impacts on water bodies especially rivers (Ayivor & Gordon, 2014). In light of this, most researchers define rivers as dynamic systems shaped by man's numerous activities and natural processes (Awotwi, Kumi, Jansson, Yeboah & Nti, 2015; Ayivor & Gordon, 2014).

Laying emphasis on natural processes impacting on water bodies especially rivers, various studies have revealed that, the frequent change in climate and climatic conditions such as temperature, precipitation/rainfall are major natural processes forming and controlling hydrological extremes of river systems. As an illustration, the Intergovernmental Panel on Climate Change (IPCC), (2001) reported in its Third Review Report that a worldwide average increase in surface temperature of about 0.2 °C (Minimum Temperature) and 0.6 °C (Maximum Temperature) during the 20th century led to a 0.3 percent decrease in rainfall over most of the Northern Hemisphere's subtropical regions. Increased temperatures can cause more rapid snowmelt, altering the timing and amount of water flowing into rivers. Changes in precipitation patterns can affect river flow, with increased rainfall leading to higher flows and decreased rainfall resulting in reduced flows.

These changes in streamflow can impact water availability for various uses, including agriculture, industry and ecosystems.

Also, major climatic factors like temperature and precipitation have significantly impact on river flow/discharge, sediment delivery, catchment bedrock and vegetation in river catchments (Aktar, 2015; Saadon, Abdullah & Ariffin, 2014; Queensland Government Natural Recourse and Water, 2006). Whitehead, Wade, & Butterfield (2009) from the same point of view as other studies also believe that, climate change has a great impact on the behavior (hydrology) of rivers. They predict that, climate change will cause an increase in sediment delivery during spring and autumn by 2050 and these changes will be as a result of increased storms which will impact on inflows and outflows.

Shifting the scope of the discussing from natural processes to how human activities impact on hydrological extremes of water bodies, especially rivers, it has been revealed in a number of studies that, human activities such as; land use variations in agriculture, recreation, transportation, housing, mining, deforestation, afforestation, hydraulic construction, and artificial water consumption contribute to the hydrologic dynamics and downstream discharge routing of rivers (Awotwi, et al, 2015; Zhang, Shoemaker, Woodbury, Cao & Zhu, 2012). For instance, changes in land use, such as agriculture or urban development, can modify the natural flow of rivers. Deforestation can lead to increased soil erosion, altering river channel morphology and stability. Changes in land cover can also affect vegetation along riverbanks, impacting bank stability and increasing the risk of erosion and sedimentation. These modifications can result in changes to the river's shape, depth, and width, affecting its ability to transport water and sediment effectively (Cong, Yang, Gao, Yang & Hu, 2009).

It has also been revealed in several LULC and hydrological related studies that, farming near rivers deposits excessive sediment in rivers, while urbanization has exacerbated the degradation of rivers and streams. When there is more cultivated land and impermeable surface in a watershed, there is more runoff, relatively high flows, and more silt in rivers. (Silk & Ciruna, 2005; Walsh, et, al, 2005; McMahon & Cuffney, (2000).

According to some scholars, the rate of landscape modification leading to alterations in the hydrological extremes of water bodies, especially rivers is a direct effect of population increase and widespread poverty (Ayivor & Gordon, 2014; Boakye, et al, 2008; Mather & Needle, 2000). The high rate of poverty worldwide and in rural areas in particular, as well as human responses to economic opportunities, levels of prosperity, levels of technology, policies, and industrialization, are the main drivers of land use and cover dynamics (Lambin, et al, 2001; Geist & Lambin, 2002). For instance, industrialization has led to a concentration of people in urban regions and a depopulation of rural areas. It has also intensified agriculture to the most productive (Ayivor & Gordon, 2014). Changes in land usage are heavily impacted by local subsistence demands in a traditional agrarian economy like Ghana, where roughly 60% of the population relies on agricultural land directly or indirectly for survival (Ayivor & Gordon, 2014).

By implication, hydrological response of climate and land use land cover dynamics therefore refers to the way in which changes in climate patterns and modifications in land use and land cover affect the water cycle and the overall behavior of water within a given region Joachim (Abungba, et al, 2022). It involves studying the complex interactions between climate variability, land use changes, and hydrological processes. Climate change can influence precipitation patterns, temperature, evaporation rates, and the frequency and intensity of extreme weather events such as droughts and floods. These changes in climate can have significant implications for the hydrological cycle, altering the timing, magnitude, and distribution of water resources (Abungba, et al, 2022; Awotwi, et al, 2015). Land use and land cover changes, on the other hand, refer to modifications in the way land is utilized, including deforestation, urbanization, agriculture expansion, and changes in vegetation cover. These changes can directly impact the hydrological response by altering the infiltration and runoff patterns, evapotranspiration rates, and groundwater recharge capacity (Briones, Ella & Bantaya, 2016).

It is worth noting that, the combined effects of climate change and land use/land cover dynamics can lead to complex and interconnected hydrological responses (Awotwi, et al, 2015). For example, deforestation in a watershed can reduce the amount of interception and evapotranspiration, leading to increased surface runoff and reduced groundwater recharge. Similarly, urbanization can increase surface sealing, reducing infiltration rates and exacerbating the risk of flooding (Abungba, et al, 2022; Chien, Yeh & Knouft, 2013).

Understanding the hydrological response of climate and land use/land cover dynamics is crucial for water resource management, land planning, and assessing the potential impacts of human activities and climate change on water availability, water quality, and overall watershed health. It involves interdisciplinary research and modeling approaches that integrate climate data, land use/land cover information, and hydrological processes to analyze the complex interactions and provide insights for sustainable water management strategies (Garg, et al, 2017; Awotwi, et al, 2015). The study therefore made use of various hydrological models such SWAT and the Mann Kendall test tool to evaluate the hydrological response of the Oti River to climate and LULC dynamics.

Statement of the Problem

The Oti River in recent years is experiencing some hydrological variations. For instance, the river overruns its banks at certain points during the year, destroying farmlands, crops, and other property. On other occasions, the river's distance from its banks abruptly decreases causing the river's water level to decrease. In addition to the aforementioned, the river's water quality varies, making it unsafe for use (Abdul-Raza et al., 2010). It is very obvious that, the river is responding to the climate and LULC changes taking place in the catchment area (Awotwi et al., 2015; Ayivor et al., 2014), however, there is no any supporting/available data that shows the extent at which climate and land use land cove changes have impacted the river.

Also, there are records of measured climate for the catchment area indicating the daily, monthly and annual means for the various climatic elements, especially temperature and precipitation/rainfall and their associated variations over the years. Even though, one can easily make meanings out of the data and draw conclusions as to how the river is responding to these changes, however, attributing changes in Oti River's hydrological extremes solely to climate data is not evident enough to draw conclusions that climate is responsible for the changes (Nizar, 2020). It is obvious that hydrological processes in the Oti catchment are being influenced by land use changes, human interventions (such as dam construction or river channelization), and natural variability (Zahmatkesh, et al, 2018). Therefore, a comprehensive analysis that considers multiple factors is necessary to establish the link between climate and changes in hydrological extremes. Other sources of information, such as streamflow records, satellite data, and hydrological models such as the SWAT model, can be used in conjunction with climate data to provide a more robust understanding of the relationship between climate and hydrological extremes (Fabian, Kwon, Vhitanage & Lee, 2022).

Meanwhile many researchers across the globe with the aid of hydro-climatic tools and approaches coupled with spatial, observed and simulated data as mentioned above have confirm that the dynamics in climate and LULC have major impact on hydrological extremes of rivers (Dibaba, et al, 2020; Chen, et al, 2019; Liu, et al, 2017; Ayivor & Gordon, 2014). For example, Osei et al (2019).'s SWAT analysis in the Owabi catchment showed that topography and forest cover are responsible for the increasing water loss in the catchment, while transpiration rate and surface water runoff were the main regulating processes. Awortwi et al. (2017) discovered that the predominant small-scale alluvial gold mining taking place in the Pra river significantly adds to the net runoff fluctuation in the river. In the midst of all these studies, little or no attention has been given to Oti River's responds to climate and LULC changes, meanwhile the effects of the problems as stated repeats themselves all year round.

In light of this, this study investigates the extent at which the Oti River in Ghana is responding to climate change and land use land cover (LULC) dynamics. The practical relevance of this study lies in its potential to inform water resource management, climate change adaptation strategies, land use planning and management, ecosystem conservation, biodiversity protection, and sustainable development initiatives in the Oti River basin in Ghana.

Research Questions

The following research questions guided the study:

1. How has the Oti River responded to climate change that has taken place between 1990-2020?
2. How has the Oti River responded to LULC changes between 1990-2020?
3. How has the changes in climate and LULC impacted on the flow of the Oti River between the period 1990-2020?

General Objective

The main objective of the study is to investigate the extent at which the Oti River is responding to climate change and land use land cover (LULC) dynamics in Ghana.

Specific Objectives

1. evaluate the trends of changes in the Oti River catchment as a result of climate change between 1990 and 2020.
2. evaluate the trends of changes in the Oti River catchment as a result of LULC dynamics between 1990-2020.
3. examine the impact of climate and LULC dynamics on the flow of the Oti River using SWAT.

Purpose of the study

Climate and LULC change is what is being manifested in the rising temperatures, declining rainfall amounts, high incidence of weather extremes, increase in disasters, floods, droughts, extent of sedimentation and flows of river systems in Ghana. This study is therefore geared towards investigating the hydrological responses of climate and LULC dynamics on the Oti River, Ghana.

Hypothesis

H0: There are no trends of change resulting from climate and LULC change.

H1: There are trends of change resulting from climate and LULC change.

Significance of the Study

This study's practical relevance lies in its potential to inform water resource management, climate change adaptation strategies, land use planning and management, ecosystem conservation, biodiversity protection, and sustainable development initiatives in the Oti River basin in Ghana.

First, understanding how the Oti River is responding to climate change and LULC dynamics is crucial for effective water resource management. This study will therefore provide valuable insights into the river's hydrological behavior, such as changes in water availability, flow patterns, and quality. This information can help inform decision-making processes related to water allocation, infrastructure planning, and sustainable water resource management practices.

Second, climate change poses significant challenges globally, including Ghana. By studying the response of the Oti River to climate change, my research will contribute to climate change adaptation strategies specific to the catchment area. The findings can guide policymakers, water resource managers, and local communities in developing appropriate measures to mitigate the impacts of climate change on water resources, such as implementing adaptive water management strategies and identifying vulnerable areas that require intervention.

In addition, investigating the relationship between LULC dynamics and the Oti River will provide valuable information for land use planning and management. Understanding how land use changes impact the river's hydrological processes, sedimentation, and water quality can assist in formulating sustainable land management strategies. This knowledge can guide policymakers and land managers in making informed decisions regarding land use policies, agricultural practices, deforestation prevention, and urban development, aiming to minimize negative impacts on the river system.

Further, the Oti River ecosystem supports diverse aquatic and terrestrial species, including fish, plants, and wildlife. Climate change and LULC dynamics can significantly affect these ecosystems and biodiversity. The study's practical relevance lies in providing insights into the potential impacts on the river's ecological health and biodiversity. This information can aid conservation efforts, facilitate the identification of critical habitats, and guide the implementation of measures to protect and restore the river's ecosystem.

Finally, the Oti River and its surrounding areas are often vital for local communities, supporting livelihoods, agriculture, and economic activities such as fishing and tourism. Understanding how climate change and land use changes are affecting the river can inform sustainable development strategies that balance economic growth with environmental conservation. It will enable policymakers and stakeholders to promote sustainable livelihoods and economic activities that rely on the river while considering its long-term health and resilience.

Limitations of the Study

The study investigates the extent at which the Oti River in Ghana is responding hydrologically to climate and LULC changes. The SWAT model employed for the study's climatic component does not account for factors that contribute to climate change, such as population growth. There were a number of gaps in the observed climate data acquired from GMET. Acquiring climate data on the other hand was also problematic. Spatial data for some years were not freely available.

Organisation of the Study

The study has been organized into five (5) chapters: The study's background, problem statement, objectives, research questions, purpose, significance, limitations, and organizational structure are all presented in Chapter One. The conceptual, theoretical, and empirical review on rivers, LULC, and climate dynamics is reviewed in Chapter 2. The study area, methods and materials employed for the study are briefly described in Chapter 3. This covers the study methodology, data sources, and data utilization. The research discussions presented in Chapter 4 are based on the specific study objectives. The study's conclusions, a summary, and recommendations are presented in the final chapter.

CHAPTER TWO

HYDROLOGICAL RESPONSE OF RIVERS TO CLIMATE AND LULC DYNAMICS: A REVIEW OF LITERATURE

Introduction

This chapter takes into account pertinent earlier writings and concepts that are consistent with this study. The researcher examines a variety of books, articles, journals, concepts, models, theories, findings, and viewpoints offered by numerous academics and researchers of diverse ideologies in relation to rivers and river systems, major hydrological processes associated with rivers, natural drivers of climate change, human activities as drivers of climate change, impact of climate and LULC change on hydrological extremes of rivers such as; flow, erosion, runoffs and sedimentation, drivers of LULC change, relationship between river processes (hydrology) and morphology. The chapter further reviewed literature on the empirical methodology used for the study and a brief description of the SWAT Model. The study is also backed by the Theory of Synergistic Effects.

The Theory of Synergistic Effects

The theory of synergistic effects in land use land cover (LULC) and climate studies suggests that the combined impact of land use changes and climate change on the environment can be greater than the sum of their individual effects. This theory recognizes that changes in land use and land cover can interact with climate change, leading to amplified or diminished impacts on various environmental processes and systems (Pielke, et al, 2002; Foley, et al, 2005).

The concept of synergistic effects arises from the understanding that land use and land cover modifications can alter the surface characteristics of an area, such as vegetation cover, albedo (reflectivity), evapotranspiration rates, and surface roughness. These modifications can then affect local climate patterns, including temperature, precipitation, wind patterns, and humidity. The changes in local climate, in turn, can feedback to influence land surface processes and further modify land use patterns (Pielke, Marland, Betts, Chase, Eastman, Niles, & Williams, (2002) Foley, DeFries, Asner, Barford, Bonan, Carpenter, & Snyder, 2005). Synergistic effects can manifest in several ways within LULC and climate studies:

First, synergistic effects manifests on feedback loops: Changes in land use and land cover can create feedback loops with the climate system. For example, deforestation can lead to reduced evapotranspiration and increased surface runoff, which can alter precipitation patterns and further exacerbate the drying of the area. This positive feedback loop intensifies the impact of both land use change and climate change on the environment (Turner, Lambin & Reenberg, 2007; Pielke, et al, 2002).

Second, synergistic effects can also be manifested in the form of non-linear responses: Synergistic effects can result in non-linear responses, where the combined impact of land use change and climate change is not simply additive. Instead, the interaction between the two factors can lead to exponential or disproportionate changes in environmental conditions. For instance, a small increase in temperature combined with deforestation may trigger a significant decline in soil moisture, which can then lead to increased vulnerability to drought and further vegetation loss (Turner, Lambin, & Reenberg, 2007; Foley, et al, 2005)

Finally, it can be manifested on threshold effects: Synergistic effects can also lead to threshold effects, where a relatively small change in either land use or climate triggers a disproportionately large response in the system. Once a critical threshold is crossed, the impacts can become irreversible or significantly more challenging to mitigate (Foley, et al, 2005). An example is the conversion of forested areas to agricultural land, which may be relatively benign until a certain threshold of deforestation is reached, beyond which the loss of ecosystem services and biodiversity becomes rapid and severe (Foley, et al, 2005; Turner, et al, 2007)

It is important to note that the specific synergistic effects observed in LULC and climate studies can vary depending on regional and local contexts, as well as the specific interactions between land use patterns and climate conditions (Foley, et al, 2005; Turner, et al, 2007).

River and River Systems

According to National Geographic Society (2018), a river is water flowing down a hill in a natural linear channel created by the water. According to Chapman (1992), a river is a complex network of fluid flows that drains a particular geographical surface known as a river basin or water shed. Rivers are dynamic systems shaped by a variety of human activities as well as natural forces (Awotwi, et al, 2015). It is very clear from the definitions that, Rivers are water networks generated by natural processes and human-dominated activities on the earth's surface. For a long time in history, humanity had no idea where river water came from Chapman (1992). Old renowned intellectuals and researchers such as Aristotle, Leonardo da Vinci, Bernard Palissy, and Pierre Perrault considered that river water was produced by the lateral extension of the ocean beneath the surface. Aristotle, for example, was of the notion that, river water was formed by water vapor condensation in soil pores. Despite his assumption that water that percolates or sinks through soils could not sustain stream flow all year, he did recognize it as a source of river water (National Geographic Society, 2018). Meanwhile, scholars such as Bernard Palissy and others have asserted unequivocally that springs and rivers get their water only from rainfall (Gurnell, Bertoldi & Cornenblit, 2012). Pierre Perrault later concluded that there was more than enough rainwater to sustain the flow of every river wherever in the world, based on his quantitative experiments and research of river flow systems (Gurnell, Bertoldi & Cornenblit, 2012). As a result, it is now widely accepted that precipitation is the primary source of water in river systems (Gurnell, Bertoldi & Cornenblit, 2012). Rivers get their water from a variety of places. The immediate source of rivers, according to Chapman (1992), is surface runoff caused by rainfall, subsurface water originating from springs and seepages, and precipitated water temporarily held in swamps, lakes, snowfields, and glaciers. Because rain is the primary source of water for rivers, it is an irrefutable reality that climate and climatic conditions affect and form the hydrology of rivers and river systems (Chapman, 1992).

Rivers and river catchments within a basin have a lot in common in terms of the features found inside the river. Rivers are frequently linked by their size, shape, and basin geological properties (Brierley, Jain & Fryirs, 2016). In addition, the climatic conditions within rivers impact the amount of water that will be drained by the entire river system (Dingman, 2015).

Rivers are classified according to their size, channel shape, discharge and flow, and intensity of change (Kondolf, Gomery, Piegay & Schmitt,2005). Variations in river classification, processes, and characteristics have caused a fundamental friction among scholars and researchers throughout the years. It's hardly surprising, then, that diverse efforts to classify rivers have culminated in a wide range of classification methods, each serving a unique purpose. For example, rivers have been classed by typologies with the intention of understanding and interpreting landscape change throughout geologic time in the field of engineering for designing engineering designs for channel conservation projects (Kondolf, et al, 2005). However, according to Kondolf et al. (2005), classifications can be highly effective with any tool if applied correctly to the specific problem, although classification schemes work best with limited tools whose potentials are often exaggerated by users with less technical experience in geomorphology. Rivers can be classed depending on the type of flow pattern and discharge magnitude (Chapman, 1992). Modifications arising from natural forces prevailing in lakes, dams, or water storage systems, have a substantial impact on the flow regime. As a result of the numerous uses of water, flow regimes are also altered. Flow regimes are constantly being altered by activities and processes such as water extraction for irrigated agriculture as well as other water supply purposes, changes in flood characteristics owing to soil modifications, infiltration resulting from agriculture, and urbanization. Specified discharge rates are frequently used to describe river flows and their annual oscillations even if there isn't a clear and widely accepted definition of these classes. River discharge categories might include average maximum discharges, month - to - month average discharges, and average low flows, but river size classifications can also be dependent on discharge, drainage area, and river width.

Rinaldi, et al, (2017), like Chapman (1992), highlight flow regimes as a significant category of river classification in their multilevel, inter, hydro morphological model for European rivers produced within the REFORM project. Rinaldi, et al (2017) categorized rivers as per the river channel morphology and floodplain morphology, similar to Kondolf et al (2005). However, Rinaldi, et al, (2017), indicated that channel morphology is defined at two levels: a basic river typology and an extended river typology. Rivers were also categorized by Rinaldi (2017) based on floodplain morphology and groundwater-surface-water interactions.

Hydrological Extremes of River Systems

Researchers have been paying close attention to hydrological responses to LULC changes in recent years, with a focus on land use and climate dynamics. Because of their powerful destructive power on rivers and river systems, LULC and climate dynamics are two of the most important factors affecting hydrological processes (Chen, et al, 2019). Many researchers have drawn contradictory interpretations from various hydro-meteorological studies, claiming that the hydrological cycle will be adversely affected as a result of global warming. For example, some researchers have discovered a rise in precipitation patterns across most of the globe, indicating that climate change dynamics are influencing hydrological systems such as rivers and river systems (Chen, et al, 2019; Gao, et al, 2016).

Furthermore, various climate model projections show that rainfall extremes will continue to rise in the twenty-first century, resulting in more frequent floods, directly threatening water security and human activities. This is also a major determinant of rainfall-runoff processes like surface runoff, evapotranspiration, and infiltration. The entire hydrological cycle of water systems is affected in the long run (Burn, Sharif & Zhang, 2010; Allen & Ingram, 2002; Wetherald & Manabe, 2002).

Major Hydrological Processes Associated with Rivers

The hydrological cycle, which involves constant water interactions through vertical and lateral mass fluxes, is made up of three main elements: the land surface, the underground, and the atmosphere (Lastoria, 2008). Precipitation and runoff are the components of this process that are visible. Among the other crucial mechanisms in this cycle are absorption, infiltration, evaporation, percolation, groundwater recharge, and discharge. (Lastoria, 2008). Rivers and river systems are associated with a variety of hydrological processes such as erosion, flow, discharge, and evapotranspiration, among others. Climate and climatic conditions, as well as man's numerous activities, are major triggers for these processes. According to Anderson (2013), each of the three primary river courses—the upper stream, middle course, and lower course has its own unique landforms and related processes Anderson (2013), went on to say that a river system is more or less an organism with its own life. Its young stage, he explained, is steep and rugged, as it runs more towards the sea, eroding the bed and bank in the process. The river has matured in its middle course, flowing steadily through wide valleys and adjusting to its role as a water and sediment transporter. Near the river's mouth, which is where it enters the ocean that has fed it with sustaining waters for its entire existence, the plain is practically level, and the river drifts in a direction toward final extinction that is more or less aimless.

Queensland Government Natural Recourse and Water Management, (2006), on the other hand, believe that water flows automatically and is constantly replenished. It evaporates from the oceans, evapotranspires from land, precipitates back onto the ocean waters and land, works its way into the ground, and reverts to the ocean via rivers and lakes. In the long run, these processes result in rivers transporting large amounts of sediments and nutrients, as well as erosion and deposition of river banks and channels (Syvitski, et al. 2005). Humans, on the other hand, significantly alter the hydrologic cycle through activities such as urban development, the extraction and construction of dams and bridges to convert and regulate the flow of water, the extraction of water to satisfy the requirements of urban residents, and agriculture, among others. This also aids in the promotion of hydrological parameters like erosion, surface runoff, and infiltration. Allan (2004) argued that the constant alteration of urban areas contributes to the alteration of the microclimate and precipitation rate. This reduces infiltration and encourages runoff in the long run (Syvitski, et al. 2005) and as a result, it can be concluded that hydrological processes such as erosion, transportation, and deposition in their three different stages, flow/runoff, evapotranspiration, infiltration, percolation, groundwater recharge, and discharge play a very important part in the formation, shaping, and control of rivers and river systems. Climate and man's numerous activities influence all of these processes (Allan, 2004; Syvitski, et al. 2005; Anderson, 2013).

Climate Dynamics/Change

Climate is the average of the weather in a particular location on the earth (Riedy, 2016). On the basis of historical data, the projected temperatures, precipitation, and wind conditions are typically used to describe the climate (Riedy, 2016). A thorough understanding of each component of the climate and its historical variations is the main goal of improved and observational-based estimations in addition to data from climatological archives. According to the United Nations Framework Convention on Climate Change (UNFCCC), (1992) defined climate change as a change in the climate that is directly or indirectly attributable to human activity that modifies the composition of the atmosphere. The Public Health Institute/Center for Climate Change and Health (2016) defines climate change as "a structured change in the long conditions of the atmosphere over several decades or more". Climate change, according to Riedy (2016), is the sustained modification of the world's climate or its variation. Nearly all climate experts (97%) concur that climate change is occurring and is primarily caused by both natural and human factors (IPCC, 2021; Riedy, 2016; Ankomah-Baffoe, 2018). The Public Health Institute/Center for Climate Change and Health (2016) defines climate change as a structured effect in the long conditions of the atmosphere over multiple decades or longer. Climate change, according to Riedy (2016), is defined as a long-term change in the average climate or climate variability. 97 percent of climate scientists believe that climate change is occurring now, and it is largely caused by natural and human factors (IPCC, 2021; Riedy, 2016; Ankomah-Baffoe, 2018). In recent years, new climate model simulations, studies, and techniques that integrate numerous lines of data have been employed to increase our understanding of climate change and, consequently, to lessen its consequences and advancement (IPCC, 2021; Ankomah-Baffoe, 2018).

Drivers of Climate Change

Earth's climate has changed and is still changing, according to research conducted on a global and local scale (IPCC, 2021; Ankomah-Baffoe, 2018; Riedy, 2016). Natural drivers and human-dominated activities on the earth's surface are the main causes of climate change (Neill et al., 2017; IPCC, 2013; Gaume & Payrastre, 2017). The increase in greenhouse gas concentrations, particularly carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), is a significant driver of climate change. These gases trap heat in the Earth's atmosphere, leading to the greenhouse effect and resulting in a warmer climate. Human activities, such as the burning of fossil fuels for energy, deforestation, and industrial processes, contribute to the majority of greenhouse gas emissions (IPCC, 2014).

Industrial activities, such as the production of cement, steel, and chemicals, release significant amounts of greenhouse gases into the atmosphere. Additionally, the burning of fossil fuels for energy generation is a major contributor to greenhouse gas emissions, particularly from power plants and transportation (EPA, n.d.). Agricultural practices, including rice cultivation, livestock production, and the use of synthetic fertilizers, contribute to greenhouse gas emissions. Methane emissions from livestock, nitrous oxide emissions from fertilizer use, and land-use changes for agriculture all play a role in climate change (FAO, 2016).

Also, deforestation, primarily driven by activities like logging, agriculture expansion, and urbanization, contributes to climate change. Trees absorb carbon dioxide and help regulate the climate, so deforestation reduces the Earth's capacity to remove CO2 from the atmosphere. Land-use changes, including conversion of forests to agricultural land, also release carbon stored in vegetation and soils (Chu & Karr, 2017).

In addition, alterations in land and water management practices, such as irrigation, drainage, and water storage, can impact the hydrological cycle and contribute to climate change. These changes can affect regional climate patterns, leading to shifts in precipitation and evaporation (IPCC, 2014). Improper waste management, including the decomposition of organic waste in landfills, generates methane, a potent greenhouse gas. Inefficient waste disposal practices contribute to climate change by releasing methane into the atmosphere (EPA, 2021). It is important to note that while natural factors, such as volcanic eruptions and variations in solar radiation, also influence climate change, the current observed changes in the climate are primarily attributed to human activities (IPCC, 2014).

The hydrology of rivers is significantly influenced by climate change, as it affects various drivers that impact the water cycle and precipitation patterns. According to IPCC, (2014), climate change can alter the timing, intensity, and distribution of precipitation. Some regions may experience increased rainfall, leading to higher river flows and more frequent flooding (Ankomah-Baffoe, 2018). Other areas may face reduced rainfall, resulting in lower river flows and potential water scarcity. Changes in precipitation patterns can affect the overall water availability in river systems (Ankomah-Baffoe, 2018; IPCC, 2014). Many rivers are fed by glaciers, which are highly sensitive to climate change. (Huss and Hock2018) on the other hand came up that, rising temperatures cause accelerated melting and retreat of glaciers, impacting river flow. Initially, glacier meltwater may increase, contributing to higher river discharge (Barnett et al., 2005). However, as glaciers shrink over time, the reduced ice reservoir leads to decreased meltwater contributions, potentially causing water scarcity in downstream regions (Huss and Hock, 2018).

Natural Drivers of Climate Change

Climate is affected by a variety of internal and external factors, including the distribution of land masses on Earth's crust, volcanic activity, changes in the earth's orbit about the sun, and other occurrences. According to Riedy (2016), these persistent climatic patterns are referred to as natural factors causing climate change. Other variables causing climate change include adjustments to the earth's energy balance, or how much of the sun's energy enters the planet and its atmosphere before being reflected back into space (Huss & Hock, 2018; Public Health Institute/Center for Climate Change and Health, 2016). Although the Sun is the primary energy source for the Earth's climate system, the Royal Society and the US National Academy of Sciences (2020) claim that the Sun's variations have had minimal effect on recent climatic changes; no net increments in the Sun's output have been observed since the late 1970s, despite rising global surface temperatures. These causes have previously caused the Earth to go through frigid periods, with glaciers covering sizable portions of the planet's surface. Sea levels were significantly greater than they are today when Earth was warmer (The Royal Society and the US National Academy of Sciences, 2020). A rather warm, warming climate that has endured since the end of the most recent ice age 11,700 years back characterizes the current period in Earth's long history.

According to Hannah et al., (2011), climate change influences the interactions between rivers and groundwater. Changes in precipitation patterns and evapotranspiration rates affect groundwater recharge rates, which, in turn, influence river baseflows. Reduced groundwater availability due to increased evaporation and changes in precipitation can lead to lower baseflow levels, affecting river ecosystems and water supply. Climate change can intensify extreme weather events, such as storms and hurricanes. Hall et al., (2014) These events can result in rapid increases in river discharge, causing flash floods and damaging riverine ecosystems, infrastructure, and communities.

Human Activities as a Driver of Climate Change

In recent years, human activities have considerably contributed to climate change. (The Royal Society and the US National Academy of Sciences, 2020; Ankomah-Baffoe, 2018; IPCC, 2021 and 2014). Human activities have produced enormous amounts of greenhouse gases (GHG) into the atmosphere since the Industrial Revolution began more than 200 years ago (Ankomah-Baffoe, 2018;

IPCC, 2014). The concentration of these GHG in the atmosphere traps too much heat, causing the earth to become warmer from outside (Public Health Institute/Center for Climate Change and Health, 2016). Over time, these GHG prevent the sun's heat and energy from reflecting into the atmosphere through absorption. After the middle of the 19th century, the global ocean and land surface temperature have risen by 0.60.2 degrees Celsius, with the majority of the shift occurring since 1976, according to the IPCC (2001). The IPCC (2001) also stated that patterns of precipitation had taken place: while other regions, especially those located in the mid- to high latitudes, had recorded increases in precipitation, arid and semi-arid regions had grown drier. The intensity of the largest annual precipitation events has risen unevenly where precipitation has increased. Based on a variety of possible growth scenarios and model parameterizations, the IPCC came to the conclusion that, in the absence of concrete measures to cut carbon emissions, global average temperatures will in fact increase between 1.4 and 5.8 degrees Celsius between 1990 and 2100.

According to the IPCC, (2021), human intervention has heated up the atmosphere, oceans, and land, causing huge and quick changes in the earth's atmosphere, ocean, cryosphere, and biosphere. Since 2011, the greenhouse gas concentration has increased (IPCC, 2021 and 2014). In 2019, the annual average values for carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) were 410 parts per million (ppm), 1866 parts per billion (ppb), and 332 parts per billion (ppb), respectively (IPCC, 2014). With regional variations, land and ocean have absorbed almost the same amount of CO2 emissions from human activities over the past 60 years (globally, about 56 percent every year) (high confidence) (IPCC, 2014).

According to Ankomah-Baffoe, (2018), excessive urbanization, forest degradation, population growth, and the burning of fossil fuels are the main factors contributing to climatic changes brought on by human activity. Water resources and hydrological processes are significantly impacted by climate change, forcing the creation of solutions to reduce or eliminate the issue.

Human activities as drivers of climate change can have significant impacts on rivers, and these impacts can contribute to climate change. For instance, deforestation and land use change, such as urbanization and agricultural expansion, can lead to increased sedimentation in rivers. When forests are cleared, the vegetation cover is lost, and the exposed soil is more prone to erosion (Kasvi, Pöyry, Huttunen, & Virtanen, 2018). This erosion results in sedimentation in rivers, reducing their capacity and altering their flow patterns. Sediment-laden rivers can impact the climate by affecting the water cycle and the global carbon cycle. Changes in river flow and sediment transport can influence the amount of water available for evaporation and the transport of organic matter and nutrients downstream (Syvitski, et al. (2005).

Effects of Climate Change and River Discharge/Flow

The most effective way to move fresh water from its source to its mouth and into the sea is through the flow or discharge of rivers. According to Mamo, Assefa, & Melesse, (2019). River discharge/flow is a unified outcome of hydrological processes that convey runoffs from rainfall. The ratio of moving water in a river given in ms/-1 or cm s/-1 is referred to as river flow (Chapman, 1992). The flow velocity of the river is calculated using the flow, which equals the river's speed multiplied by its cross-sectional area. Additionally, it is important to note that rainfall intensity and river discharge/flow are closely related (Gaume & Payrastre, 2017), and that rainfall intensity is a key driver of runoffs, floods, and other hydrological processes that change the hydrological components of rivers and river systems. All of these phenomena are direct consequences of climate and climate dynamics.

Various scholars and researchers from various persuasions in the physical/natural sciences have developed a series of flow models explaining the mechanisms, characteristics, and other events associated with the flow/discharge of water into and within rivers and river systems (Arthur, et al, 2020; Kirkby, et al, 2018; Kankam-Yeboah, Arnold, et al, 2012; Gao, et al, 2011). Models that explain rivers and their flow systems include the Horton overland flow model, the subsurface storm flow model, and the saturation overland flow model.

Horton overland flow model

The Horton overland flow model is a conceptual/hydrological model that describes the process of overland flow, which occurs when rainfall intensity exceeds the infiltration capacity of the soil. It was developed by Robert E. Horton in 1933 and is widely used in hydrology and water resources engineering (Schroers, et al, 2021). The Horton (1945) overland flow states that when rainfall intensity is high enough, not all of the precipitation percolates into the soil but instead flow directly into streams. The amount of rainfall and the soil's capacity for infiltration have a significant impact on the model. After precipitation and before it subsequently enters clearly defined stream pathways, the water is subjected to numerous agents including evaporation, infiltration, and absorption by the ground. Rainwater accumulates and fills any depressions or potholes at the surface when rainfall intensity surpasses the maximum limiting rate at which soils can absorb rain water. Any additional rainfall will cause the potholes' full depression capacity to be exceeded, causing the water to overflow and flow in an uneven sheet down the slope (Schroers, et al, 2021).

Through networks of trickles and streamlets, surface runoff travels through the ground surface into tributary streams before reaching surface rivers and streams. Horton's overland flow can occur concurrently all through the basin in minor drainage basins with equal soil qualities, and when additional intercepted precipitation is deposited downstream, the level and speed of the stream increase. The equation $q=(i-f)\,a$ state that, the typical flow velocity of a sample that is about one centimeter deep is between 10 and 500 meters per hour (Schroers, et al, 2021; Horton, 1945). According to Horton (1945), the drained area is denoted by a, the top soil infiltration rate is denoted by f, the top soil infiltration rate per unit contour length is marked by q, and the overland flow/discharge per unit contour length is denoted by I. The equation consequently suggests that, especially when rainfall intensity is high, the amount of overland flow is greater than the infiltration capacity.

The main concepts of the Horton flow model include:

1. ***Drainage basin***: A drainage basin is an area of land where all the precipitation and runoff drain into a common outlet, usually a river or a lake. The boundaries of the basin are defined by the topography of the land (Horton, 1945; Leopold, et al, 1964).
2. ***Stream order***: Streams within a drainage basin are classified into different orders based on their position in the hierarchy. The smallest tributaries are assigned the first order, and as streams merge, their order increases. The main stream, or the trunk stream, typically has the highest order (Horton, 1945; Leopold, et al, 1964).
3. ***Stream length ratios***: Horton's laws describe the relationship between the lengths of streams of different orders. According to Horton's first law, the ratio of the number of streams of a given order to the number of streams of the next higher order is constant throughout the basin. This ratio is known as the bifurcation ratio. Horton's second law states that the ratio of the lengths of streams of a given order to the lengths of streams of the next higher order is also constant (Horton, 1945; Leopold, et al, 1964).
4. ***Stream frequency***: Stream frequency refers to the number of streams of a given order per unit area in the drainage basin. It is often used as an indicator of the density of the river network and can be calculated by dividing the total number of streams of a specific order by the total area of the basin (Horton, 1945; Leopold, et al, 1964).

Despite the benefits, Horton's flow approach has drawn criticism for lacking empirical evidence of widespread sheet flow over significant portions of hill slopes, a higher incidence of infiltration observed in humid regions with dense vegetation and substantial soil cover, and a lack of empirical evidence of widespread sheet flow over significant portions of hill slopes (Schroers, et al, 2021). When infiltration capacity surpasses rainfall intensity in the majority of humid environments, the model is inappropriate (Schroers, et al, 2021). The model is not applicable to large areas of the terrain because percolating or infiltrated water travels through the soil downhill to recharge water tables, with some of it traveling downslope inside the soil as through flow or subsurface flow to impact the storm runoff hydrograph (Schroers, et al, 2021).

The Subsurface Storm Flow Model (SSF)

The Subsurface Storm Flow Model (SSF) demonstrates that, depending on the location and environmental factors, some rain that falls on land may infiltrate into the soil and, upon encountering a relatively impermeable layer, the water may spread out and flow laterally some few centimeters underneath the surface in the direction of a stream without mixing with any underground water. The system's interflow element is also referred to as storm seepage, secondary base flow, or translator flow (USDA-NRCS, 2009; Beven, 2012). The Subsurface Storm Flow Model has also been questioned due to the subsurface storm flow's contributions to overall runoff (USDA-NRCS, 2009; Beven, 2012).

Saturation Overland Flow Model

The Saturation Overland Flow Model shows how downpours can boost water tables in areas where they are already close to the surface, forcing water to emerge at the surface. When water from a heavily saturated surface moves overland to stream channels, this is known as return flow. The model predicts that storm water discharges as an overland flow because a hill slope experiencing return flow is impervious to precipitation. These elements, along with return flow, result in saturation overland flow (Kirkby, 2018; Hassaballah, et al, 2017). According to the model, the area that is initially saturated during downpours expands anywhere along valleys, lower portions of the hillside, and upslope, resulting in a wider area contributing to the saturation overland flow. The regions that are most prone to get saturated and cause saturation overland flow are those that are close to perennial streams, have a concave upward slope pattern, hallows, and have thin or impermeable soils (Kirkby, 1969).

The literature analyzed so far shows that climate and climatic conditions, especially rainfall, have a substantial impact on the flow/discharge rate of rivers and river systems. Mamo, et al. (2019) discovered that in low-lying locations, flood events come from severe rainfall patterns that are brought on by increasing runoffs throughout the rainy season in a changing climate like the one we are currently experiencing. In addition, historical flow statistics for the Blue Nile Basin's Gumara River point to a monthly mean high flow of 400 m/3 s/1 throughout the summer between 1986 and 2009, which caused significant flooding in the Fogera plain (Mamo,et al 2019).

According to Milliman & Syviski, (2007), the rate of sediment delivery to the ocean or embayment, which is largely dependent on catchment size, lithology, and climate, is even more crucial in terms of the formation of landmasses. The rate of sediment delivery to the ocean or embayment determines what actually happens at a river's mouth. The aforementioned presumptions lead to the conclusion that climate and climatic dynamics significantly affect river flow and discharge.

In their investigation into how the consequences of climate change on river discharge flow regimes is related to the impact on mean annual runoff, Doell & Schmied (2012) discovered for the very first time that, at the global level, flows may alter from perennial to occasional flow conditions and vice versa as a result of climate change. How the environment and climatic circumstances effect infiltration and flow, however, is one extremely important factor that Doell & Schmied's, (2012), research neglects to address. Humans are impacted by climate dynamics that alter river flow regimes in terms of water availability, transportation, energy production from hydropower, floods, and ecosystems in terms of sustaining habitats for freshwater-dependent biota (Zeiringer, et al, 2018). Additionally, Xu and Luo (2015) studied the dynamics of the climate and how it affected the flow and discharge of rivers in two climate zones in China. The results of their study show that in the two catchment areas studied, there is a clear distinction between climate dynamics and their effects on river discharge/flow. The northern semi-arid area's watershed is best characterized by increased temperature rise and wetting, which results in an annual increase in river discharge/flow, in contrast to the study area's southern subtropical humid area.

Arnell (1992) also looked at the variables determining the influence of climate variations/dynamics on catchments in UK using a monthly water balance model. In his research, Arnell used fifteen different catchments with a range of climatic and geological conditions. He found that the sensitivity of the most arid catchment areas—which have the smallest runoff coefficients—to climate change depends on the relationship between anticipated yearly runoff and average rainfall totals. Despite the fact that multiple separate empirical equations produced results that were in disagreement with those from the monthly water balance models used in the study, the impact of a given annual rainfall variation on runoff increased with the concentration of that variation in winter. Last but not least, Arnell, (2004) asserts that catchment geology, the existing summer balances of rainfall and prospective evapotranspiration, and fluctuations in monthly discharge are all influenced by these factors. Given the assertions in this section, it should not be surprising that climate and climatic factors, including temperature variations and rainfall, among others, have a considerable impact on river flow and discharge.

Climate Dynamics and River Erosion

Disciplines, organizations, institutions, and individuals frequently define erosion as the removal of loose materials or soil. For instance, Balasubramanian (2019) defined erosion as the process through which topsoil fields are worn away by the natural physical processes of water and wind. Erosion is described as the gradual wearing away of rocks or soil due to physical disintegration, chemical solution, and material transportation caused by water, wind, or ice (Encarta World English Dictionary, 1999). Erosion is one of the main processes brought about by climate dynamics and climatic conditions. Water, ice, and wind are the main elements that causes erosion, with running water being the most potent (Aghamajidi, 2019).

The combination of numerous professions is necessary to combat or lessen river erosion, one of the most complex challenges the world has ever seen. For example, geologists study the formation and behavior of rivers, including the geological processes that contribute to erosion by analyzing the river's sediment composition, studying the riverbed's stability, and assessing the surrounding terrain, geologists can provide valuable insights into erosion patterns and develop strategies to counteract them (Brunsden et al., 2001). Hydrologists on the other hand specializes in studying the movement, distribution, and quality of water in various environments. They collect data on river flow, analyze precipitation patterns, and evaluate the impact of factors such as climate change and human activities on river erosion. Their insights help develop effective erosion management plans (Smith, 2018). Meanwhile, environmental engineers specialize in developing and implementing engineering solutions to environmental challenges. In the context of river erosion, they design erosion control structures, such as bioengineering techniques, to stabilize riverbanks and prevent sediment runoff. They also work on projects related to stormwater management and flood control, which are closely linked to erosion prevention (Smith, et al, 2018). Erosion is an important fluvial dynamic process that affects the social, ecological, and physical aspects of the environment (Smith, et al, 2018). Erosion results in sedimentation of water bodies and decreased soil fertility, both of which have detrimental effects (Natural Resources and Water Management, Queensland Government, 2006). Arekhi (2008) estimates that 38 percent of the world's farmlands has been lost to erosion, with 65 percent of that land located in Africa, 74 percent in Central America, and 45 percent in South America.

Posner & Duan (2012) assert that mass collapse and hydraulic action are the two key factors contributing to river erosion. However, the weather and important climate variables like temperature and precipitation have an impact on and cause river erosion. When water with dissolved carbon dioxide flows over rock surfaces and acts as a solvent, erosion by corrosion (solution) occurs. The chemical reaction between the flowing water and the river's bed and bank materials causes this process to progressively dissolve away the sediments. In contrast to slate and gabbro, which are less soluble in water, dissolved carbon dioxide has little effect on rocks like limestone and chalk, which are more soluble in water (Florsheim, Jeffrey & Chin, 2008). Abrasion, often known as corrosion, is a physical process wherein rivers scour and rip apart riverbanks and beds with material like stones. The load in suspension is used as a grinding tool to scour and excavate channels to create features like potholes, undercut banks, and smooth and rounded rocks. It moves via saltation (jumping and jerking) or traction (rolling along river beds) (Syvitski, et al, 2014). Through hydraulic action, the sheer force of river water cracks and removes rock fragments from the surface (quarrying). Rock chunks or whole quarries are displaced into river beds and slabs are raised from the bedrock by the sheer power of river water forcing its way into fissures and crevices. The flow energy increases as the possibility for hydraulic action to extract materials from the bank increases

(Posner & Duan, 2012). Cavitation happens when water vapor bubbles abruptly burst, sending shock waves that strike nearby things like a hammer. Rocks crack and melt as a result. Rapids, waterfalls, and tiny channels are particularly prone to cavitation. When the bed load runs into the current flow and fragments into smaller pieces, this is what happens. Attrition is the process by which the bed load moves downstream, boulders bump into other objects, and rocks shatter into smaller pieces. When rock fragments conveyed by the river collide with one another, they atrophy and fragment even further (Florsheim, et al; Syvitski, et al, 2014).

Mass failure is the process by which massive slabs of material move away from the river bank and slide to a lower location. When the threshold height and angle of the riverbank are exceeded, something occurs (Hungr, Leroueil &Picarelli, 2014). The morphology, structure, and material properties of the riverbank determine the mass failure of the river (Knighton, 1998). The speed of River erosion is affected by fluid flow. Fluid flow metrics include the river's discharge's amplitude, frequency, and fluctuation. Other features include the degree of turbulence in the water, the presence of waves, and the distribution of shear stress that flowing water places on the riverbank (Cruden, & Varnes, 2001). It's also important to keep in mind that rivers constantly erode their banks, beds, and other river features in order to alter their morphology and attain equilibrium through a number of natural and artificial processes (Cruden, & Varnes, 2001).

In addition, it is important to keep in mind that river erosion, which is primarily brought on by human activity and natural phenomena like climate, has a substantial long-term impact on river hydrology (Cameron & Bauer, 2014; Saadon, Abdullah & Ariffin, 2014; Posner & Duan, 2012). River hydrology is more significantly impacted by climatic and climate dynamics. For instance, as described in the literature, fluid flow is a direct result of climatic elements like rainfall and temperature, among others, and fluid flow promotes erosion, particularly river erosion.

In Bangladesh, riverbank erosion is significantly impacted by climate change, according to a study by Aktar (2013) to determine the relationship between flooding and increased erosion in addition to the threat of climate change on bank erosion. Additionally, according to the study's conclusions, riverbank erosion along the three principal rivers under consideration will increase on average by 13% and 18% by 2050 and 2100, respectively.

Climate Dynamics and Runoff

In the last two decades, the discharge patterns of several tropical rivers have undergone significant changes (Legesse et al., 2003; Syvitski et al., 2014). Runoff is the end outcome of both climate change and changes in land use in a basin. The spatial organization of runoff and the geographical distribution and temporal variability of atmospheric precipitation are all directly impacted by climate change (Chen, et al, 2019). According to an examination of climate change scenario simulation data conducted in the Upper Heihe River Basin by (Chen, et al, 2019), Variations in precipitation have a direct correlation with changes in runoff. The influence of the change in temperature is less significant despite the more complex relationship between the change in rainfall and the change in temperature. Awotwi et al. (2015a) found that in the Volta River Basin, increases in precipitation and temperature were accompanied by comparable surface runoff, base flow, and evapotranspiration increments. According to analyses and predictions of watershed runoff in several studies along the Upper Heihe River, the rise in runoff has a causal relationship with the increase in upstream air precipitation and temperature (Chen, et al, 2019; Zhang et al; 2012; 2009).

According to research by Zahmatkesh, et al, (2018) and Nyarko, (2000) changes in precipitation brought on by climate change have an immense impact on urban runoff. Results from the simulation of runoff in the study indicated an increase in volume and peak discharge. In order to facilitate strategic planning, a frequency assessment of the predicted runoff was conducted. The results indicate a marked increase in the frequency of severe rainstorms and their peak values. A storm water climate sensitivity factor (SCSF) is suggested to be used to analyze runoff responses at the sub-watershed level. Based on sub watershed factors like area, width, slope, and imperviousness, this sensitivity factor illustrates the potential for sub watersheds runoff sensitivity to climate change. The findings of the SCSF study show that storm water run-off is more vulnerable to sub river basin slope in a warmer environment. Roudier, Ducharne, & Feyen (2014) also found that differences in runoff are closely related to variations in rainfall and, to a lower extent, to variations in evapotranspiration. Runoff may be greatly impacted by other variables, such as the impact of carbon on plants' capacity to utilize water effectively, modifications to land use, and water withdrawals, but they rarely offset the climate change's effects. Both temperature and precipitation are the primary climatic variables that regulate the pace and runoff volume in a river basin, according to the findings of several research.

Land Use Landcover Dynamics and River Systems

Land use refers to the various ways in which land is utilized or occupied by humans for different purposes such as residential, commercial, agricultural, industrial, recreational, or conservation activities (Grunewald & Davis, 2019). It encompasses the allocation, management, and modification of land for specific functions or uses, considering factors like economic, social, and environmental considerations (Grunewald & Davis, 2019).

The analysis of shifting land usage and land cover variations are both included under the umbrella term "land use dynamic." (International Soil and Water Conservation Research, 2017). Major concerns have been raised by changes in land use, especially in relation to watershed water management and global changes in soil hydrologic characteristics (International Soil and Water Conservation Research, 2017). The majority of scholars link changes in land use to factors like the world population's rapid rise, urbanization, regional and global economic development, competition for water, and rising food consumption (Dibaba et al, 2020; International Soil and Water Conservation Research, 2017; Ayivor & Gordon, 2012). For example, the ecosystem is impacted by population growth that is occurring quickly, increased demand for water and food, high precipitation variation, and regular hydrologic extremes (Dibaba et al, 2020). According to several research, the expansion and intensity of agricultural fields, the necessity to harvest forest products, and the growth of urban areas are all direct factors that influence how land is used. This demonstrates how factors influencing land use dynamics are connected to the expansion of both the global and regional human populations.

Numerous studies conducted in Ghana, revealed that, land degradation brought on by inappropriate agricultural methods, urbanization brought on by rapid population increase, and illegal mining activities all negatively affect river systems and agricultural fields (Ayivor & Gordon, 2012). For instance, research by Yeboah, Awotwi, et al, (2015) reveals that between 1985 and 2010 in Accra, the utilization of agricultural lands and water bodies decreased by 38% and 36%, respectively. According to Adjei, Buor & Addrah, (2014) from 1986 to 2008, changes in land use resulted in a 0.03 percent annual reduction in the area covered by water in the Lake Bosomtwe Basin. Land use dynamics, including those in agriculture, mining, reforestation, residential construction, transportation, and domestic water usage, among other activities, have a substantial impact on natural resources like soil, water bodies, and plants, according to Lawler et al. (2013). Soil erosion, flooding, and landslides have all been greatly exacerbated by the development of agriculture along river banks and forests.

These changes in land use are also having significant adverse effects, including a rise in human-caused CO2 emissions, decreased air and water quality, and altered river flow and sediment patterns. River system hydrology as a whole is impacted. The flow and discharge of river systems are directly or indirectly impacted by changes in land use, which also affect erosion and sedimentation processes (Wu, 2008).

Land Use Landcover Dynamics and River flow

Land use and cover changes affect rivers and their networks, especially flow and discharge. For instance, human activities like urbanisation, deforestation, and agricultural growth contribute to the spatial and temporal change in land use and land cover, which affects flow of water and balance (Rawat & Manish, 2015). Increased agricultural and bare land areas led to increased year-round and seasonal stream flows in addition to higher sediment yield in rivers, according to a study by the International Soil and Water Conservation on the effect of land use and land cover dynamics on the hydrological response of watersheds in Tekeze, Northern Ethiopia.

The study also revealed that changes in land use and land cover caused an increase in the mean yearly stream flow of 6.02 percent (129.20-137.74 m3/s) and an increase in sediment output of 17.39 percent (12.54-15.18 t/ha/yr) as a result. In a study on Hydrogeological changes in urban streams and their ecological significance, published in 2005 and cited in Brown, Gray, Hughes & Meador's impacts of Urban development on Hydrological Systems, Konrad & Booth (2005) linked land use dynamics to human development in Mediterranean landscapes by asserting that these dynamics all contribute to the eradication of indigenous vegetation and soils. Open monoculture crops are grown and impermeable surfaces are created. These dynamics hasten rainy season runoffs and flash floods while slowing groundwater recharge, leading to reduced dry season flows or prolonged no-flow periods. Even after smaller storms pass, there may be an increase in runoffs and tiny peak flow events in river systems due to the presence of impervious surfaces as a result of excessive urbanization (Walsh et al., 2005). While human modification of river catchments has a significant impact on the natural seasonal discharge of water in rivers, other human-dominated activities like irrigation have an impact on river flow. For instance, during the dry season, sewage treatment plant discharges or irrigation return flows can change river flows, sometimes keeping flowing rivers that might otherwise dry up (Prat & Munne, 2000). The findings of a study by Cooper, Sabo & Sabata (2013), which found that irregular water flows (1-100 m3/s) in the Llobregat River of northeastern Spain are influenced by the 55 wastewater treatment plants (WWTPs) dispersed throughout its drainage network (WWTP) discharge occasionally constituting the most of the river flow, amply demonstrate this.

According to research by Aduah, Graham & Toucher (2017) on the hydrodynamic of a lowland-based rainforest catchment in Ghana, under the existing land use patterns, peak and dry season stream flows rose by 21% and 37%, respectively, between 1991 and 2011 compared to the baseline. This increase is the result of evergreen and secondary forests declining by 18 and 39%, respectively. The study's conclusions also showed an 81 percent, 310 percent, and 343 percent increase in the growth of communities, mining regions, and farms, respectively, as dry season streamflow increased. Future research of projected land use also indicated that streamflow might increase further, A continuing impact on streamflow dynamics will be seen in any future land use analysis, according to an analysis of historical land use changes between 1991 and 2011. In accordance with Aduah, Jewitt & Toucher (2017), Truong, Nguyen & Kondoh (2018)'s study of

LULC dynamics and their impact on the flow regime in the upper course of Dong Nai River basin - Vietnam revealed that population growth, which is responsible for the conversion of large acres of land for agricultural purposes, has significantly reduced the amount of land used for such purposes. These processes have had a significant impact on the Dong Nai River Basin's overall discharge, maximum flow, including abundant, typical, low, and small-scale runoff. In the Dinder and Rahad tributaries of the Blue Nile, Ethiopia-Sudan, Hassaballah, Mohamed, Uhlenbrook & Biro (2017) examined streamflow responses to changes in LULC using satellite data together with hydrological models. According to the study's findings, agriculture has increased and woodland has significantly declined. For example, in Dinder and Rahad, respectively, woodland decreased from 42 to 14 percent and from 35 to 14 percent, while cropland increased from 14 to 47 percent and from 18 to 68 percent. This suggests that LULC in the Dinder and Rahad rivers both have an impact on streamflow. The severe drought in the middle of the 1980s and the most recent major expansion in agricultural lands can both be linked to the effect of LULC on streamflow as being significant between 1986 and 2011. This was further revealed by the study by Hassaballah, Mohamed, Uhlenbrook & Biro (2017). Literature makes it clear that the rapid growth in human population is increasing the dynamics associated with land usage, including agriculture, urbanization, mining, and the development of infrastructure, among other things.

Land Use Landcover Dynamics and River erosion

River erosion is a natural occurrence that is becoming more prevalent due to human activity (anthropogenic influences) (Posner, A. & Duan, 2012). Since the late Holocene, the dynamics of human land use have significantly changed the hydrologic and geomorphic extremes of rivers (Allen, et al, 2002). The countless human activities continue to have an impact on rivers and river systems, either negatively or favorably, according to Ansah-Asare (1995). In the long run, this adds to the hydrology of rivers and river systems changing. Watershed erosion, following river sedimentation, water shortages, pollution, as well as other physico-chemical consequences on rivers are among the hydrological processes that are becoming more common and intense as a result of these human activities.

According to Allen, et al, (2002) in their study on the impact of LULC on rivers, removing vegetation, overgrazing, mining, road building, and construction all tend to speed up erosion in the form of sheet flow, gullies, and rills. These other human activities include increasing flood magnitude, decreasing infiltration capacities, altering flow and discharge patterns, and more. Significant upland and downstream erosion is caused by changes in land use and land cover (Aslam, et al, (2020). For a 20-year period spanning from 2000 to 2020 in Pakistan, Aslam, et al used the Revised Universal Soil Loss Equation (RUSLE) model, which is solely based on Geographic Information System (GIS). The findings of their analysis showed that in the year 2000, 4% of the study area was at very high danger of erosion, and that percentage would rise to 8% by the year 2020.

The area's 4 percent increase in agricultural land had an impact on this result, indicating that human activities were mostly responsible for the erosional processes in the studied area. In Western Kenya, a comparable study conducted between 1995 and 2017 found that between 1995 and 2017, there was an average soil loss of 0.3 t/ha/y and 0.5 t/ha/y, respectively, mostly due to sheet, rill, and cross soil erosion processes. The data revealed that farms contributed more than 50% of the total soil loss in both 1995 and 2017. Farms were followed by grass/shrub (7.9% in 1995 and 11.9 percent in 2017) and the forest area (16% in 1995 and 11.4 percent in 2017). The farms that were converted from grass/shrub regions had the highest rates of soil erosion (0.84 tons/ha), followed by those that were converted from forests (0.52 tons/ha). Due to the high speed and erosivity of the discharge, it was also discovered that the rate at which soil erosion increased with slope. High erodibility areas in the area are mostly found on slopes greater than. In the long run, rivers are impacted by these agricultural-related erosional processes because rivers carry and deposit large amounts of silt. Severe cutting of river banks and channels results in direct or indirect changes to the hydrology of rivers.

Land Use Landcover Dynamics and Runoffs

The runoff patterns of many rivers, especially those in tropical regions, have changed dramatically over the past 20 years, according to numerous studies (Syvitski et al., 2014; Legesse et al., 2003). Runoff fluctuations are believed to be mostly a result of climatic changes and anthropogenic activities (Ma et al., 2010). According to Awotwi et al. (2015), human activities such as residential and commercial water consumption, farming, mining, different land use, deforestation, afforestation, development of dams, irrigation canals, and dams, have also caused radical changes in hydrological parameters, particularly runoffs. Studies along the lower Pra River Basin in Ghana, for instance, have revealed that increased human activities—such as those related to agricultural production, logging, industrial water usage, and—most substantially alluvial gold mining, also known as "Galamsey," are, in fact, the main factors influencing the change in runoff (Awotwi et al., 2015; Water Resources Commission, 2012). Awotwi et al. (2015) evaluated the impacts of land use, land cover, and climate variability on water balance components in the White Volta Basin, West Africa, using the SWAT model. The findings showed that evapotranspiration and groundwater or surface runoff traveling both above and below the ground rose and reduced as savannah and grasslands were converted to farmlands. Therefore, according to Awotwi et al. (2015), a rise in temperatures and precipitation causes an increase in evapotranspiration, base flow, and surface runoff.

In a study by Dong, Zhang & Xu, (2012), anthropogenic factors and climate change have caused major alterations in the spatial and geographic distribution of regional river discharge and water supplies in the Nenjiang River System in Northeast China. Wetland’s ecosystem and sustainable agriculture are seriously at risk as a result of this. Dong, Zhang & Xu (2012) employed statistical analysis to look at runoff and rainfall changes in the river basin over a 55-year period, from 1956 to 2010, to estimate the effect of humans on local hydrology. The findings demonstrate that runoff in the Nenjiang River Basin has been steadily declining over the past 55 years, and the effects of anthropogenic activities and climate change on this loss have varied throughout the upstream, middle, and downstream sectors across different time scales. The contribution of human endeavors rose over the course of the study, rising from 19.7 percent as in 1950s to 30.4 percent in contemporary times. As the runoff reduction expanded progressively toward the downstream regions, the large wetlands ecosystems in the lower river basin became increasingly vulnerable to the threat of water availability. It follows that it is clear that human activities have a big impact on how much runoff occurs within and surrounding river basins.

Land Use Landcover Dynamics and Sedimentation

Dynamics in LULC have a major influence on the extent of sedimentation in a river/reservoir. There have been several studies on the hydrologic changes in river basins, and their findings indicated that LULC and other indicators have affected the amount of sediment in rivers (Awotwi et al., 2016; Gao et al., 2016; Zhang et al., 2008). Using a statistical method, Zhang & Lu (2009) evaluated the hydrologic responses to precipitation variability and different human operations in a highland tributary of the lower Xijiang River in China. The effect of rainfall patterns and human activities on the discharge of water sediment load were assessed using dual mass curve and regression analysis approaches. The results demonstrated that human activity, particularly deforestation seen between years 1981 and 1985 as well as between 1986 and 2002, was the primary source of the rising change in sediment load. The study's conclusions on sediment load and water discharge highlight the importance of season and month time series in figuring out the diversity of hydrologic processes. According to research by Zhang, et al, (2008) on recent changes in sediment deposition and discharged load in the Zhujiang (Pearl River) Basin, China, the construction of reservoirs and dams had little effect on water discharge. Precipitation fluctuation mostly affects annual water outputs. However, they noted that at some sites in the Xijiang and Dongjiang's main channel, the sediment load had notable declining tendencies. The effects of reservoir development (human activity) on the basin are reflected in the declining sediment load in the Zhujiang. The second-largest tributary of the Xijiang, the Liujiang, on the other hand, has seen a notable rise in sediment load since 1991, which is most likely due to a rise in rock desertification in karst zones. With the exception of the delta zone, the Zhujiang's annual sediment contribution to the estuary has decreased from an average of 80.4 106 t from 1957 to 1995 to an average of 54.0 106 t from 1996 to 2004. More specifically, since the early 1990s, the sediment load has continuously decreased, reaching roughly one-third of the pre-90s midway point in 2004.

Future reservoir projects, particularly the construction of the Datengxia hydropower plant, and an expansion of the afforestation initiative in the drainage basin will have a greater impact on human activities on the water discharge and sediment load of the Zhujiang. The control of the rate and spread of vegetation in a river basin depends critically on LULC dynamics.

Drivers of LULC Dynamics

Dynamics in climate and LULC affect negatively the hydrological cycle, which causes the ecosystem to steadily deteriorate hence reducing the quality of the land resources, biodiversity, and agriculture (Boakye, et al, 2008). Monitoring

LULC change over time has grown in importance as a factor in environment protection (Kiswanto & Mardiany 2018; Mensah et al. 2019). LULC development is primarily driven by factors such as population growth, urbanization, intensification of agriculture, rising economic activity, developments in science and technology, and resource exploitation (Declee et al. 2014; Muhati et al. 2018; Rimal et al. 2019; Deng et al. 2013). According to Declee, et al, (2014) and Muhati, et al, (2018), LULC dynamics in Africa are primarily caused by the increase in global population, scientific and technological advancements, excessive exploitation of natural resources for economic activities, agricultural expansion, timber harvesting, charcoal production among others. For instance, in the quest to meet the needs of the growing population, people have recently begun turning forests and other types of land cover into agricultural lands. According to Milkessa, Demissie & Dessalegn, (2020), it is anticipated that this transformation of forests to farming land would continue in the future. According to a study done by Yawson, Adu, Ason, Armah & Yengoh (2016), urbanization will likely be higher than what we already experience in the world. For instance, urban populations in developing nations are growing quickly as people move there in search of better lifestyles, financial independence, trade, investment opportunities, and information access (Ma et al., 2010). Alongside this increase in population comes an expansion in economic activity, industrialization, infrastructure development, and transportation, all of which influence LULC dynamics (Ma, et al., 2010). Due to the increased population density that comes with urbanization, water supplies are also put under higher stress.

The extent and factors that influence LULC dynamics have also been the subject of much research (Deng et al. 2013; Geng, et al, (2015); Lark, Mueller, Gibson, Munch, Palmer & Mantel, 2018). LULC data currently available indicate that forests are the land cover system that is most in danger due to deforestation (Fokeng, Forje, Meli & Bodezemo, 2019). Globally, there are 3 percent less hectares of forest, down from 4128 million in 1990 to 3999 million in 2015. Keenan, et al, (2015). In some areas, it is expected that forest areas would continuously shrink uncontrollably (d'Annunzioin & Sandker). Therefore, modifications to LULC may change how ecosystem services are provided and have an impact on human welfare (Deng et al. 2013; Olson, et al, 2008).

Surface mining, coupled with sand winning as drivers of Land Use and Land Cover (LULC) change, can significantly impact the hydrology of rivers. This form of mining involves the extraction of minerals or other valuable resources from the Earth's surface, resulting in substantial alterations to the landscape. According to Cudney et al., (2017), Surface mining facilitates the removal of topsoil and vegetation, which exposes the underlying soil and rock layers. This leads to increased erosion and sedimentation in rivers, as rainwater washes away loose materials from mining sites and carries them downstream. The influx of sediments can negatively impact water quality and aquatic ecosystems, affecting both flora and fauna. From a different point of view, Pejman et al., (2017) believes that, surface mining can modify the natural drainage patterns of an area, resulting in changes in the timing and volume of runoff. The excavation of mining pits, creation of spoil piles, and construction of haul roads can disrupt natural water flow, leading to increased surface runoff and accelerated drainage into rivers Pejman et al., (2017). These alterations can contribute to flash floods, decreased base flow, and changes in streamflow regimes Pejman et al., (2017).

Relationship between River Processes (Hydrology) and Morphology

As a river flows from its source to its mouth, it engages in a variety of processes that sculpt the land around it and the river itself. The main processes connected to rivers are erosion, transportation, and deposition (Amofa–Appiah. (2019). According to Posner & Duan, (2012), the main river process of erosion is the wearing away and decomposition of the rocks, soil, and plants found along the river banks and channels. Abrasive wear, attrition, hydraulic action, corrosion, cavitation, and mass collapse are the main causes of river erosion. River channels in the vicinity are shaped and changed as a result of this process. The primary mechanism that produces loads of materials for transportation, including stones/rocks, boulders, silt, particles, and sediments (Posner & Duan, (2012).

The process by which rivers move their load from their source to outlet is known as river transportation. The method by which rivers move their load depends on both the volume of the materials or particles being moved and the river's energy. The eroded materials are moved toward the downstream channel by a river using its energy Aktar, (2015). Large boulders or other bedload rolling or sliding along the riverbed are known as traction; pebbles, sand, and gravel are known as saltation; these materials are lifted or hopped along the bed by current; and these materials are known as saltation. Saltation is the process of transferring dissolved river minerals like calcium bicarbonate along the riverbed. Suspension is a process in which extremely minute grains of sand or silt are moved along with the water. The majority of the materials carried by rivers are dumped at their mouths, hence the process by which a river deposits or discharges its burden is known as deposition. When rivers' velocity starts to fall, they start to unload their load (Aktar, 2015). The larger particles or materials start to be deposited at this point since the river lacks the strength, capability, and energy to carry its complete burden. When there is little discharge due to little precipitation, there is reduced velocity when the river enters a lake or the ocean, when shallow water reaches a meander, when there is an increase in load, and when the rivers overflow their banks (Allen, et al, 2001).

Because river processes alter the banks, channels, and surrounding land through erosion, movement, deposition, and other processes in addition to human activity, they directly affect how rivers look (Allen, et al, 2001). That is, river processes influence catchments' morphology in addition to their hydrology Aktar, (2015). The shape of a river and the alterations to its shape and flow are described by the morphology of a river. The morphology of rivers is influenced by a variety of erosive processes, particularly erosion, as well as by environmental factors and human activities.

Empirical Literature on how Climate and LULC Changes Affects Rivers Morphology

The relationship between climate and land use/land cover (LULC) changes and river morphology has been extensively studied in the empirical literature. Bracken & Wainwright (2006) investigate the impact of land use change on hillslope-channel coupling in an abandoned agricultural catchment. It highlights the linkages between LULC changes, particularly agricultural abandonment, and river morphology. It was revealed from the results of the study that, the lack of vegetation cover at the abandoned fields is the cause of the increased erosion rates the area is experiencing. Sediments from eroded fields are further transported into rivers, affecting the morphology of river channels. Excessive sedimentation can lead to channel aggradation (filling up) or deposition in floodplains, altering the river's shape and profile (Bracken & Wainwright, 2006).

Grabowski & Droppo (2013) predicts the impact of land use changes on sediment yields in a mixed-use watershed. It examines how LULC changes affect river morphology by altering sediment transport processes. The researchers found that conversion of forested areas to agricultural land will result in increased soil erosion and sedimentation rates. They observed that the removal of vegetation cover and the introduction of intensive farming practices is likely to increase erosion processes, leading to higher sediment yields in streams and rivers within the watershed. Grabowski & Droppo (2013) further predicts that, the expansion of urban areas within the watershed was also associated with elevated sediment yields. Urbanization typically involves the clearing of vegetation, the construction of impervious surfaces, and alterations to natural drainage patterns, all of which contribute to increased surface runoff and sediment transport. The study highlighted the need for effective land management strategies to mitigate the impacts of land use changes on sediment yields in mixed-use watersheds.

Kasvi, Pöyry, Huttunen & Virtanen (2018) examine the effects of climate and land use change on river habitat conditions, this study explores how these changes influence river morphology. It highlights the importance of considering both climate and LULC changes in understanding and managing river ecosystems. Results of the study can be associated with the loss of riparian vegetation reduces shade, increases water temperatures, and weakens bank stability. Without proper vegetation cover, riverbanks are prone to erosion and sedimentation, altering the habitat conditions for fish, macroinvertebrates, and other organisms that rely on riparian zones for shelter, food, and reproduction.

Rinaldi & Lastoria (2017) focusing on the Metauro River in central Italy, assessed the impacts of climate and land-use changes on river ecosystems. It examines the relationship between these changes and alterations in river morphology, emphasizing the need for integrated management strategies.

Empirical Methodology

Climate and LULC dynamics/changes and their associated effects on water bodies especially rivers is a critical area that needs attention. In view of that, various researchers, scholars, institutions and stakeholders in the area of physical and natural sciences and geography (physical geography) among others are putting much of their energy, resources and researches towards finding solutions to curbing climate and LULC dynamics and associated problems.

Various methodological approaches and hydrological models have been employed by these researchers and in the long run have come out with various results, conclusions and recommendations that are being helpful to solving climate and LULC dynamics and associated problems. For instance, Wiwoho & Astuti, (2021) used the SWAT model to evaluate the effects of LULC change and climate variability on hydrological processes in the Indonesian Upper Brantas river basin. The regional variations and temporal trends of the hydroclimatic variables in the basin were examined using the Mann-Kendall (MK) test. Statistical measures such as the coefficient of determination (R2), Nash-Sutcliffe model efficiency (NSE), the ratio of root mean square error to measured standard deviation (RSR), and percentage bias were used to evaluate the effectiveness of the model (PBIAS).

A study on the hypothetical future climate scenarios in Taoer river revealed that, there is a minor rise in the Taoer River's expected runoff in the 2020s and 2030s but a drop in the 2040s compared to the base period. Results from the SWAT model revealed that, in the TRB, the contribution coefficient of farmland is negative, which means that farmland inhibits runoff; the contribution coefficient of woodland is positive, which means that woodland enhances runoff; and, for grass land, the contribution coefficient is catalytic for runoff in the upper reaches of the mountainous area, whereas it inhibits runoff in the downstream plains. The imbalance between the water availability and demand for agriculture has grown over the past 20 years as a result of changes in land use types.

The SWAT model was also employed in Kenya by Kibii, Kipkorir & Kosgei (2021) to assess the effects of LULC and climate variability on the Kaptagat watershed river discharge. The model was calibrated, validated, and tailored for the research area. Simulations were run to determine how the yield and river flow changed over time. Finally, the study found that as population in the watershed increased, land use altered over time, resulting in a drop in forest cover (natural and planted), from about 37% in 1989 to 26% in 2019. The frequency of rainfall episodes also declined but increased. Elegirini and Two Rivers dams in the basin saw significant variations in water levels over the dry and rainy seasons as a result of the shifting land use and climate variability, which were brought on by increased surface runoff and decreased baseflow and groundwater recharge. According to the modeling of the watershed management scenarios, surface runoff dropped by 9%, while groundwater recharge rose by 17%. Therefore, the watershed response regime will improve greatly over time, despite the growing climatic variability, if farmers continue their ongoing activities of afforestation, reafforestation, and terracing, which are expanding the plant cover in the catchment.

Mango et al. (2011) used the Soil Water Assessment Tool (SWAT) in Kenya to examine how the Mara River's headwater hydrology will react to scenarios with continuous land use change and anticipated climate change. Model performance was enhanced utilizing satellite-based estimated rainfall data under the basin's data-limited conditions, which may also increase the usefulness of runoff models in other regions of East Africa. The analysis's findings suggest that any further conversion of forested land to agricultural land and grassland in the headwaters of the basin is likely to decrease dry season flows and increase peak flows, resulting in greater water scarcity at crucial times of the year and escalating erosion on hillslopes.

Combining the investigation of forest cover change with geographic information systems and remote sensing methods, a spatio-temporal study was conducted on the Komto Protected Forest priority area, East Wollega Zone, Ethiopia, by Negassa, Mallie, and Gemeda in 2020. They used the 1991 Landsat

TM image, the ETM + image from 2002, and the 2019 OLI-TIRS image to study variations in forest cover dynamics throughout the years 1991 to 2012. According to the LULCC detection results, agricultural land increased dramatically, rising from 24.78% in 1991 to 33.5% in 2019, with an annual growth rate of 23.68% per year, while forest cover decreased, falling from 20.1% in 1991 to 37.38% in 2019, with an annual decreasing rate of 4.18% per year. The finding demonstrates the expansion of settlement, grassland.

In the case of Ghana, a number of researchers, including Arthur et al., Awortwe et al., (2015), Bessah et al., (2020) Aduah et al., (2017), Kamkam-Yebouh et al., (2003) and Osei et al., have used different methodologies in their individual investigations on climate and LULC-related studies. For instance, the integrated value of ecosystem services and trade-offs model at three time periods of land use and land cover was driven by model outputs at spatial resolutions of 44 km, 12 km, and 0.002 km, respectively, by Bessah, Rajib, Taiwoc, Agodzod, Ololadee & Strapasson in 2020.

A comparison was made between historical water yield changes for annual, seasonal, and monthly timescales (simulated for 1986, 2002, and 2018 LULC using the mean climatic parameters from 1981–2010) and future scenario changes (simulated for 2018 LULC using the mean climatic parameters from 2020–2049). According to the findings, under the regional, sub-regional, local, and ensemble mean of the climate scenarios, the future annual water yield might change by -46%, -48%, +44%, and -35%, respectively. The ensemble means of the future climate scenario predicted that seasonal water yield will decline by 2 to 16 mm, with a mean decline of 33.39% over the season of December to February. The direction of the impact of spatial resolution on water yield was nonexistent.

Aduah, Jewitt & Toucher (2017) used the ACRU hydrological model to analyze the individual and combined effects of climate and land use changes on hydrology on the Bonsa catchment in Ghana, West Africa. For the year (2020-2039) and distant (2060-2079) future time slices, the study analyzed five RCP8.5 climate change scenarios from the CMIP5 AR5 models (wet, 25th percentile, dry, and a multi-model median of nine GCMs). The baseline, present land use, and three future land use scenarios (BAU, EG, and EGR) for two time slices (2030 and 2070) were employed as the change factors to downscale the GCM scenarios.

The study showed that whereas stream flows decreased under all individual climate change scenarios, they increased under combined climate and land use changes. The streamflow responses resulting from the various future land use scenarios were not noticeably different under the combined scenarios. Additionally, the main determining factor in variations in streamflow is land use. In watershed streamflow variations caused by combined land use and climate change, geographic variability was higher than it was for climate change-only streamflow changes. The Bonsa catchment's natural resource and environmental managers now have the first-ever and most up-to-date knowledge needed to create effective adaptation and mitigation strategies and get ready for climate and land use changes (Aduah, Jewitt & Toucher, 2017).

To determine the effect of climate change on streamflow in the White Volta and Pra basin, Kankam-Yeboah et al. (2013) employed the Soil and Water

Assessment Tool (SWAT) and downscaled climate forecasts from the ensemble of two global climate models (ECHAM4 and CSIRO). The SWAT model was calibrated for the two basins, and streamflow estimates for the 2020s (2006-2035) and 2050s were then generated using downscaled future climate projections (2036–2075). The White Volta basin's mean annual streamflow was projected to decline by 22 and 50%, respectively, in the 2020s and 2050s compared to the baseline. Similar decreases of 22 and 46% were seen in the Pra basin's projected streamflow for the 2020s and 2050s.

Researchers studying climate and LULC dynamics have therefore prioritize the necessity to implement appropriate adaptation measures to build resistance to climate change in order to improve water security within river catchments by employing a variety of scientific approaches. In the midst of these approaches and hydrological models, the Soil and Water Assessment Tool (SWAT) is chosen over the other models SWAT in this study simply because the SWAT model integrates various hydrological processes, including rainfall-runoff, evapotranspiration, soil erosion, nutrient transport, and sedimentation (Arnold, et al, 1998). This comprehensive approach enables researchers and water resource managers to assess the complex interactions among these processes within a watershed (Arnold, et al, 1998).

SWAT has been extensively calibrated and validated across numerous watersheds worldwide. Its performance has been evaluated against observed data, ensuring its reliability and accuracy in simulating hydrological processes. These validations have been documented in scientific literature, providing a robust foundation for its application Neitsch, et al (2011). SWAT offers flexibility in simulating different land use scenarios, management practices, and climate change scenarios (Abbaspour, 2015). This allows users to explore various what-if scenarios and assess the potential impacts of different management strategies on water resources within a watershed (Abbaspour, 2015).

Finally, SWAT is specifically designed for watershed-scale analysis, making it suitable for studying water resources management, land use planning, and agricultural practices at a regional level. It considers the hydrological processes within a watershed, including the impact of land use, climate, and management practices on water quantity and quality (Gassman, et al, (2007).

In conclusion, this chapter explored pertinent earlier writings and concepts that are consistent with the study. The researcher looked at a variety of books, findings, ideas, models, theories, and viewpoints expressed by numerous academics and researchers of various ideologies about rivers and river systems, hydrological extremes, major hydrological processes connected to rivers, the influence of climate land use dynamics on rivers, the interaction with both river mechanisms and morphology and the analytical frameworks of the entire research.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

Physical geography research methods are frequently complex. A small number of methods and techniques are frequently used, along with a number of laboratory exercises and the introduction of methods that are separated from one another and the rest of geography (Simm & David, 2002). Consequently, the discussion of the techniques, steps, and resources used in the data collection process is the focus of this chapter. It will consider the research methodology and design, research philosophy, trend analysis of land LULC dynamics using Mann Kendall test tool and satellite images, trend analysis of climate dynamics, description of SWAT inputs, parameter sensitivity analysis, model calibration, and performance evaluation of SWAT model.

Study Area Description

Location of the Study Area

The study was conducted in oti River Basin. The Oti River Basin, a continuation of the Volta Lake, starts as River Pendjari in the Atakora Mountains in Boom, a forest reserve in northern Benin. It travels across and follows the Burkina Faso-Benin border, the highlands of northern Togo, and the border with Ghana. It can be found in Ghana in the eastern edges of the Northern Region, across the middle belt, and into Oti Region and Volta Region. It covers the area latitudinally between 10o 50' and 7o 30' N. Parts of Nalerigu, Gushiegu, Cheriponi, Yendi, Bimbila, Saboba, Zabzugu, and some communities in the Kpandai District of the Northern Region leading to Dambai and Kete-Krachi in the Oti Region into the Volta Lake (Abdul-Razak1, Asiedu, Entsua-Mensah1 and deGraft-Johnson, 2010).

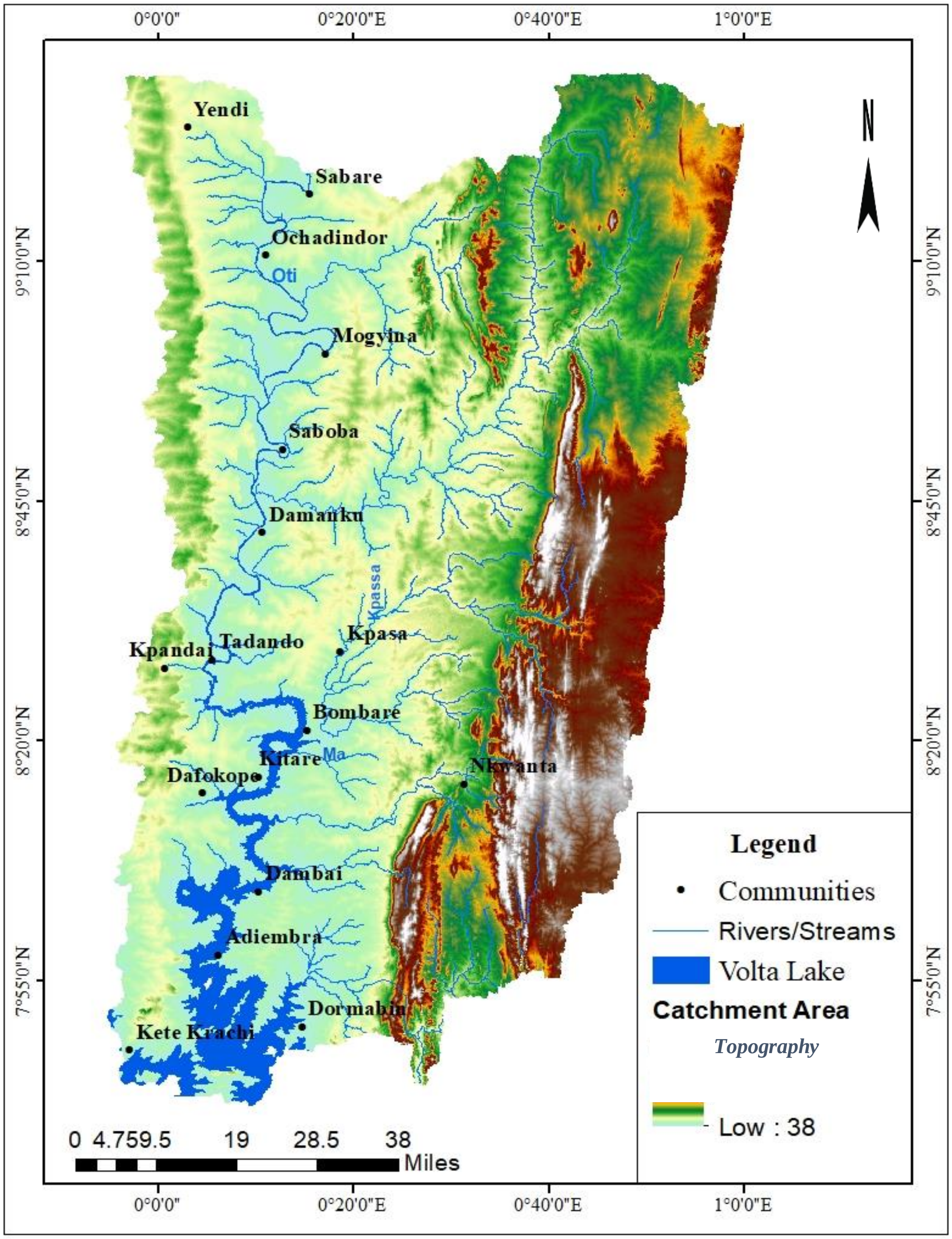

Figure 1: Map of Study Area: River Oti Basin

Source: USGS, 2021.

Geology and Soils

The Oti River in Ghana is primarily composed of cemented sedimentary formations, including limestones, sandstones, mudstone, arkose, and sandy and pebbly beds (Abdul-Razak, et al, 2010). The river also contains granite sand linked granites and other formations. According to Kankam-Yeboah, et al, (2003), the soils in the vicinity of the river are primarily Laterite-Ochrosols, Acid Gleisols, Savannah Ochrosols and Groundwater Laterites.

Climate of the Study Area

The climate of Oti River is either tropical continental or interior savannah. Rainfall is largely distributed in a unimodal fashion. The rainy season runs from May to October, and from November to April there is a prolonged dry season. There is between 1,000 and 1,300 mm of precipitation on average each year. The average yearly temperatures in the Oti River region range from 24.4 to 28.1 DC (Gyau-Boakye & Tumbulto, 2000).

Agricultural Activities of the Study Area

Agriculture plays a significant role in the area's economy and livelihoods of its inhabitants. Several agricultural activities are carried out within the Oti River Catchment Area, contributing to food production and income generation (Azuma et al., 2020). Farmers in the Oti River Catchment Area engage in crop cultivation as a primary agricultural activity. Crops such as maize, millet, sorghum, rice, yam, cassava, and vegetables are commonly grown in the region (Owusu, 2019). These crops provide sustenance for the local population and serve as a source of income through local markets and trade (Azuma et al., 2020).

Livestock rearing is another agricultural activity practiced in the Oti River Catchment Area. Cattle, sheep, goats, and poultry are raised for meat, milk, eggs, and other by-products. Livestock farming contributes to food security, income generation, and employment opportunities for the local population (Owusu, 2019).

The Oti River, along with its tributaries and associated water bodies, supports fishing activities. Local communities engage in artisanal fishing, utilizing traditional fishing methods and equipment. Fish such as tilapia, catfish, and mudfish are commonly caught and provide a source of protein and income for the local population (Gockowski et al., 2004).

Finally, the catchment area is known for its palm oil production. Oil palm plantations are established, and the harvested palm fruits are processed to extract palm oil, which is widely used in cooking and various industries (Azuma et al., 2020).

Settlement Patterns of the Study Area

The Oti River’s catchment area encompasses a diverse range of landscapes, including savannahs, forests, and wetlands, which influence settlement patterns in the region (Abdul-Raza, et al, 2009). The majority of the Oti River Catchment area consists of rural settlements. Traditional agrarian communities are prevalent, with farming and livestock rearing being the primary economic activities. Villages are often clustered around fertile lands, water sources, or transportation routes (Abdul-Raza, et al, 2009).

Within the catchment area, there are several urban centers that serve as administrative, commercial, and transportation hubs. For instance, in Ghana, cities such as Tamale, Bolgatanga, Yendi, Dambai among others are important urban centers in the Oti River Catchment area. Given the presence of the Oti River, settlements along its banks exhibit distinct patterns. Riverine communities often rely on fishing and agriculture as their primary livelihoods. These settlements tend to be more concentrated around riverbanks, where fertile soils and access to water resources are abundant (Gockowski et al., 2004).

The Oti River Catchment area is home to various ethnic groups, each with its own settlement patterns and cultural practices. The distribution of settlements is influenced by historical, cultural, and linguistic factors, with communities often clustered according to their ethnic affiliations (Abdul-Raza, et al, 2009).

Settlement patterns are also influenced by the surrounding natural environment. For instance, areas with favorable climatic conditions, access to water, and fertile soils tend to attract more settlements (Azuma et al., 2020; Abdul-Raza, et al, 2009).

Research Design

Since the study's objectives required substantial or exact measurement and observation, a case study methodology was adopted. According to Yatsu, (1992). intensive study may comprise a careful analysis of a single or a limited number of examples with the main objective of describing the mechanisms underlying the patterns discovered throughout a lengthy investigation. The case study research method is also referred to as an empirical investigation that examines a contemporary phenomenon in its actual context, once the discrepancies for both phenomenon and setting are not entirely obvious, and when various sources of data are used. This is how Yin (2017) describes the case study research method. Even though the case study approach has frequently been referred to be a qualitative approach, the bulk of claims about methodology are only mental constructions meant to indicate a level of comprehension of the way knowledge is obtained and are judged satisfactory for some purposes (Richards, 2018). Consequently, it is essential to understand the many circumstances and contexts in which a particular technique is both created and applied. The case study approach provides a thorough investigation of a single incident or a series of related incidents that show how a particular general theoretical concept is applied (Mitchell 2013; Ragin & Becker 2015). Detractors of the case study method contend that the validity or generalizability of conclusions cannot be established by looking at a small sample size. The validity of the theoretical basis is necessary for generalization because statistical results cannot be used to extrapolate real data or be representative (Mitchell 2013). Although the complexities of these systems can vary, this theoretical justification identifies conceptual frameworks that try to mimic natural mechanisms. Therefore, rather than employing empirical evidence of form or product, theoretical understanding of processes can be used to explain the actions of the systems for which the case study is indicative. This problem is a nice illustration of the need to address non - linearity differently in each case.

Research Philosophy

Behaviorism, a theory that is often used in psychology and the natural sciences, is a notion that is used in this study. When Watson (1913) suggested renaming the discipline of human psychology, he coined the term "Behaviorism" to do so. His main goal was to place psychology on a much more experimental basis by investigating behavior using a range of natural science techniques. In contrast to the mainstream, which comprised introspective and common-sense psychologists, Watson (1913) campaigned for a fundamentally distinct approach to psychology. He proposed, that psychology should approach the study of scientific phenomena or organism understudy through observation. He said, "Second, that some stimuli induce the organisms to create responses," and that "organisms, man and animal alike, do modify themselves to their environment."

Behaviorism is therefore a scientific research philosophy that uses the tenets, theories, and procedures of other natural sciences to produce hypotheses and justifications for the study of behavior. A common idea governing behaviorist research philosophy is that behavior should be explained without particularly identifying mental events since behaviorism is concerned with the science of conduct rather than the study of the mind (Moore, 2011).

Behaviorism places a strong emphasis on the significance of contextual and environmental influences in shaping behavior, almost exclusively to the exclusion of innate or hereditary factors. Essentially, this corresponds to a learning-centered approach (Moore, 2011). In modern times, logical behaviorism uses dualism, physicalism, and cognitivism alongside quantitative methods like nominal data and questionnaires to find knowledge. It follows that it is very clear that behaviorist research philosophy uses both quantitative approaches (in the form of nominal data and questionnaires) and qualitative approaches (in the form of observations) to critically examine the underlying presuppositions, phenomena, features, products, and the implications (behavioral effects) on organisms, systems, humans, and animals, among others.

Employing the behaviorist research philosophy in this study, the river understudy is a system and in one way or the other the organism, which adjust itself to the changes present within its environment. To back this statement, Anderson, (2013) states that river system is more or less an organism which have life on its own. These changes occur as a result of certain stimuli causing the organism (the river) to make responses in the form of behavioral change. River systems responds to natural changes or factors in the form of dynamics in climate and human factors such as land use dynamics in agriculture, mining, afforestation, deforestation, residential development, artificial water consumption, dam construction among others. River systems in responding to these processes and activities of nature and man changes and reshapes their hydrology (behavioral change) in order to maintain its equilibrium (Awotwi, Kumi, Jansson, Yeboah & Nti, 2015; Cameron & Bauer, 2014; Sadoon, Abdullah & Ariffin, 2014; Posner & Duan, 2012). In simple terms, the river which denotes an **organism or feature** responds to climatic and human activities i.e., **stimuli or phenomena** which affects or influences its hydrology (**behavior**). The researcher in the quest to come out with findings of how these stimuli or phenomena are influencing the behavior of the river employs both quantitative approaches.

Trend Analysis of Climate Change Using the Mann Kendall Test Tool

The Mann-Kendall test is a nonparametric statistical test used to analyze trends in time series data. It has been widely employed in various research works across different fields (Meshram & Singh, 2018). It has been very useful in climate studies, hydrological studies among others. In a study by Mishra & Singh (2012), the Mann-Kendall test was applied to analyze the trend of precipitation in the Mahanadi River Basin in India. Zhou et al. (2012) employed the Mann-Kendall test to assess the long-term trends of temperature and precipitation in the Dongjiang River in China whiles Rahman et al. (2020) utilized the Mann-Kendall test to investigate trends in streamflow and rainfall patterns in the Lower Mekong Basin. The Mann Kendall test has not only been useful in Climate and hydrological studies, it has also proven to be useful in medical research, economics and finance. For instance, Kipruto, et al, (2017) applied the Mann-Kendall test to analyze the trends in malaria cases in Baringo County, Kenya whiles Zhang et al. (2008) used the Mann-Kendall test to examine the trends in carbon emissions in China's power industry.

Analyzing the trend of climate change and its relation to hydrological extremes of the Oti River will assist in examining historical climate data, study hydrological records, and understanding the cause-and-effect relationship between climate patterns and river behavior. Figure 2 below shows how the Mann Kendall test was used to examine trends in temperature and rainfall in the Oti River catchment with associated effects on the river.

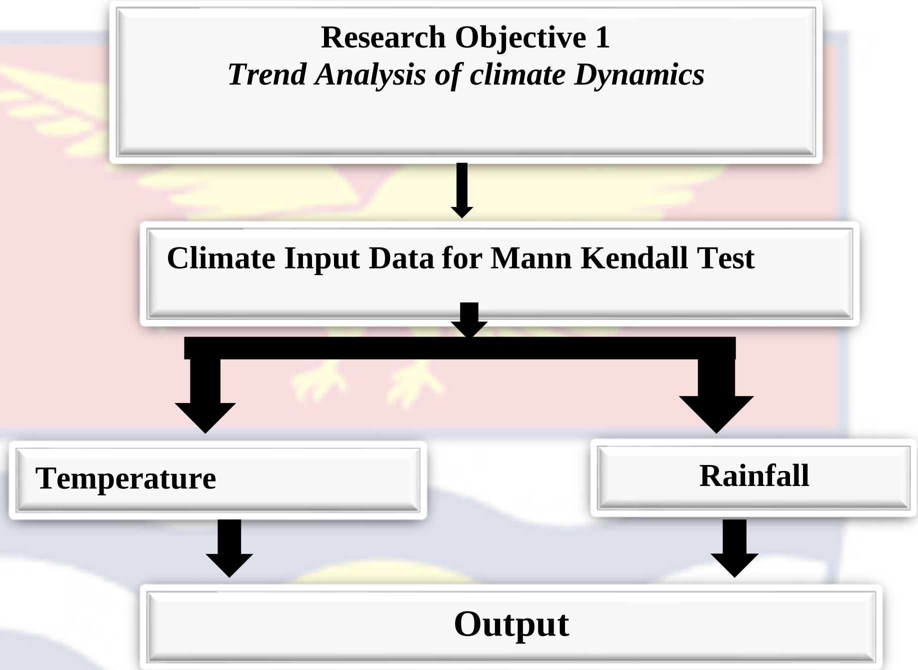

Figure 2: Flow Chart for Time series analysis of climate

Source: Field Data, 2021.

To understand variations in both precipitation (rainfall) and temperature, a time series analysis of climate (temperature and precipitation) data was carried out. The choice of rainfall and temperature for the trend analysis is influenced by the fact that; both rainfall and temperature are major climatic elements contributing to dynamics in climate and hydrology in a given area at a specific time period (IPCC, 2014). Annual trends in rainfall and temperature data were analyzed using Mann-Kendall Statistical Test (M-K test). XSTAT (trial version); an extension of Microsoft Excel houses the Mann-Kendall test tool. XSTAT (trial version) was therefore downloaded from https://www.xlstat.com/en/download on 3rd October, 2021.

A time series' monotonic upward (increasing) or downward (decreasing) trend can be identified using the Mann-Kendall Statistical Test (M-K test), a nonparametric statistical technique. When identifying sudden changes in hydrological and climatic data, it is particularly useful (Zaiontz, 2021). Due to its tolerance for non-normally distributed data and its parity with parametric competitors in terms of power (Gao, Mu1, Wang & Li1, (2011), the Mann-Kendall Statistical Test (M-K test) was chosen. This statistical tool is based on two fictitious premises: 1. In the two-sided test, there is no trend for either the null hypothesis or the alternative hypothesis, and in the one-sided test, there is either an upward or downward trend (Zaiontz, 2021).

The negative and positive signs of the S value, which correspond to the datasets upward and downward trends, respectively, are displayed, while S = 0 shows no trend. By matching them to the standard normally distributed table at the required significance level, the normalized variation j and I values in Eq. (3) can be utilized to determine the statistical significance of the trends Z. The two-sided trend test rejects the null hypothesis H O if |Z|>|Z (1-) /2|; otherwise, H O is accepted. The significance threshold was set at 0.05 (Zaiontz, 2021).

The interpretation of the MK test output depends on the values of the test statistic and the p-value.

Test Statistic (S):

If $S > 0$: It indicates a positive (upward) trend in the data.

If $S < 0$: It suggests a negative (downward) trend in the data.

The magnitude of S represents the strength of the trend. Larger absolute values of S indicate stronger trends (Kendall, M. 1975; Yue & Wang, 2004).

P-value:

The p-value assesses the statistical significance of the trend. If the p-value is less than the chosen significance level (0.05), it indicates that the observed trend is statistically significant. In other words, the trend is unlikely to have occurred by chance. If the p-value is greater than the significance level, it suggests that the observed trend is not statistically significant. In this case, we fail to reject the null hypothesis, which states that there is no trend present in the data (Kendall, 1975; Yue & Wang, 2004).

When interpreting the MK test results, it is important to consider both the test statistic and the p-value together.

If $S > 0$ and the p-value < 0.05: There is a statistically significant positive trend in the data.

If $S < 0$ and the p-value < 0.05: There is a statistically significant negative trend in the data.

If the p-value > 0.05, regardless of the sign of S: There is no statistically significant trend in the data (Kendall, 1975; Yue & Wang, 2004).

The Mann-Kendall Tau

The Mann-Kendall Tau (also known as the Kendall rank correlation coefficient) is used to determine if there is a trend in a time series data set. It measures the strength and direction of monotonic association between two variables, typically in a time-ordered sequence. The Mann-Kendall test assess if there is a statistically significant increasing or decreasing trend in the data over time, without making any assumptions about the distribution of the data.

Trend Analysis of Land use/landcover Changes Using Landsat Images

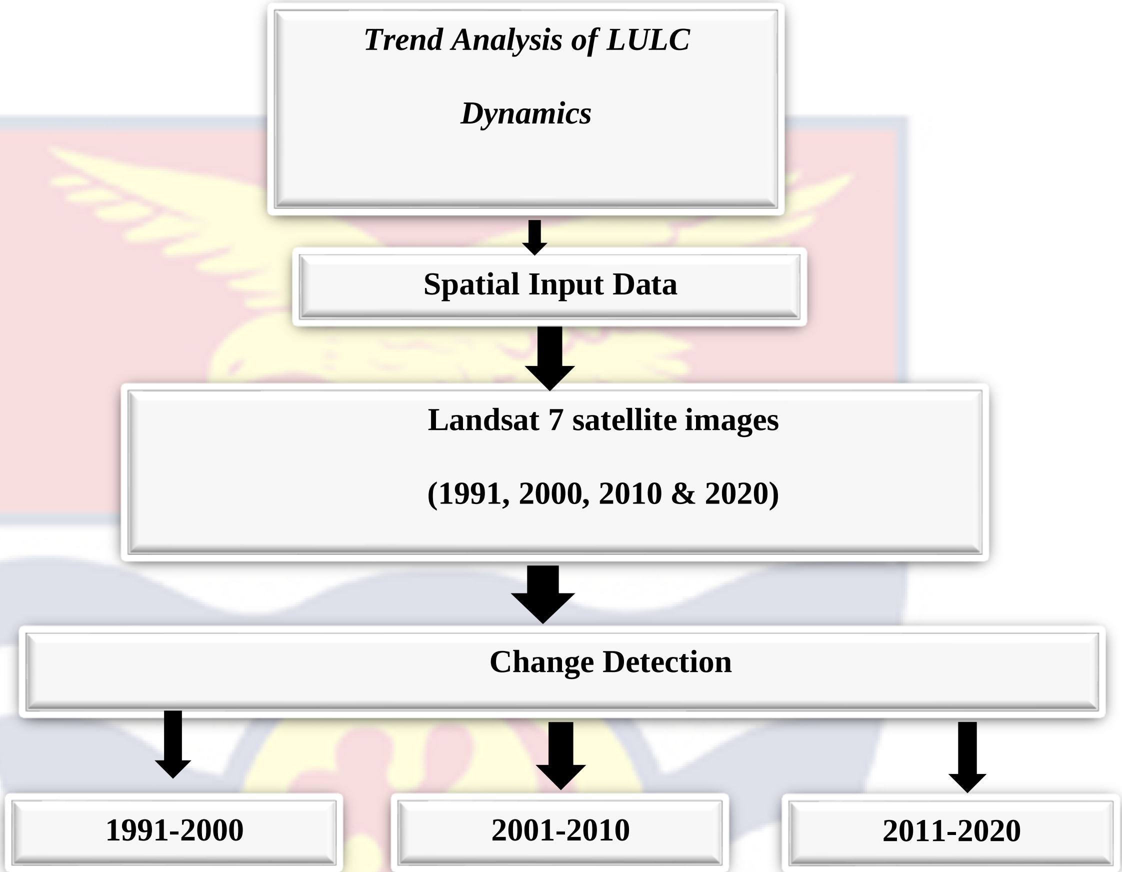

Figure 3: Flow chart for Trend Analysis of Land use/landcover dynamic

Source: Field Data, 2021.

The dynamics of LULC of the Oti River were investigated using satellite data from remote sensing. In order to identify changes in LULC and categorize the land uses of the basin, Earth Explorer (http://earthexplorer.usgs.gov) was specifically used to download Landsat 5, 7 and 8 images for the years 1991, 2000, 2010 and 2020 from the US Geological Survey website (USGS). These years were used because, the researcher wanted to monitor the changes in the trends by categorizing the 30-year period of the study to ten (10) years each. After downloading the images for the period under study, the images/data was imported to ArcMap for processing. Data alignment was done to ensure that all the data sources were in the same spatial reference system for consistency in spatial resolutions and so the images were projected onto the UTM zone 30N/WGS 84 coordinate system. A composite image was created from the 8 bands of the actual image downloaded using a combination of three different bands: 6-5-4 (i.e., near-infrared, red, and green bands, respectively). NDVI was done to determine the strength of the vegetative areas. Unsupervised classification was done to help determine the variabilities within the dataset. This was followed by the running of supervised classification to help correct any errors. The primary target classes were water bodies, farms, urban/bare/built up areas, and forest cover (closed and open). The spectral classes were identified using high-resolution Google Earth pictures, auxiliary data (field records and agriculture maps from Ministry of Food and Agriculture) and the vegetation image with combination of different bands for the different Landsat images for the different years.

It is important to note that, satellite sensors capture electromagnetic radiation in different spectral bands, such as visible, near-infrared, and thermal bands. While these bands can provide useful information for distinguishing between different land cover classes, differentiating farmlands from other classes based solely on spectral signatures can be challenging. This is because farmlands may exhibit similar spectral characteristics to certain types of vegetation, making it difficult to differentiate them purely based on spectral information. In light of this, data on farmlands in the Oti area was taken from Ghana Census of Agric, field records and maps from the Ministry of Food and Agriculture was used to serve as the ancillary data.

Hydrological Modelling Using SWAT

There are now more sophisticated methods for analyzing our planet and its properties thanks to advancements in computer technology (Jayakrishnan, Srinivasan, Santhi & Arnold, 2005). One of these cutting-edge approaches involves the use of the SWAT model, a semi-distributed model typically used in the analysis of rivers and river management techniques.

In broad watersheds with fluctuating soils, land uses, and agricultural factors over long periods of time, the SWAT model is typically used to forecast the effects of land management strategies on water, sediment, and agrochemical outputs (Arnold, et al 1998; Mango et al, 2011). This model was developed in 1990 by the USDA Agriculture Research Service (USDA-ARS) to evaluate the effects of various management options on water resources and pollution in key river basins. According to Arnold et al. (2012), the SWAT model is a computational model based on processes that can perform continual simulation for a very long time. The SWAT model is made up of various procedures that serve as sub-models, with the weather, hydrology, soil conditions and features, plant development, micronutrients, pesticides, bacteria, and diseases, as well as land management being key SWAT model components. SWAT's sub-models include the Chemicals and Runoff from Agricultural Management Systems (CREAMS) model, the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model, the Routing Outputs to Outlet (ROTO) model, the Simulator for Water

Resources in Rural Basins (SWRRB) model, the Routing Outputs to Outlet (ROTO) model, the Environmental Policy Integrated Climate (EPIC) model, and the Inland River (Wang, Jiang, Xie, Zhao, Yan & Yang, 2019; Arnold et al., 2012).

The two basic components of the SWAT modeling method, according to Wang, et al, (2020), are the water surface, which also includes the concentration of channels, and the land surface, which includes runoff and slope confluence. Each sub-main watershed's channel is supplied with water, sediment, nutrients, and chemicals by the model's Land surface component. The surface water model, which also calculates the load, controls the flow of water, silt, and other material components from the river system to the basin. According to the concept of water circulation, the water balance expression used in the SWAT model is expressed as follows: The daily evapotranspiration is denoted by ***ET***, the daily evaporation by ***R,*** the daily percolation by seep ***W,*** and the daily return flow by ***gw Q***. The soil's final water content is represented by the numbers ***t SW, 0SW***, and ***t,*** where ***t*** is the number of days.

Millimeters are used to measure all dimensions. When the SWAT model is applied, the sub-watersheds are organized into several hydrological response units (HRUs). This is a result of the various soil types and land uses. Using the model to divide sub-watersheds into HRUs will improve the model's simulation accuracy (Gassman et al., 2007). The Digital Elevation Model (DEM) for the watershed or drainage basin, the land use map and index table, the type of soil and soil attributes database, meteorological data, observation runoff, and management data are some of the primary data needed to run the model.

The researcher’s choice of the SWAT model over other models is due to its accuracy in modelling ungagged rivers. It provides accurate results over a short period of time using spatial data from satellite images and climate data.

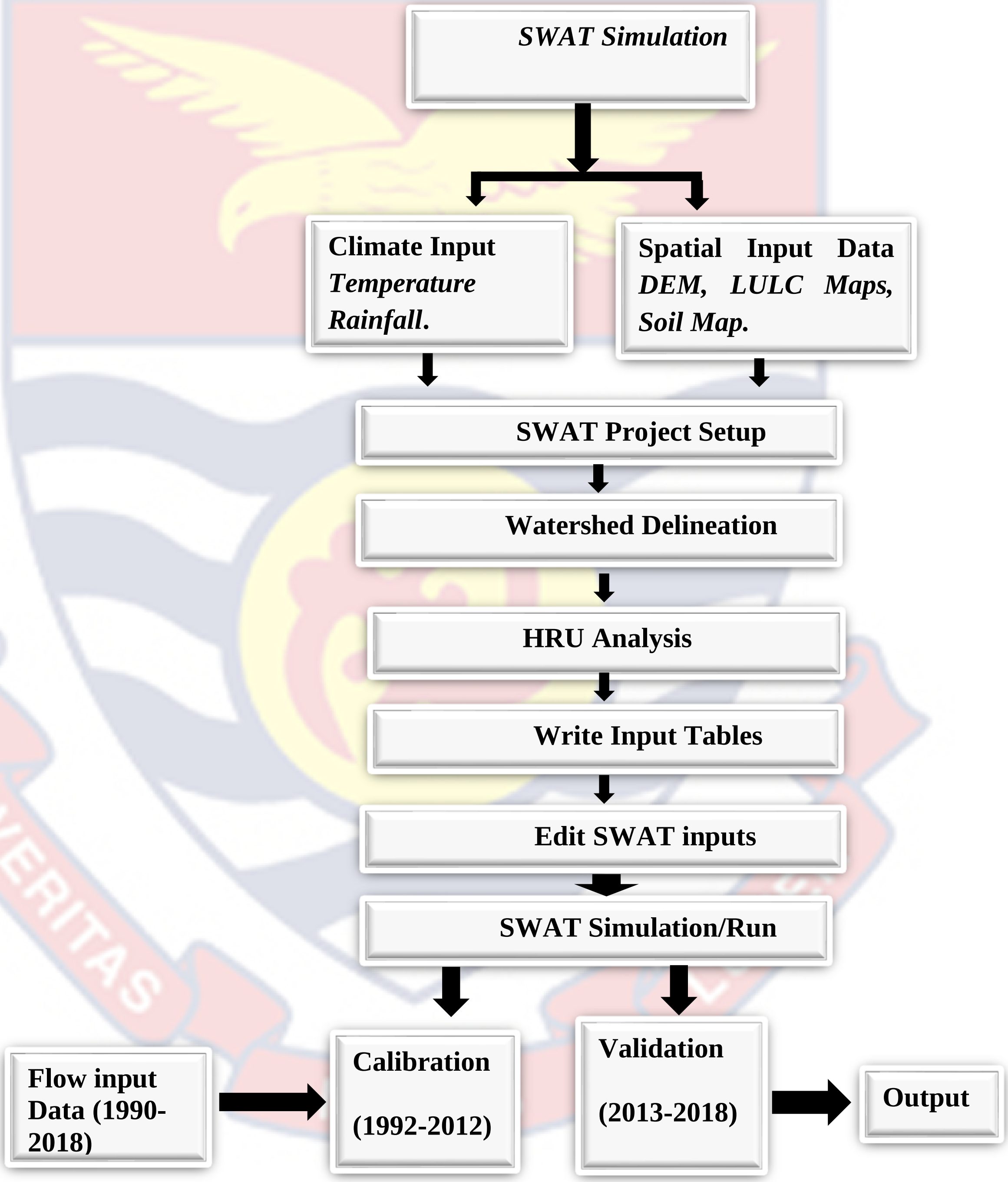

Figure 4: Flow Chat for SWAT Simulation and Calibration

Source: Field Data, 2021.

Hydrological modelling using the ArcSWAT for ArcGIS is one of the major tools used in the study. GIS data comprising of topographic data in the form of Digital Elevation Model (DEM), soil and land use data and sub-catchment ID were the first badge of inputs for running the SWAT model. The second badge of input needed to run the model include climate data. Temperature (Minimum and Maximum) and precipitation (Rainfall) are the main climate inputs used for running the model. In order to successfully run the ArcSWAT for ArcGIS, first of all, Arcmap (version 10.5-64bit) was downloaded from link: https://www.esri.com/en-us/arcgis/products/arcreader and installed. ArcSWAT and SWAT editor for free were also downloaded from http//swat.tamu.edu and installed.

The hydrological component of SWAT is driven by the soil water balance of a river basin, which is represented by Equation 1

$$SWt = SWo + \sum_{i=1}^{t}(\mathrm{Rday} - \mathrm{Qsurf} - \mathrm{Ea} - \mathrm{Wseep} - \mathrm{Qq} - a)^{n} \;\ldots\ldots\; \text{Eq (1)}$$

Where:

SWt = Soil water content (mm)

SWo = Initial soil water content on day i (mm)

t = time (days)

Rday = Amount of precipitation on day i (mm)

Qsurf = Amount of surface runoff on day i (mm)

Eai = Amount of evapotranspiration on day i (mm)

Wseep=Amount of water entering the vadose zone from the soil profile on day i (mm) and

Qqw = Amount of return flow on day i (mm).

Spatial Data (Digital elevation model (DEM)

The 90-m resolution Shuttle Radar Topography Mission (SRTM) DEM was the DEM that was utilized (USGS 2006). On September 9th, 2021, it was freely downloaded from the US Geological Survey's (USGS) seamless website at https://earthexplorer.usgs.org. The downloaded data was first processed from the rasta format to mosaic and then merged with the Universal transverse Mercator (UTM). The DEM with its coordinates was projected on ArcSWAT, followed by the ordering and accumulation of flow and flow direction. To determine streams of higher order and the dynamics involved in the flow of the river, the Oti River has to be ordered into a stream network.

Land-use/land cover Inputs

Downloaded from the United States Geological Survey (USGS) website was a cloudless Landsat 7 satellite image of the study region. With a 30 m spatial resolution, the Landsat 7 image comprises four bands. On August 25, 2020, the image was captured. Using ArcMap, a composite image with the band combination 6-5-4 (i.e., near-infrared, red, and green bands, respectively) was created, exposing the satellite image to pre-processing. An investigation of the spectral classes in the image was aided by ISO Cluster Unsupervised. A supervised categorization was then done after that. For this study's purposes, the land use and land cover classes created for the study area are (1) Closed Forest, (2) Open Forest (3) Water, (4) Bare lands/Built-up Areas and Farmlands.

Soil maps and Properties

The FAO digital soil map of the world was used to obtain the soil maps, from which soil attributes were deduced (FAO, 2016). It is available in raster format and has a spatial resolution of 10 km. On the map, about 5000 different soil types may be identified, with some soil characteristics for two levels (0–30 cm and 30–100 cm depth) (Shope, et al, 2014). FAO-derived soil parameters were used to collect information on soil characteristics, such as texture, bulk density, saturation conductivity, organic carbon content, and accessible water content.

Streamflow data

The Hydrological Services Department (HSD) of the Ghanaian Ministry of Water Resources, Works, and Housing provided daily streamflow data for the stream gauge at Sabari on the Oti River for the years 1990 to 2020.

Climate Input Data

Observed daily climate data on precipitation and temperature (minimum and maximum) were obtained from the Ghana Meteorological Agency. The observed climate data covered a 29-year period ranging from 1990-2019. Even though, the initial plan was to cover a 30-year period but it was later on found out that data for the year 2020 was not readily available hence the researcher resought to limiting the coverage to a 29-year period. The WXGEN weather generator available in SWAT was used to fill in any missing records in the climatic data from modelled stations. For the river understudy modeling method, two climate stations were utilized.

SWAT Simulation

From the Oti River drainage network, Dambai and Kete-krachi were selected as the main hydroclimatic stations used for the study whiles Sabari, a hydrological gauge at the upstream of the Oti River catchment was used as the gauge station for calibration. A total of 8 sub basins were delineated at the course of defining the river networks for the study region. A threshold region of 103.5 km2 was thought to zoom into the Oti river's relatively larger streams. A multiple land surface slope with four classes of slopes (0–7 percent, 7–17 percent, and 17–87 percent) was selected to describe the land surface slopes in the HRU definition. While the soil data was reclassified in accordance with the "User soil" table in the SWAT2012.mdb database, the land use data was reclassified in accordance with the crop and urban tables. The numerous criteria were used, with the land use, soil class, and land cover slope classes set at 2 percent, 1 percent, and 2 percent, respectively, taking into account the HRU definition. The threshold values were established to guarantee that all the dominating classes in the definition of land use, soil, and land cover slope are taken into account when the HRUs are created (Arthur et al., 2020). Last but not least, the simulations were run for a total of 29 years (1990-2019), with the first two years serving as a warmup period (1990-1991). A monthly timestep was used for printing the output.

Parameter Sensitivity Analysis

Based on the literature, r__CN2.mgt, v ALPHA BF.gw, v GWQMN.gw, r_REVAPMN.gw, r_REVAP.gw, r_RCHRG_DP.gw, r_SOL_AWC().wgn, r_PCPMM().wgn, r_PR_W1().wgn were selected as the sensitivity parameters. Following the flow calibration approach suggested by Neitsch et al., (2002). sensitivity parameters were assessed in SWAT-CUP using a one-at-a-time and global sensitivity analysis. The Absolute SWAT Values.txt file in SWAT-CUP was used to determine the initial range for the model parameters. By using the absolute change (a) approach and replacement, the parameters were changed (v).

Table 1: Parametric table

Parameter	***Description***
r__CN2.mgt	Curve number for moisture conditions
v ALPHA BF.gw	Baseflow alpha factor
v GWQMN.gw	Groundwater minimum threshold
V_GW_DELAY.gw	Groundwater process
r_REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur
r_REVAP.gw	Groundwater "revap" coefficient
r_RCHRG_DP.gw	Deep aquifer percolation fraction
r_SOL_AWC. wgn	Available water capacity of the soil layer
r_PCPMM().wgn	precipitation simulation code
r_PR_W1().wgn	Probability of a wet day following a dry day in the month.

Source : (Arthur, et al, 2020 ; Arnold et al., 2012)

Model Calibration and Validation

The calibrating process involved both Manual and Automatic steps. A manual calibration was performed using SWAT Calibration Helper (version 1.0), and an automatic calibration was performed using SWAT-CUP (SWAT Calibration Uncertainty Program). The algorithm Sequential Uncertainty Fitting (SUFI-2) was used to carry out the automatic calibration. The Hydrological Services Department's flow data from Sabari was used for the calibration and validation. Data for the calibration was utilized from January 1, 1990, to December 31, 2012, whereas data for the validation was used from January 1, 2013, to December 31, 2019. On a monthly time-step, the calibration and validation were carried out.

Performance Evaluation of the Model

The performance measures utilized to assess the degree of adaptation between the outcomes of the SWAT model simulation and the observed/measured values included the Nash-Sutcliffe efficiency coefficient NSE, the correlation coefficient R2, the percentage bias, and the root mean square error (RMSE). The computational formulas of NSE, $R2$ RSR and PBIAS are as follows:

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}-Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs}-Q_{mean})^2}, \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq (2)}$$

where Q_{obs} the ith observation for the constituent being evaluated, Q_{sim} is the ith simulated value for the constituent being evaluated, Qmean is the mean of observed data for the constituent being evaluated, and n is the total number of observations. NES ranges between −∞ and 1.0 (1 inclusive), with NSE =1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Liu, et al, 2007).

$$R^2 = \frac{= \sum n\ i=1\ [(Qobs - Qm)\ (Qsim - Qs)]2}{\sum n\ i=1\ (Qobs - Qm)\ 2 \sum n\ i=1\ (Qsim - Qs)\ 2\ ,} \ldots\ldots\ldots\ldots \text{Eq (3)}$$

A correlation coefficient R^2 value closer to 1 indicates that the performance value and measured value trends are more synchronized; that is, the performance value is better (Liu, et al, 2017).

$$\text{PBIAS} = \frac{\sum_{i=1}^{n}(\text{Qobs}-\text{Qsim})*(100)}{\sum_{i=1}^{n}(\text{Qobs})} \text{……………………Eq (4)}$$

where Q_{obs} is the observed data; Q_{sim} is the simulated data and N is the number of compared values. PBIAS is the percentage deviation of the data under evaluation. Percent streamflow Volume Error (Shope, et al, 2014), Prediction Error (Arthur, et al, 2020), and percent variation of streamflow volume are all calculated using similar methods (DV). The deviation term (Dv) is employed to evaluate the accumulation of changes in river discharge volume between simulated and observed data for a particular time of analysis (Moriasi, et al, 2007).

$$\text{RSR}= \frac{RMSE}{STDEVobs} = \frac{[\sqrt{\sum_{i=1}^{n}}(\text{Q}obs-\text{Qsim})2]}{\sqrt{\sum_{i=1}^{n}}(\text{Qobs}-\text{Qmean})2} \text{………………Eq (5)}$$

RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in the equation (Shope, et al, 2014).

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents and discusses the results in accordance with the research objectives of the study. The chapter therefore presents results from the trend analysis of climate dynamics. These includes; trends result for rainfall and temperature changes. The discussion also includes results from the trend analysis of LULC changes, and results from change detection in LULC in the Oti River basin. The last part of the results and discussion presents results of the combined impact of climate and LULC change on the flow of the Oti River. This includes results of soil distribution in the watershed, results for sensitivity of model parameters after final calibration in SWAT-CUP with their Fitted Values, performance indicators of SWAT model and a sub-basin analysis and presentation of inflows and outflows.

Results from the Trend Analysis of Climate Change

Dynamics in climate have a significant impact on hydrological extremes of river systems, especially, on flow/discharge, water balance, runoffs, erosion and sedimentation (Musie, Sen, and Chaubey, 2019). The trend analysis for climate (rainfall and temperature) on the Oti River is based on the stipulated time period for the study, that is 1990-2020 but due to lack of climate data for the year 2020, a 29year period (1990-2019) was used.

Trends in Temperature Dynamics

Table 3. shows temperature results for Kete-Krachi station. The results from M-K test indicates a mean of 7666.1 and 10773.6 for both minimum and maximum temperature respectively. It is also observed from the analysis that annual temperature has consistently been high throughout the years as used in the M-K test. Temperatures exhibited an up and down trend from 2007 to 2011 and maintained the consistently-high but decreasing temperature for the rest of the years; including recent years. As determined by the M-K test, the null hypothesis H0 cannot be ruled out if the computed p-value is higher than the significance level alpha=0.05. A commutated p value of 0.106 was obtained from the test findings, which is higher than the alpha threshold of 0.05. H0 is therefore accepted; while there are no discernible changes in the temperature dynamics of the Oti River catchment region during the specified time period, there has been an increase in the average yearly temperature. This corroborates the claim made by the Royal Society and the US National Academy of Sciences (2020), according to which direct satellite measurements made since the late 1970s have not revealed a net increase in the Sun's output while simultaneously showing an increase in the Earth's surface temperatures. The trend analysis for both rainfall and temperature data therefore proves that, there are no significant trends in climate dynamics in areas along and around the Oti River.

Table 2: Temperature Results from Mann Kendall Trend Test

Parameter	*Results*
Kendall's tau	0.215
S	87.000
Var(S)	2838.333
p-value	0.106
Alpha	0.050
Z	1.614

Source: Field work, 2021.

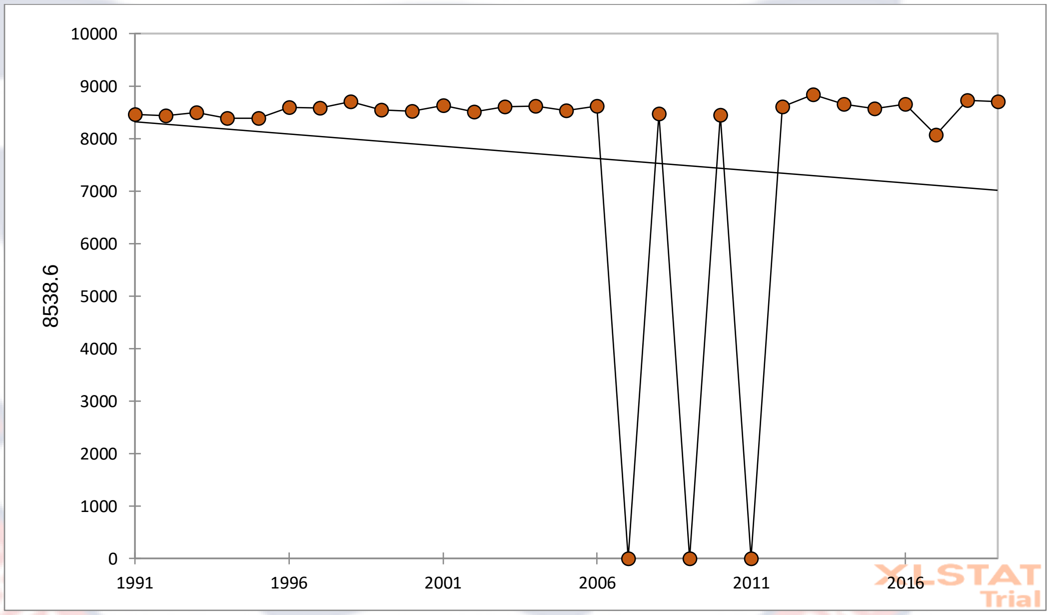

Figure 5: Graphical Representation of Trends in Temperature in the Oti River Area

Source: Field Data, 2021.

Trends in Precipitation (Rainfall) Dynamics

Table 3 shows the precipitation results from Mann Kendal Trend Test. Results from the 29 observations from both stations (Dambai and Kete-Krachi) indicates respective means of 486.879 and 1304.355. It is also observed from table

3. that there are no much variations in the dynamics in rainfall in the two stations. As established in the M-K test, if the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0. The computed p-values (0.388, 0.320) for both stations as shown in table 3. are both greater than the alpha value=0.05, therefore the H_O is accepted; there are no significant trends in rainfall dynamics in the Oti River catchment area, meanwhile the results showed a decreasing trend in rainfall over the years. This is in line with the study conducted by Ankomah-Baffoe, (2018) and WRC (2017) that in the past decade the amount of rainfall at the Densu River Basin has reduced. This also confirms Sultan & Gaetani, (2016) that simulation of future rainfall in west Africa is governed by uncertainties.

Table 3: Precipitation Results from Mann Kendall Trend Test

Parameters	***Station 1(Dambai)***	***Station 2 (Kete-Krachi)***
Kendall's tau	-0.120	-0.133
S	-46.000	-54.000
Var(S)	2716.000	2842.000
p-value	0.388	0.320
Alpha	0.050	0.050
Z	-0.901	-1.031

Source: Field Data, 2021.

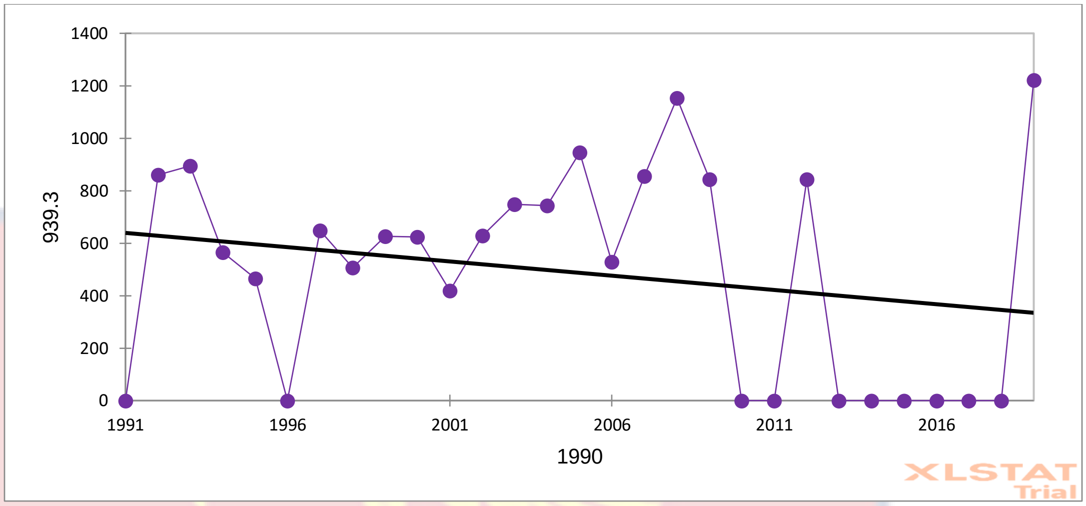

Figure 6:Graphical Representation of Trends in Precipitation (Rainfall)in Areas Around Dambai

Source: Field Data, 2021.

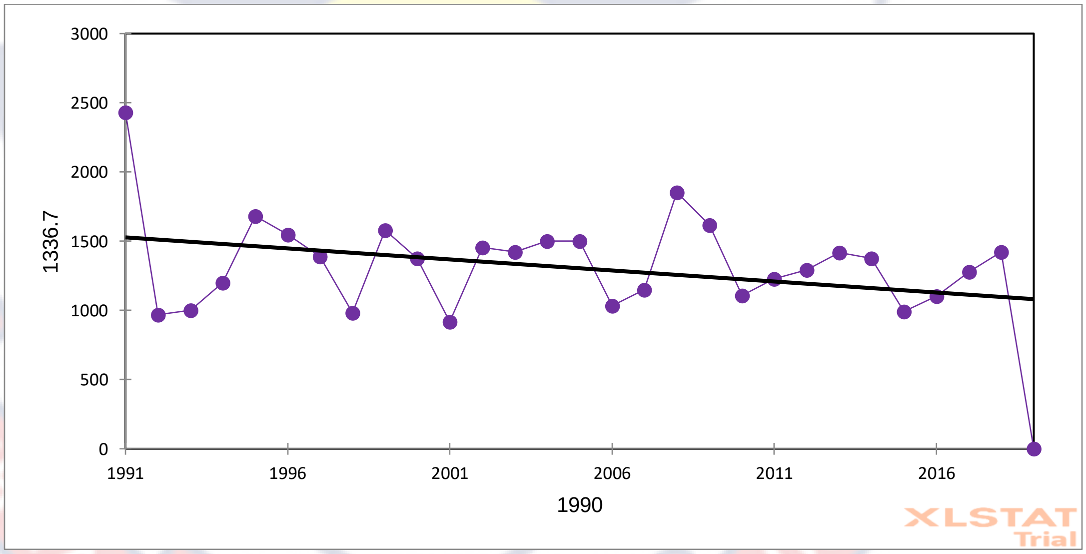

Figure 7: Graphical Representation of Trends in Precipitation (Rainfall)in Areas Around Kete-Krachi.

Source: Field Data, 2021.

Results from the Trend Analysis of Land Use/Landcover Dynamics

Land Use Land Cover (LULC) dynamics have immense influence on the hydrology of River systems. The chapter discusses the findings that resulted from the trend analysis of LULC dynamics in the Oti River catchment. The trend analysis was based on a 29-year period, that is from 1991-2020. A change detection was also carried out for the periods of 1991-2000, 2001-2010, 2011-2020 and an overall change from 1991-2020.

Fig 8 shows the LULC classifications a 29- year period, that is from 1991-2020. The initial plan is to capture a thirty (30) years LULC classification periods, that is from 1990-2020, but due to unavailability of data for 1990, the researcher re-sought to using a twenty-nine-year classification of LULC changes from 1991-2020. The broader classifications used in the classifications includes, built up/bare lands, Closed Forest, Open Forest, Farmlands and Water. The study covered a total area of 11,276sq/km.

Fig. 8 and 9 below shows the LULC classifications and a summary of LULC Classifications for 1991 respectively. As shown in the LULC map for the year 1991 and Fig 9, Farmlands dominated the Oti catchment. 4,833sq/km of lands were farmlands whiles 4,173sq/km was open forest. 1,067sq/km of lands was closed forest whiles 840sq/km was a combination of built-up area and bare lands. The area covered by water is very small. Water covers 363sq/km of the area.

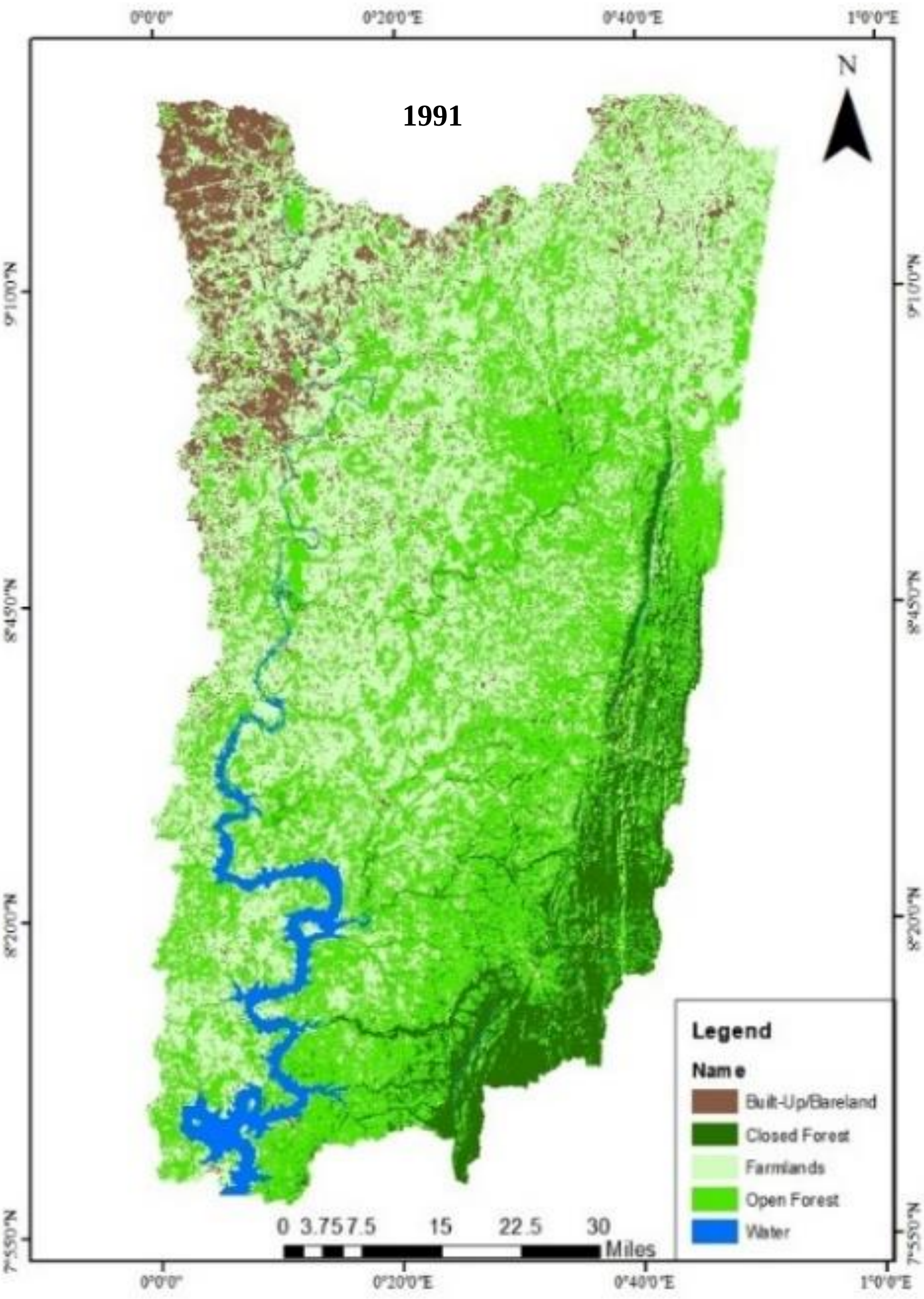

Figure 8: LULC classifications for 1991

***Source: USGS, 2021*.**

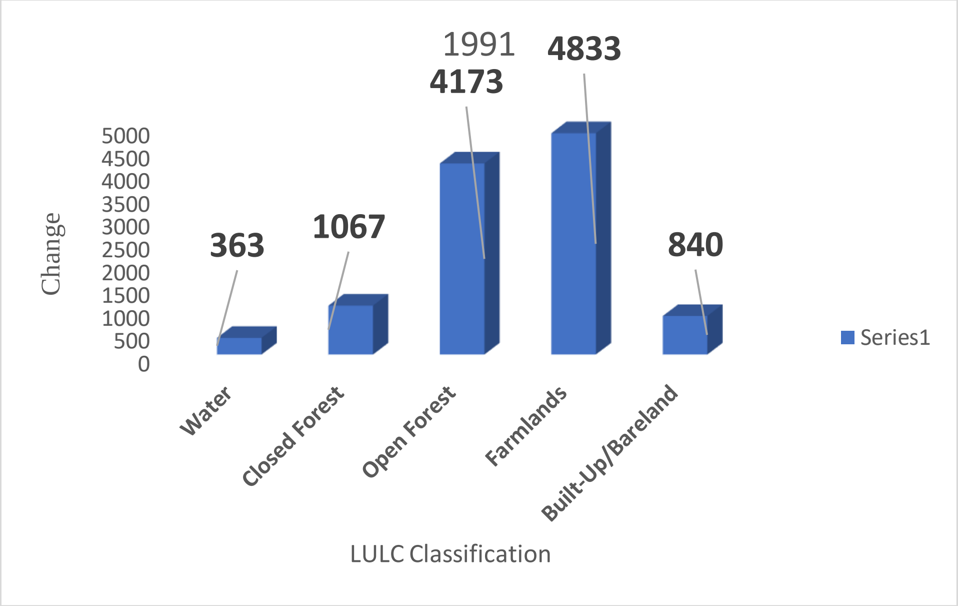

Figure 9: Summary of LULC Classifications for 1991

Source: Field Data, 2021.

Fig 10 shows the LULC classifications for 2000 whiles Fig. 11 gives a summary of LULC classifications for 2000. It is however clear from fig. 10 and 11 that, there have been a reduction in farmlands and open forest from 4,833sq/km (1991) to 3,127sq/km (2000) and 4,173sq/km (1991) to 3946sq/km (2000) respectively. Meanwhile Closed Forest, Built-up/bare lands and water increased from 1067sq/km (1991) to 2,341sq/km (1991), 840sq/km (1991) to 1,493sq/km (2000) and 363sq/km (2000) to 370sq/km (2000) respectively.

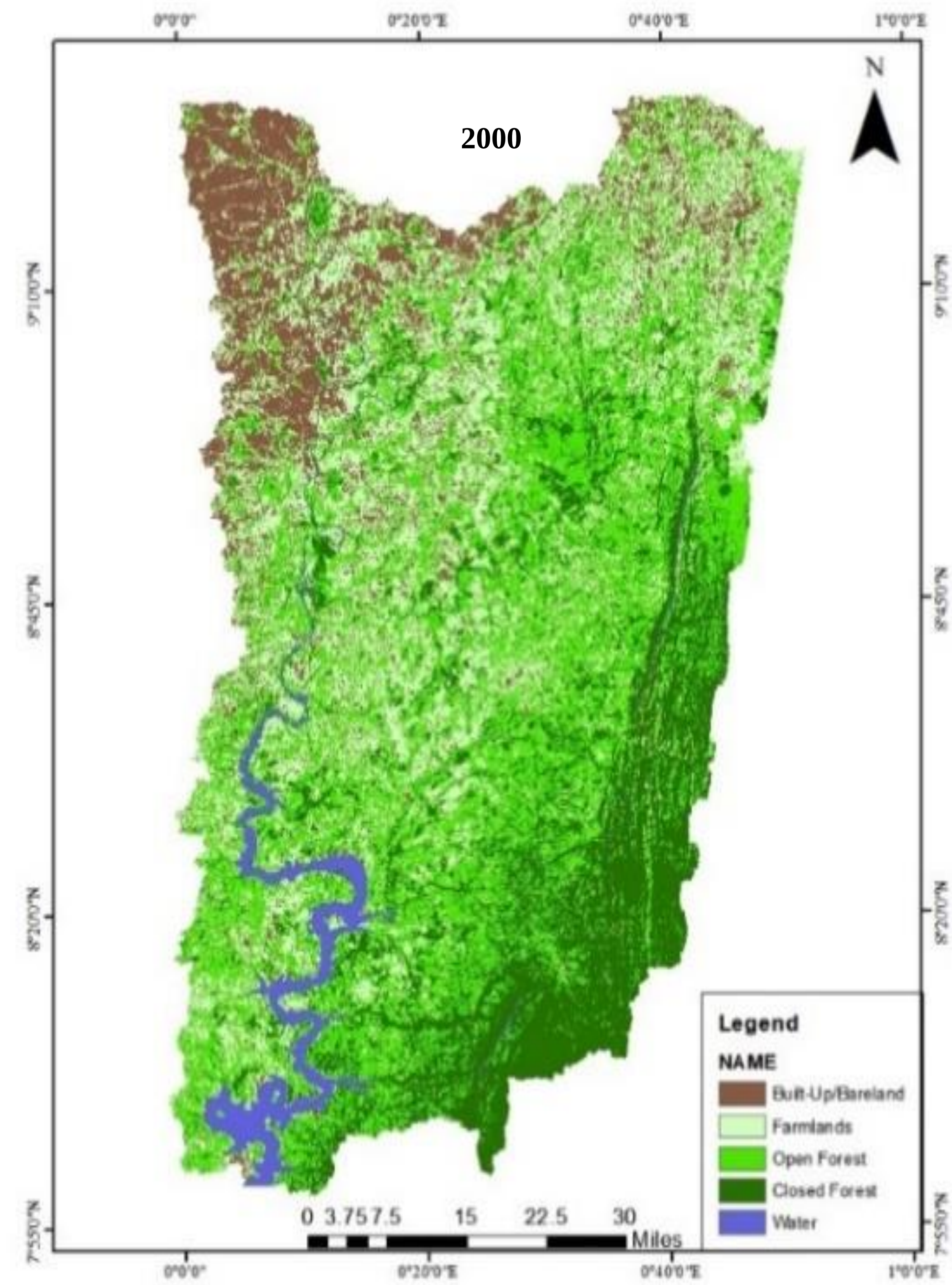

Figure 10: LULC classifications for 2000

Source: USGS, 2021.

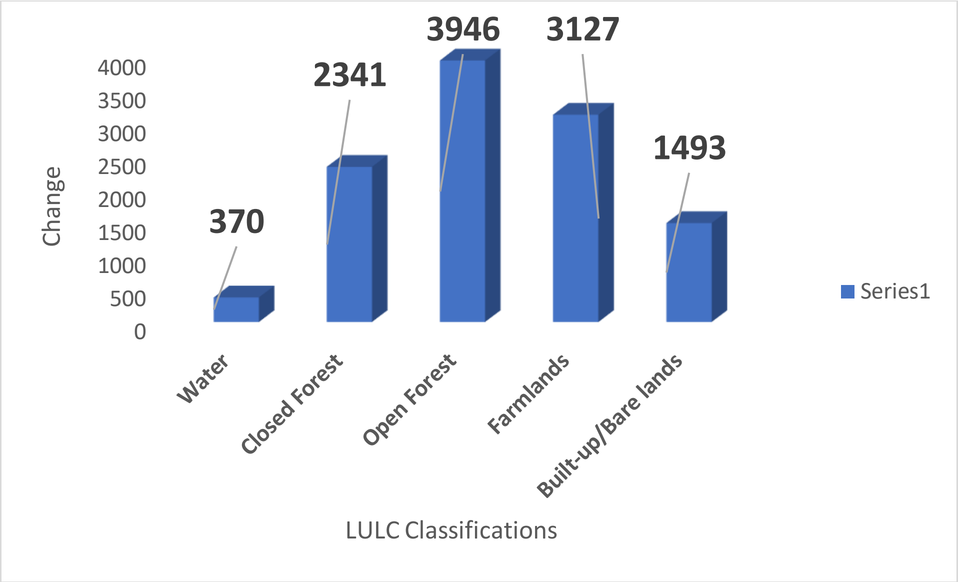

Figure 11: Summary of LULC Classifications for 2000

***Source: Field Data, 2021*.**

Figure 12 and 13 respectively shows the LULC classifications and a summary of the LULC classification for the year 2010. it was shown that farmlands covered a total area of 3,885sq/km, close forest covered a total of 3,630sq/km, open forest covered a total area of 1,528sq/km, built-up and bare lands covered 1,910sq/km and 323sq/km is covered by water. There is an indication from the map and the graph that, there has been an increase in the area covered by all the classes except water.

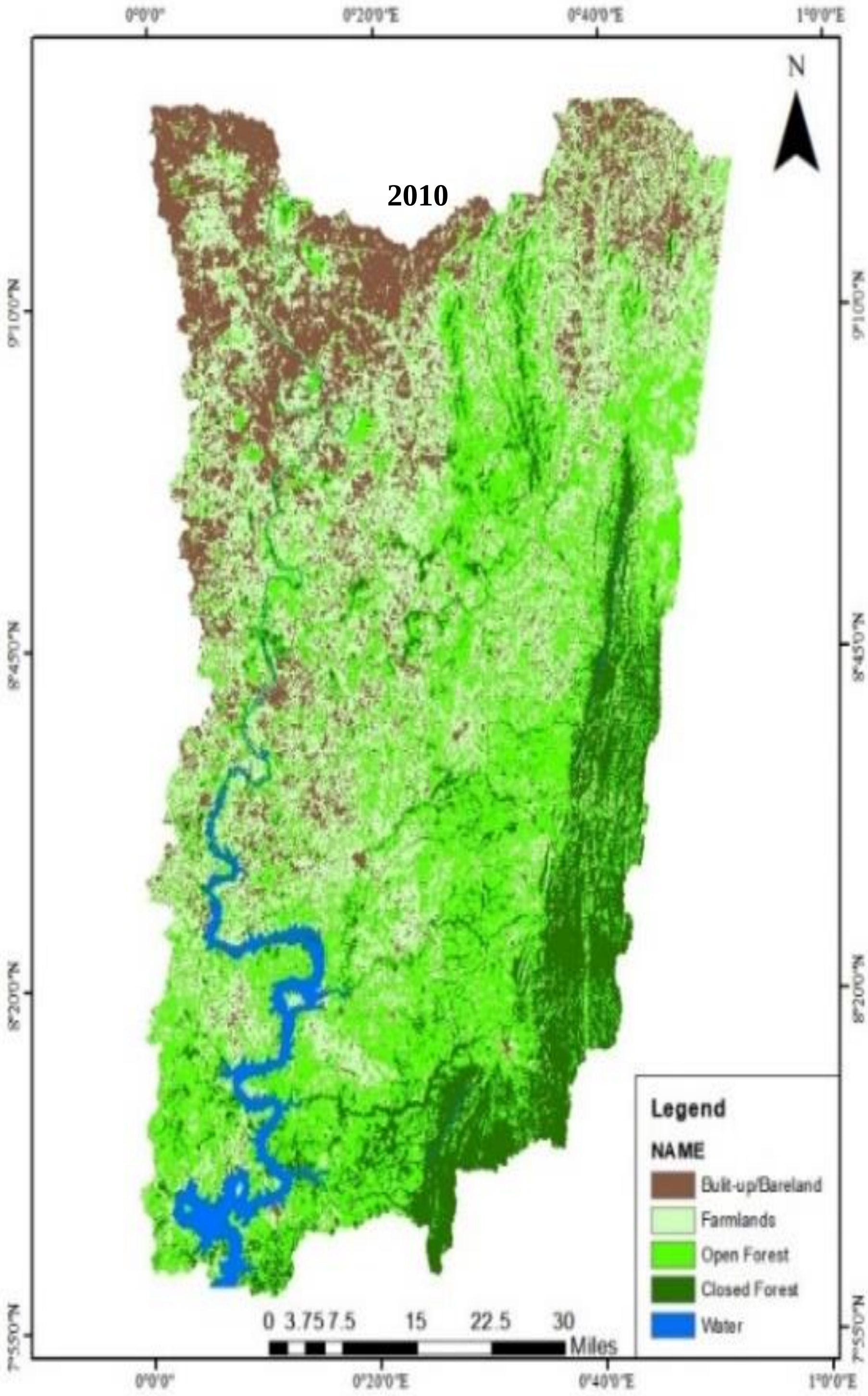

Figure 12: LULC classifications for 2010

Source: USGS, 2021.

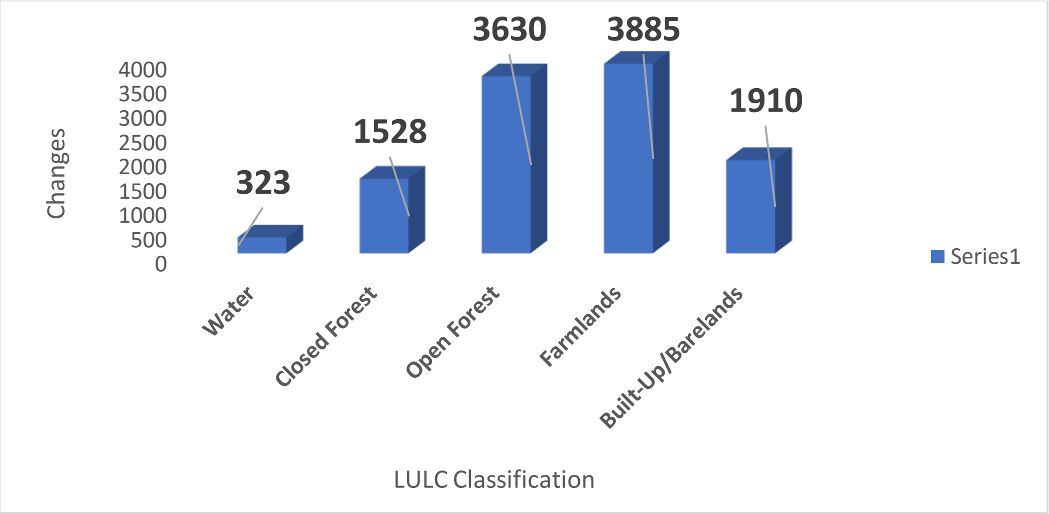

Figure 13: Summary of LULC Classifications for 2010

Source: Field Data, 2021.

Figure 14 shows the LULC classification/map for the year 2020 whiles Figure 15 summarizes the results of the LULC classifications for 2010. The results indicates that LULC of the Oti River area/catchment has changed drastically. It has been revealed that, several kilometers of farmlands, water lands and the closed forest have been lost. Majority of these lands have been converted to open forest, built-up and bare lands. Open forest in recent times covers 4,108sq/km of lands as captured in the study area whiles built-up/bare lands cover 3033sq/km of lands. There has been a drastic increase in bare lands and the built-up area over the years. Over 2000sq/km of lands in the catchment area have been converted to bare lands and built-up, an indication that, there are a lot of human activities taking place in the area. Farmlands, closed forest and water lands now covers a total area of 2,585sq/km, 1,186sq/km and 363sq/km respectively.

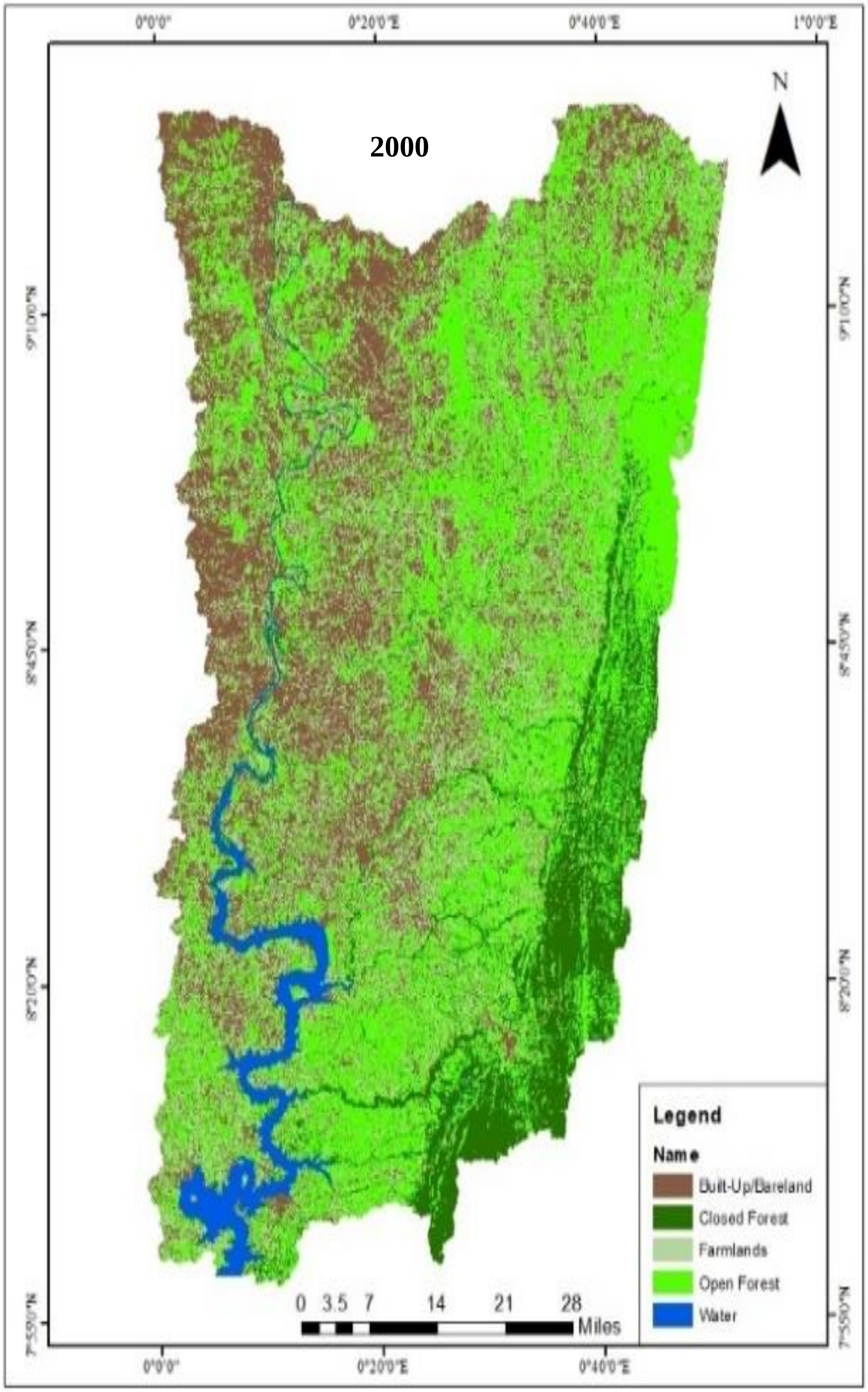

Figure 14: LULC classifications for 2020.

***Source: USGS, 2021*.**

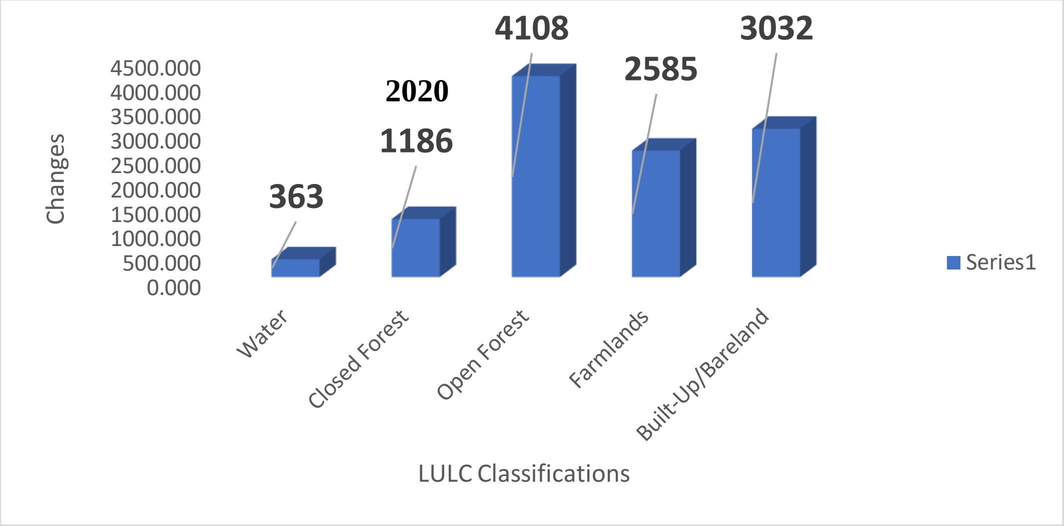

Figure 15: Summary of LULC Classifications for 2020

Source: Field Data, 2021.

Change Detection in LULC in the Oti River Basin

Change detection in Land Use and Land Cover (LULC) analysis is essential to monitor and understand the dynamics and transformations occurring in the Earth's surface over time (Cooper, et al, 2014). The researcher therefore compared and analysed the images captured at different time periods to identify and quantify changes in land use and land cover classes within the Oti catchment.

Fig. 16 and 17 presents the changes detected over the first nine-year period, that is 1991-2000 and a graphical representation of the changes detected respectively. It was revealed that, majority of farmlands were further reconverted to farmlands, followed by the reconvention of open forest lands to open forest. This confirms the prediction made by d'Annunzioin, et al, (2015) that forest areas are projected to continue to decline at alarming rates in some regions. From fig. 16 and 17, it was also shown that, 3089.06sq/km of farmlands were further converted into farmlands whiles 2,863.19sq/km of lands were reconverted to open forest. It was also revealed from the change analysis that, major open-forest lands were converted to closed forest during the nine period. 1279.96sq/km of the open forest was converted to closed forest. Shifting the attention to the extent of closed forest lost during the stipulated period, it was revealed as shown in fig. 14 7.88sq/km of the Closed Forest was lost to Water, 1,056.29sk/km of Closed Forest was reconverted to Closed Forest, whiles 2.56sq/km of the Closed Forest area was changed to Open Forest. As little as 0.12sq/km Closed Forest area was converted to Farmlands and 0.34sq/km of Closed Forest was converted to Built-up and Bare lands. It is evident from the analysis that, the closed forest has not been greatly lost to the other classes. This is majorly as a result of the presence of the Togo ranges present in the closed forest area. Human activities are very low in this area hence much of the closed forest is being reconverted into closed forest.

It was also shown that, a major component of the open forest is further converted into open forest, meanwhile, quite an extent of the open forest has been lost to the other classes. As scanty as 1.03sq/km of Open Forest lands was captured by Water, whiles as large as 1279.96sq/km of Open Forest lands were converted to Closed Forest. 27.73sq/km of Open Forest was converted to Farmlands and 0.98sq/km of Open Forest was converted to Built-Up and Bare lands. Farmlands dominated the area during this period (1991-2000) and it has been revealed from the change detection that over 3000sq/km of farmlands were reconverted into farmlands, whiles 1,079.45sq/km of Farmlands were converted into Open Forest. 0.61sq/km of Farmlands were becoming Water, 1.95sq/km of Farmlands were converted to Closed Forest and then 661.62sq/km of Farmlands were converted to

Build-Ups and Bare lands. Between the period 1991-2000, the built-up and bare lands were scanty, and so no Built-Up area was captured by Water. 0.13sq/km and 0.25sq/km of the Built-Up/Bare lands were respectively converted to Closed Forest and Open Forest. The Built-Up/Bare lands converted to Farmlands was 10.24sq/km whiles Built-Up to built-up (Bare Lands-Bare lands) was 829.61sq/km of the catchment area. 361.05sq/km of Wet lands were recaptured by water, 1.83sq/km of Water lands were converted to Closed Forest whiles 0.08sq/km of Water lands were converted to Open Forest. Due to the slow pace of human activities during this period, no water lands were converted into farmlands but 0.03sq/km of Water lands became Built-up and Bare lands. It therefore very clear from the analysis that human activities were very less in the Oti Catchment between 1990 and 2000 hence the land cover was majorly influenced by natural processes resulting from climate among others.

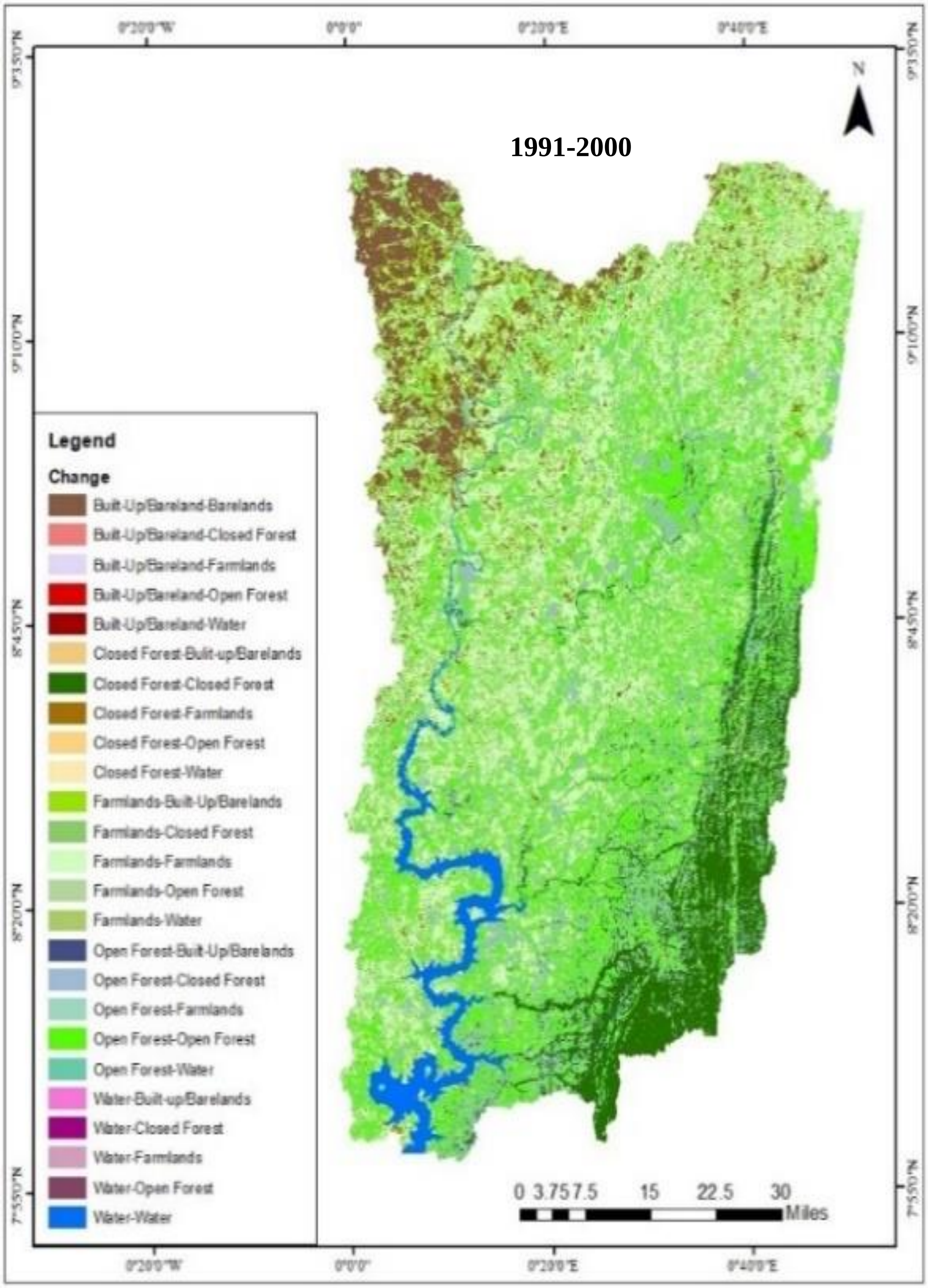

Figure 16: Change Detection for 1991-2000

Source: USGS, 2021.

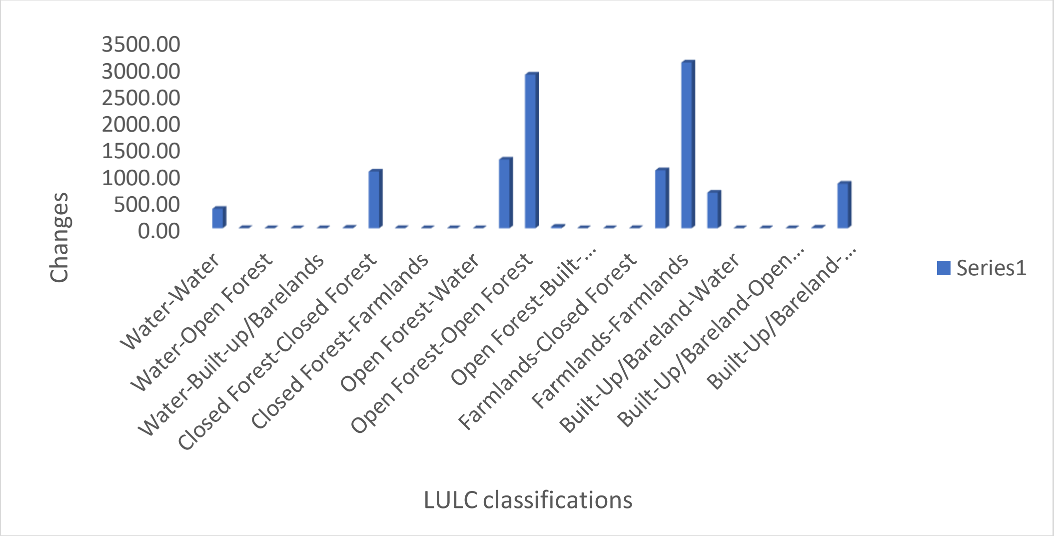

Figure 17: Graphical Representation of Change Detected for 1991-2000

Source: Field Data, 2021.

Fig. 18 shows the change detected from 2001-2010 whiles fig. 19 presents graphically the detected changes. It was revealed that many kilometers of farmlands were being lost to the other LULC classes. As revealed from the analysis, 1648.97sq/km of Farmlands were reconverted into Farmlands whiles 738.01sq/km of Farmlands were converted into Open Forest, 684.91 sq/km of Farmlands were converted to Built-Up and Bare lands. 54.14 Sq/km of Farmlands were converted to Closed Forest and 0.13sq/km of Farmlands were captured by Water. Most of open forest however, was being reconverted into open forest hence the reason for which open forest dominated the area from this period to recent years. 1967.73sq/km of Open Forest was reconverted to Open Forest, 1411.78sq/km of Open Forest was converted to Farmlands, 291.87sq/km of Open Forest was converted to Built-Up and Bare lands, 274.97sq/km of Open Forest was converted to Closed Forest whiles 0.28sq/km of Open Forest was converted to water lands.

It was also revealed from the analysis that 1,149.87sq/km of Closed Forest was reconverted to Closed Forest, 827.58sk/km of Closed Forest was converted to Open Forest, 306.97sq/km of Closed Forest was converted to Farmlands, 52.30sq/km of Closed Forest became Built-Up and Bare lands and 2.76sq/km of Closed Forest became Water lands. Built up and bare lands in the catchment area started increasing during this period (2001-2010). Bare lands-Built-Up/Bare lands increased from 829.61sq/km at the end of the 1991-2000 period to 879.75sq/km at the end of 2001-2010year period. Meanwhile, 514.97sq/km of Bare lands/built-ups was converted to Farmlands, 87.99sq/km of Built-ups and Bare lands were captured by Open Forest, 8.48sq/km of Bare lands/built ups was converted to Closed Forest

and 0.57 to water. The total area reconverted into water during the time period was 319.87sq/km. 39.72sq/km, 8.88sq/km, 1.65sq/km and 1.85sq/km of water lands was converted to Closed and Open Forest, Farmlands and Built-Up/Bare lands respectively.

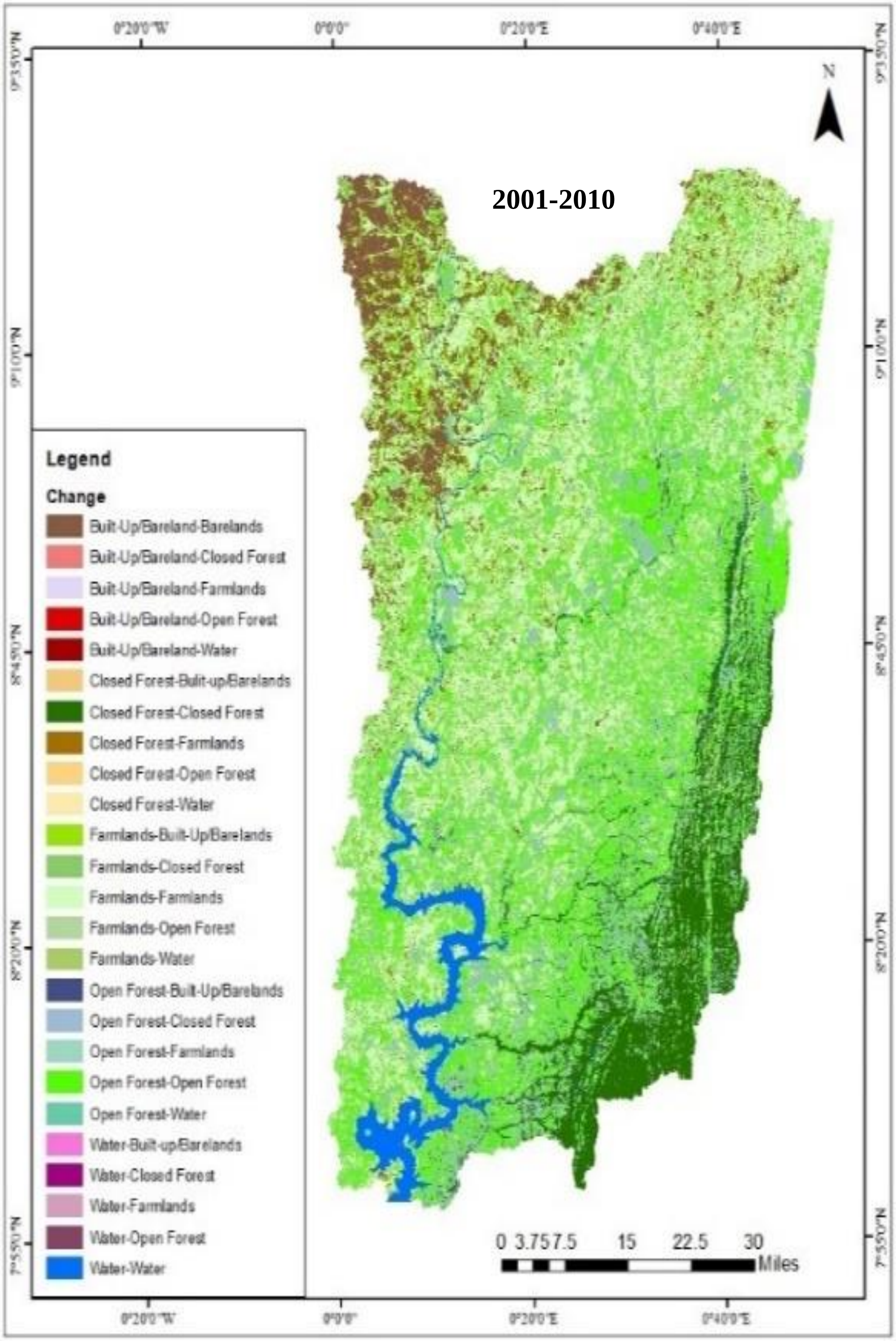

Figure 18: Change Detection for 2001-2010

Source: USGS, 2021.

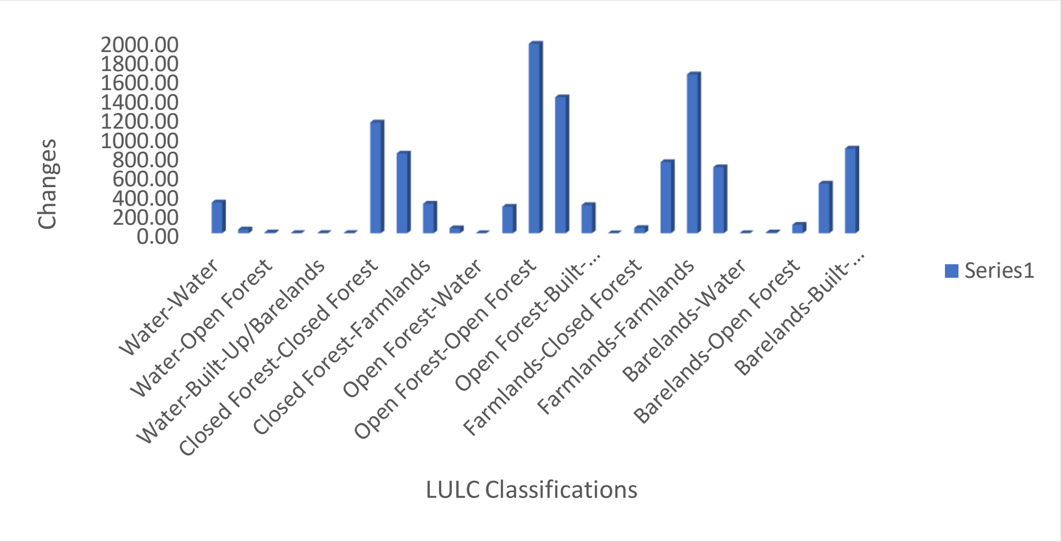

Figure 19: Graphical Representation of Change Detected 2001-2010

Source: Field Data, 2021.

Figure 20 and 21 shows and presents a graphical representation of changes detected in the Oti River catchment from the period 2011-2020. The results indicates that open forest continue to dominate the Oti River catchment area, even though there has been a sharp decrease from 1967.73sq/km (2001-2010) to 1939.84sq/km (2011-2020). 536.9sq/km of Open Forest has been converted into Built-Up and Bare lands, 243.7sq/km has been converted into Closed Forest whiles 894.2sq/km have been converted into Farmlands. 14.7sq/km of open forest has been converted into water lands. Closed forest is reducing drastically in the catchment area. Closed forest has reduced from 1,149.87sq/km (2001-2010) to 902.80sq/km (2011-2020). 55.48sq/km of Closed Forest has also been converted into Built-Up/Bare lands, 99.91sq/km Farmlands, 438.11sq/km into Open Forest and 30.92 to Water lands. The area covered by water has seen a more decrease in recent times even than the previous years; 361.05sq/km change (1991-2000), 319.87sq/km (2001-2010) and 311.46sq/km (2011-2020). This change can be associated with the conversion of water areas to forest, both closed and open, farmlands and built-up areas. For instance, the results showed that 10.78sq/km of Water has been converted into Closed Forest, 0.31sq/km to Farmlands, 0.75sq/km to Open Forest whiles 55.48sq/km has been added to the gradually increasing built up and bare lands in the catchment.

The Closed Forest has also decreased in the recent period from 902.80sq/km (2001-2010) to 834.40sq/km (2011-2020). The results from the analysis as presented in fig. 15 indicates that 26.55sq/km of the Closed Forest are now Farmlands, 192.47sq/km is now Open Forest, 9.65sq/km is now part of the built-up and bare lands whiles 3.34sq/km is now water. On the other hand, as Open Forest, farmlands water and the closed forest are experiencing a decrease in their coverage in sq/km, built-up/ bare lands are increasingly dominating the Oti River catchment. Built and bare lands is now next to open forest in size (sq/km). over the ten-year period (2011-2020), 507.92sq/km of Built-Up/Bare land have been reconverted into Built-Up/Bare land, 2.50sq/km has been converted to Closed Forest, 154.01sq/km to Farmlands, 174.00sq/km to Open Forest and 1.15sq/km has been captured by Water.

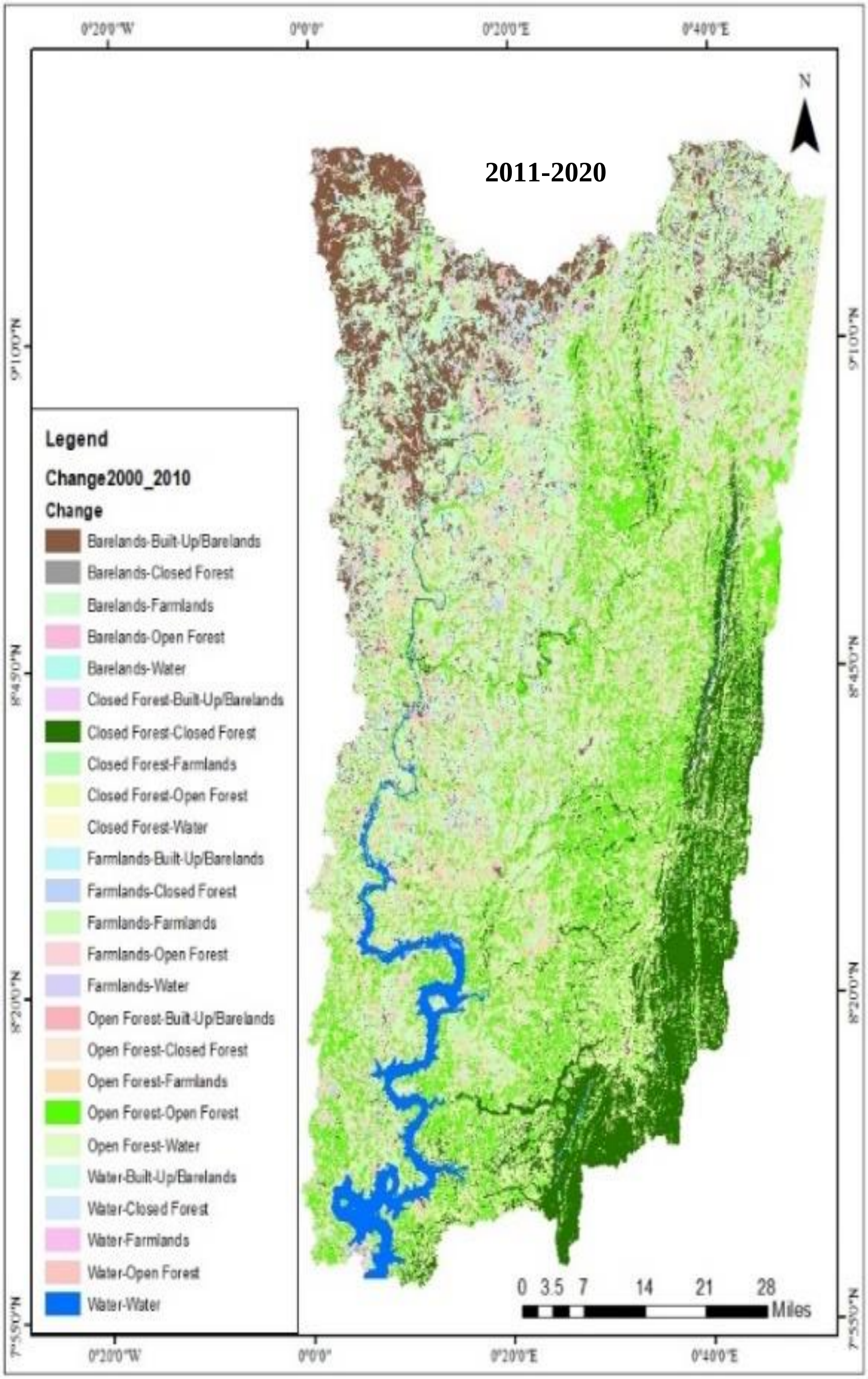

Figure 20: Change Detection for 2011-2020

Source: USGS, 2021.

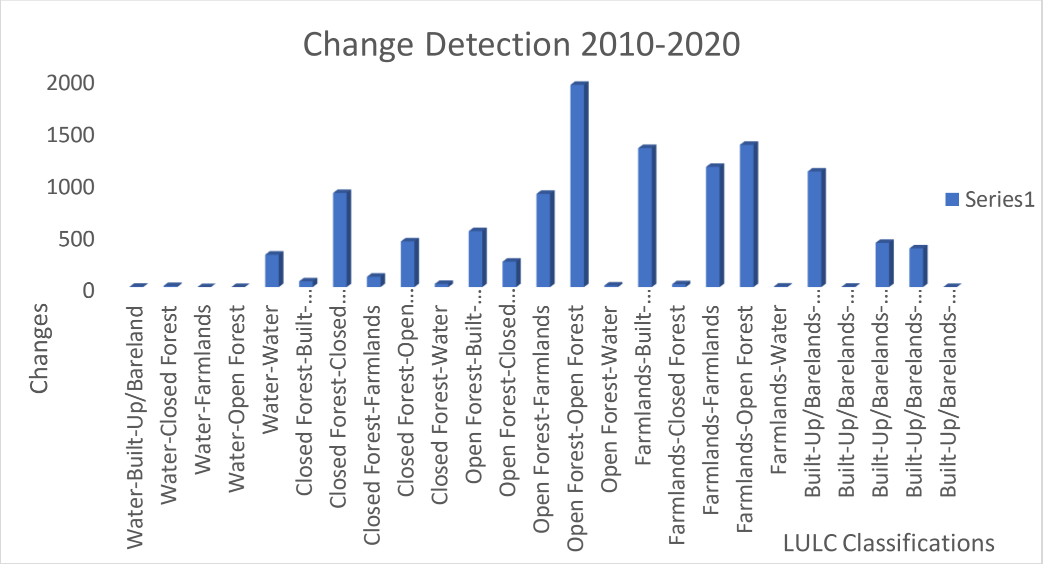

Figure 21: Graphical Representation of Change Detected, 2011-2020

Source: Field Data, 2021.

Overall Change in the Oti Catchment (1991-2020)

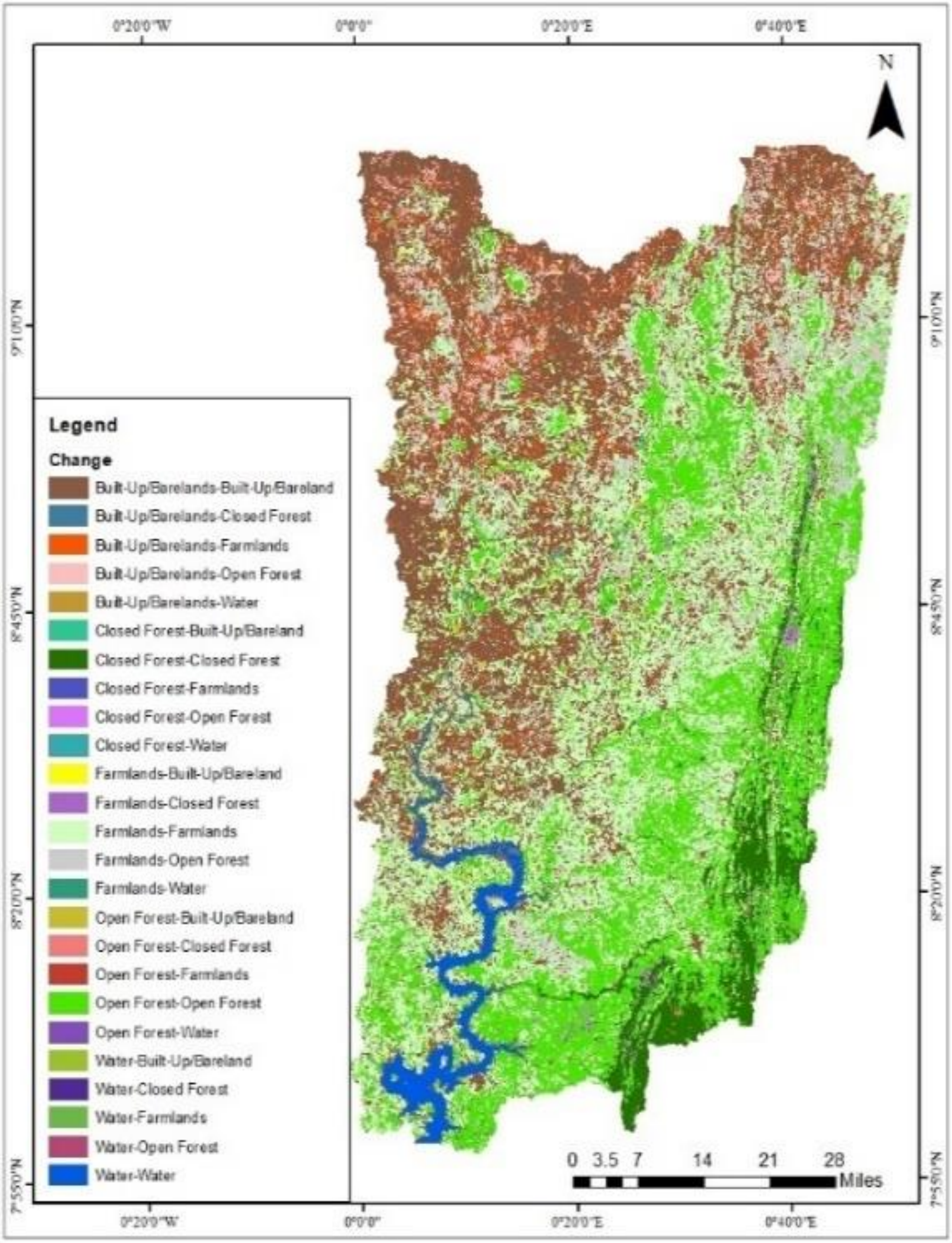

Figure 22: Overall Change in the Oti Catchment (1991-2020)

***Source: USGS, 2021*.**

Table 4: Summary of the overall change in the Oti catchment (1991-2020)

LULC Classification	*Built up/bare lands*		*Closed Forest*		*Farm lands*		*Open Forest*		*Water*	
	Change Area sq/km	*Percentage Change*	*Change Area sq/km*	*Percentage Change*	*Change Area sq/km*	*Percentage Change*	*Change Area sq/km*	*Percentage Change*	*Change Area sq/km*	*Percentage Change*
Built up/bare lands	507.9	4.50%	2.50	0.02%	154.0	1.4%	174.0	1.5	1.14	0.01%
Closed Forest	9.65	0.09%	834.40	7.4%	26.56	0.24%	192.47	1.71%	3.34	0.03%
Farm lands	1764.04	15.6%	38.82	0.34%	1400.3	12.41%	1623.5	14.4%	4.5	0.04%
Open Forest	752.71	6.68%	292.35	2.60%	990.712	8.79%	2122.6	18.8%	13.6	0.12%
Water	4.08	0.04%	20.4	0.18%	0.051	0.0004%	1.84	0.02%	340.64	3.02%

Source: Field Data, 202

Results of the Impact of Climate and LULC Changes on the Flow of The Oti River

Soil Distribution in the Watershed

Figure 23 and 24 shows the Soil Map of the Oti River Basin (FAO, Classifications, 2021) and a graphical representation of the soils in the Oti River Basin. From fig. 23 and 24, it is concluded that Lf26-a-1442; a soil type which is sandy, clay and Loamy in texture dominates the watershed. From the chart, 44.6% (5,026.1sq/km) of the watershed is made up of Lf26-a-1442 soil type, 19.9% (2,238.9sq/km) is made up of I-Lf-Rd-1264 soil type (Loamy in texture), 5.9% (662.7sq/km) is covered by J2-a-1327 soil type (Loamy in texture), 5.8% (650.9) is made up of Lp2-a-1530 soil type (Sandy-clay and loamy in texture), 8.8% is made up of water, 2.7% (304.2sq/km) is made up of Lf1-1a-5591 (Loamy Sand) and 6.9 (771.6sq/km) is made up of Lf20-1a-1436 (Sandy loam in texture). These soil classifications are based on FAO global classification of soils.

Generally, sandy soils have low water-holding capacity hence the dominance of sandy soil in the area results in rapid drainage. This potentially contributed to the increased streamflow during heavy rainfall events in the area. Clay and loamy soils, on the other hand, have lower infiltration rates due to their finer texture, leading to increased surface runoff and reduced groundwater recharge in the area.

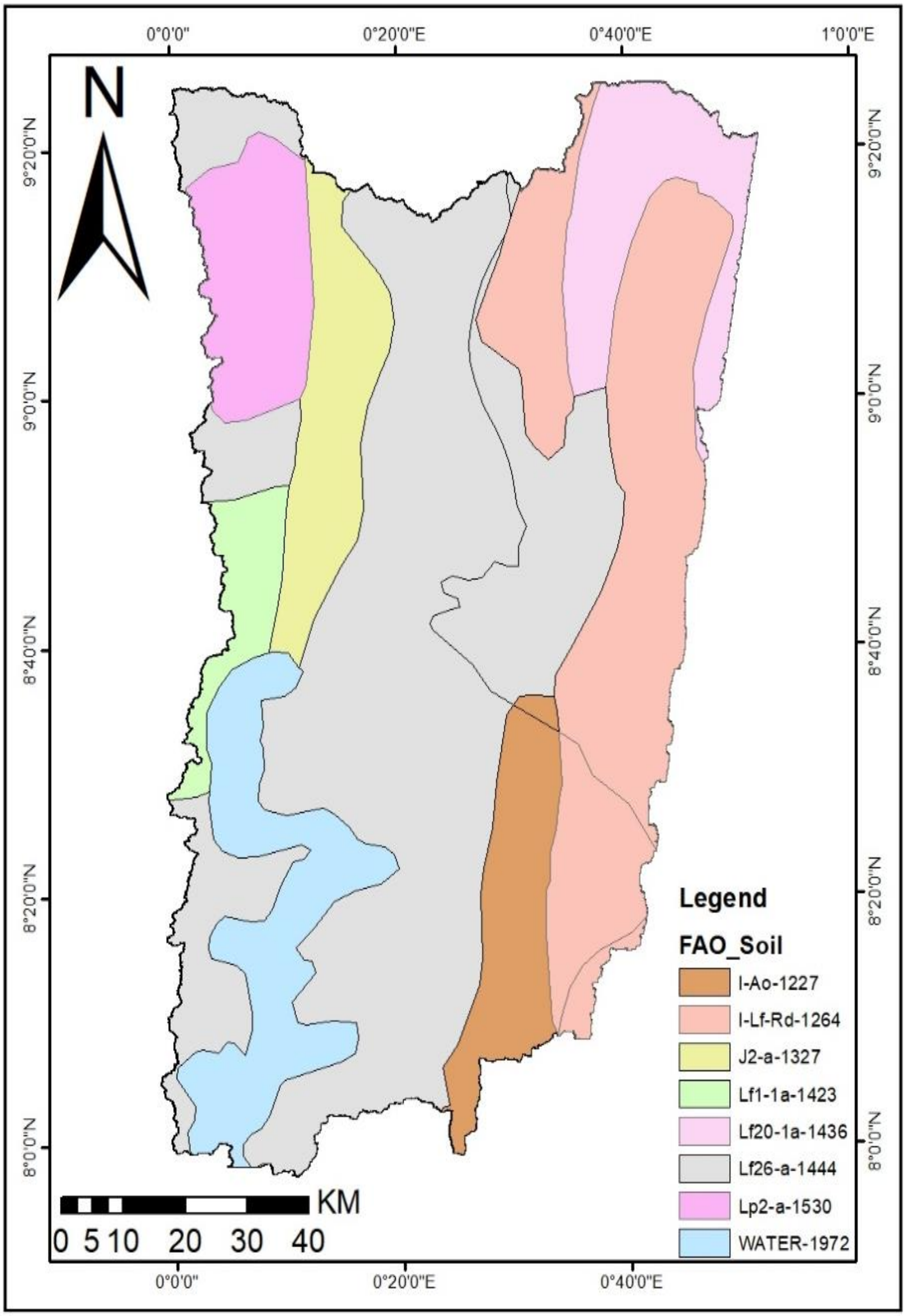

Figure 23: Soil Map of the Oti River Basin (FAO, Classifications, 2021)

Source: FAO, 2021.

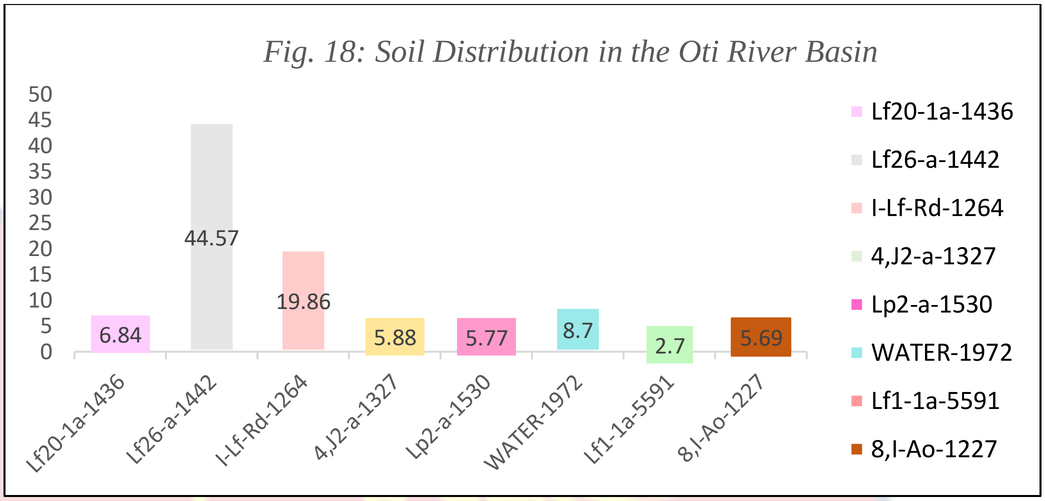

Figure 24: Graphical Representation of Soils in the Oti River Basin

Source: FAO, 2021.

Sensitivity Analysis and Fitted Parameter Values

Global sensitivity of model parameters after final calibration in SWAT-CUP

Table 5 presents the global sensitivity of model parameters after final calibration in SWAT-CUP. Global sensitivity parameters are shown in Table 5 together with the relevant p-values and t-statistics. The more sensitive a parameter is in a global sensitivity analysis, the bigger the absolute value of the t-statistic and the smaller the p-value (Arthur, et al (2020). The parameters R CN2.mgt (t-stat = 31.87; p 0), R PCPMM(..).wgn (t-stat = 2.78, p 0), R SOL AWC.sol (t-stat = -2.92, p 0), and R REVAPMN.gw (t-stat= -2.08; p 0) were the most sensitive.

Table 5: Global sensitivity of model parameters after final calibration in SWAT-CUP

Parameter	*t-stat*	*p-value*
R__CN2.mgt	31.87	0.000
R__PCPMM(..).wgn	2.78	0.0067
R__SOL_AWC(..).sol	-2.92	0.0045
R__REVAPMN.gw	-2.08	0.040

Source: Arthur, et al, (2020)

Sensitivity Parameters for Calibration and Validation with their Fitted Values

The results of the sensitivity analysis for the Oti River basins are presented in table 6. Ten (10) parameters were found to be sensitive in the Oti River basin. Four (4) out of the ten (10) parameters were found to be the most sensitive parameters. Initial SCS curve number for moisture condition (CN2) was found to be the most sensitive parameters that affected the model output. SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. It was revealed in table 5 that, impermeability of the surface increases as the curve number increases from 0.39 to 0.51. Curve number for moisture conditions (R__CN2.mgt) being the most sensitive parameters implies that, runoffs are extremely crucial for determining streamflow in the Oti River basin. Precipitation simulation code (R__PCPMM. wgn,), was the most sensitive parameter after R__CN2.mgt. Precipitation simulation code (R__PCPMM. wgn,) is responsible for the variation of simulation performance and its sensitive nature gives an indication that variations in precipitation have a direct influence on streamflow. The last two most sensitive parameters that affected the output of the study are r__SOL_AWC. wgn and R__REVAPMN.gw. r__SOL_AWC. wgn determines the available water capacity of the soil layer whiles R__REVAPMN.gw determines the threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur.

Table 6: Sensitivity Parameters for Calibration and Validation with their Fitted Values

Parameter	Fitted Values	Minimum	Maximum
r_CN2.mgt	0.45	0.39	0.51
V_ALPHA BF.gw	0.52	0.47	0.57
V_GW_DELAY.gw	107.49	80.47	134.51
v_GWQMN.gw	2319.59	1792.89	2846.28
r_REVAPMN.gw	-0.18	-0.23	-0.14
r_REVAP.gw	0.33	0.30	0.36
r_RCHRG_DP.gw	0.20	0.15	0.26
r_SOL_AWC.wgn	0.09	0.02	0.15
r_PCPMM().wgn	0.63	0.58	0.68
r_PR_W1().wgn	0.14	0.13	0.16

Source, Field data, 2021.

Calibration and Validation of Flows

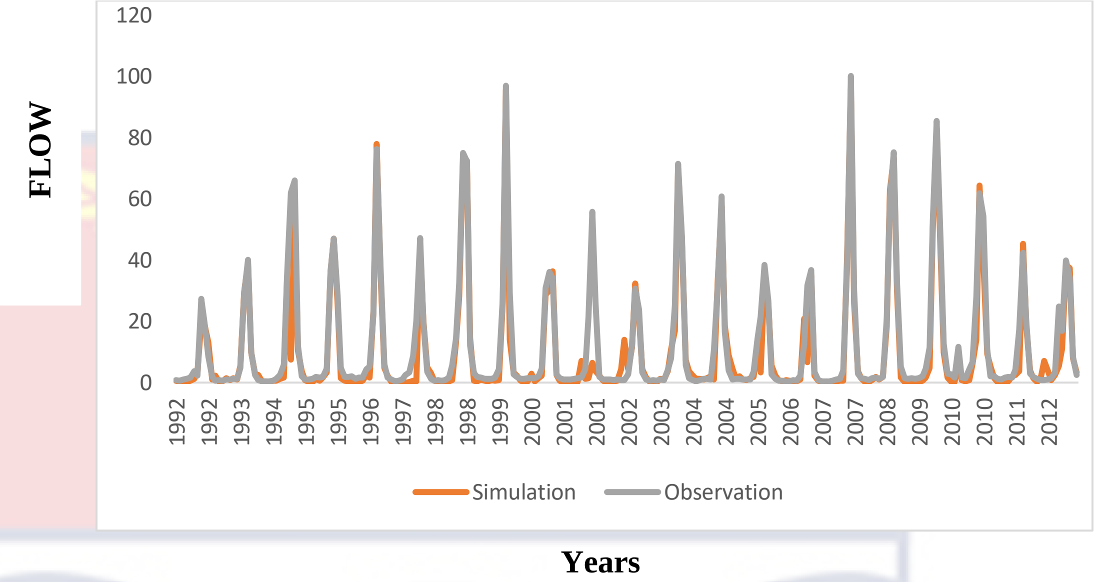

Figure 25: Simulated and Observed Flow of the Oti River for the Calibration Period of 1992-2012.

***Source: Field Data, 2021*.**

Figure 26: Simulated and Observed Flow of the Oti River Validation Period of 2013-2018.

***Source: Field Data, 2021*.**

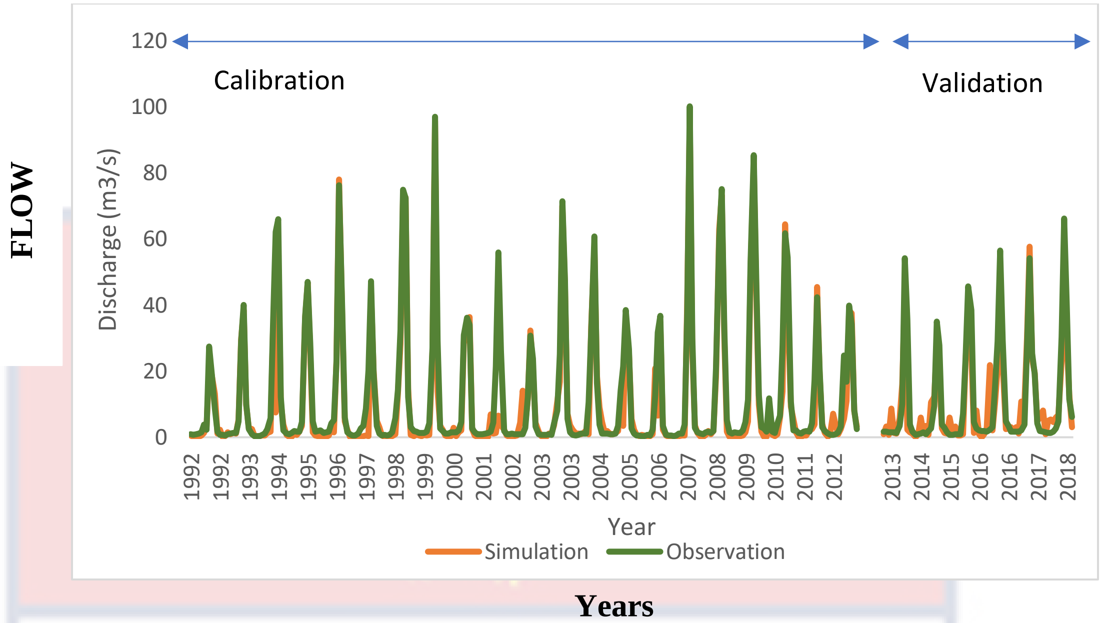

Figure 27: Combined simulated and Observed flows for calibration (1992 – 2012) and validation (2013-2018)

***Source: Field Data, 2021*.**

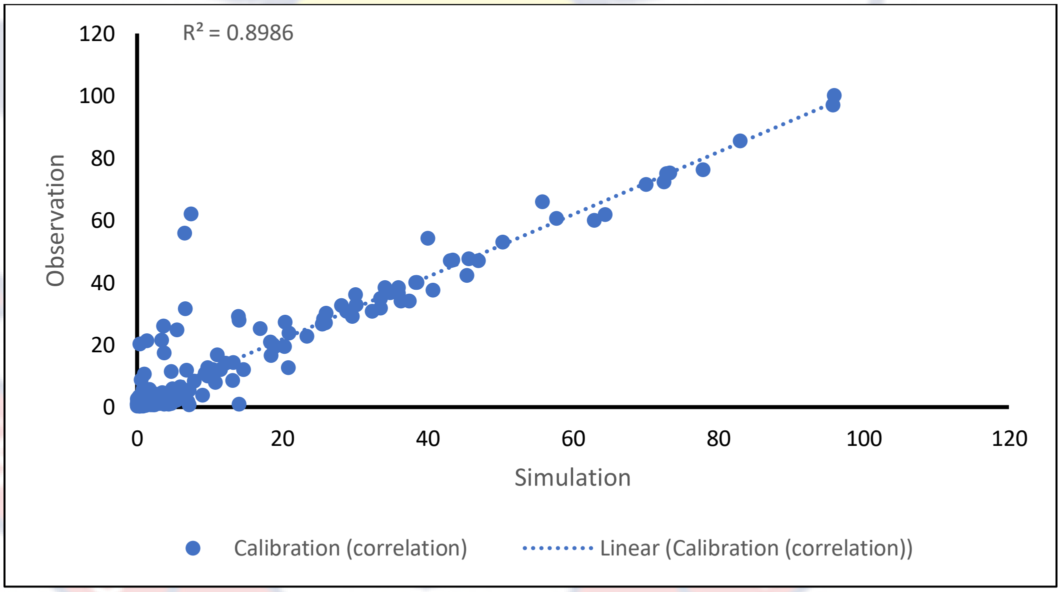

Figure 28: Liner Calibration Correlation of Flow

***Source: Field Data, 2021*.**

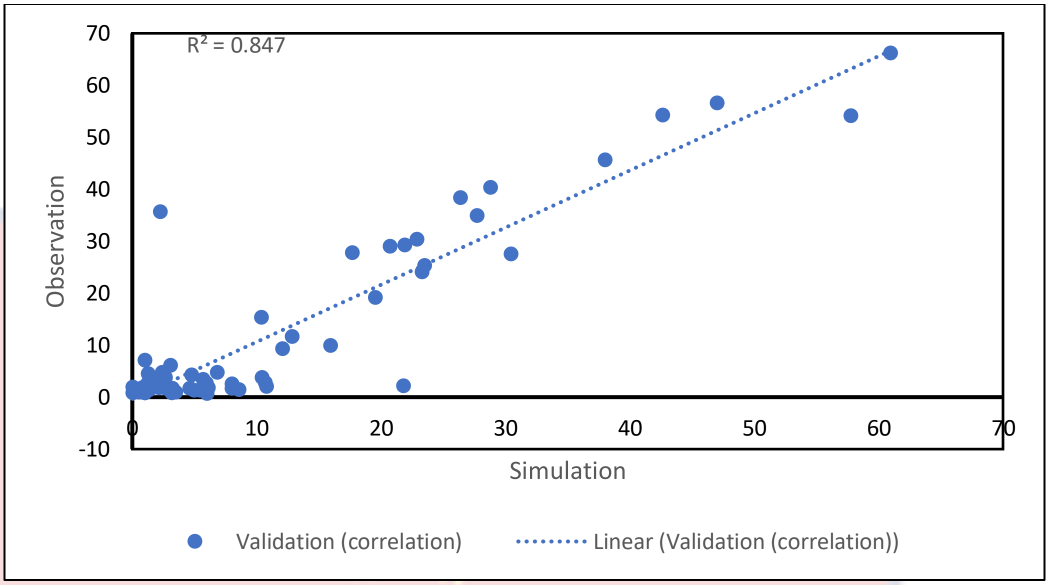

Figure 29: Linear Validation Correlation of Flow

***Source: Field Data, 2021*.**

Model Performance

As represented in figs. 19-23, simulated and observed statistics for flow for both calibration (1990/01/01-1992/12/31) and validation (1993/01/01-2018/12/31) years in the Oti River are fairly accurate. All the model's analysis fell within the acceptable limit. According to Arthur et al., (2020), a model with a Nash-Sutcliffe efficiency coefficient (NSE) value between 0.65 and 0.75 shows a good performance and in the case of this study, the model showed an NSE performance of 0.89 and 0.83 for calibration and validation respectively. An NSE performance of 0.89/0,83 is an indication that the model as run in the Oti River is very good. This supports Liu et al (2007) .'s claim that a NSE should fall between and 1.0 (1 inclusive), with NSE = 1 being the ideal value. Values between 0.0 and 1.0 are generally considered acceptable, whereas values 0.0 indicate that the mean observed value is indeed a better predictor than that of the simulated value, which denotes unacceptable performance. Both calibration and validation yielded R2 values of 0.89 and 0.84, respectively. The performance value is better when the correlation coefficient R2 is closer to 1, which denotes that the trends in the performance value and measured value are more in sync (Liu, et al, 2017). RSR values of 0.3 and 0.4 for calibration and validation, respectively, show that the model performs quite well in both of these respects. A PBIAS value of 14.8 percent for calibration shows the good agreement between both the observed and simulated flows, while a validation value of 0.61 percent indicates a very good agreement between the two. According to Gyamfi, Ndambuki & Salim (2016), a model with a PBIAS value below 10 percent shows very good performance, and between 10 percent and 15 percent in absolute value indicates the best agreement between both the observed and simulated flows.

Table 7 below presents the performance indicators of the SWAT Model.

Table 7: Performance Indicators of SWAT Model

Criteria	Calibration	Validation	Performance range	Performance rating	Reference
NSE	0.89040058	0.8383041	0.75 ≥NSE ≤ 1	Very good	Arthur, et al, 2020
R^2	0.89860641	0.8469691	0.75 ≥R2 ≤1	Very good	Arthur, et al, 2020
RSR	0.33105804	0.4021143	0.5 < RSR ≤ 6	Satisfactory	Arthur, et al, 2020
PBIAS	14.79901	6.0548803	PBIAS < 10, 10 < PBIAS ≤ 15	Good	Arthur, et al, 2020

Source, Field Data, 2021.

Sub-Basin Analysis of Inflows and Outflows in the Oti River Basin

Results from the Sub-Basin analysis for the Oti catchment was based on selected years (2000, 2010 and 2018). The changes in inflows and outflows were determined after the SWAT model was run. A year each was selected from the early, middle and recent years for the 30year period used in the study.

Table 9 shows the results for inflows and outflows in the Oti River catchment, whiles figures 30 display the graphical representation of inflows and outflows for the years 2000, 2010 and 2018. Results from the selected years as shown in table 9 and figure 30 revealed that, the difference between inflows and outflows is insignificant, even though the inflows of the Oti basin are slightly higher than outflows. The results also revealed that, flows (inflows and outflows) for the Oti basin increase as one move from upstream (starting from sun-basin 1) to downstream (ends at sub-basin 8). For instance, inflow and outflow results for the year 2000 increased from (2.64, 15.58, 11.44, 15.98, 45.33, 77.10, 112.39, 116.46 for inflows and (2.62, 15.31, 11.03, 15.65, 44.34, 74.89, 111.64, 116.16) for outflows, that is from sub-basin 1-8. This same changes in flows (Inflows and outflows) is significant in both 2010 and 2018 results.

In looking at the annual averages for both inflows and outflows for the selected years, it was revealed that inflows for the early year, that is 2000 increased from 396.93c/m to 908.11c/m in 2010 but decreased again in 893.95c/m in 2018 (recent year). Outflows also increased from 391.64c/m (2000) to 902.12c/m in 2010 and then decreased tremendously to 364.73c/m in 2018 (recent year).

It is crucial to keep in mind that the general decline in inflows in the past decade is a direct outcome of the decrease in rainfall pattern in the catchment area, as evidenced by the rainfall results, meanwhile, the significant difference between inflows (893.95c/m) and outflows (364.73c/m) is affecting the river and its ecosystem. When the inflow of water into a river exceeds the outflow, it leads to an increase in the volume and velocity of water within the river channel. This can cause several impacts, including changes in water quality, alterations in sediment transport, and modifications to the river's physical habitat (Elliott, 2010).

Additionally, the altered flow pattern of the river disrupts the natural transport of sediment within the river. The high inflows are causing erosion along the riverbanks, leading to increased sedimentation downstream. This can have adverse effects on aquatic habitats, such as smothering of bottom-dwelling organisms and alteration of spawning grounds (Elliott, 2010). This also gives an indication as to why the river over flow its banks on yearly basis leading to the destruction of crops, farmlands and other properties.

Table 8: Summary of Inflows and Outflows for 2000, 2010 and 2018

Sub-Basins	inflows 2000	Outflows 2000	Inflows 2010	Outflows 2010	Inflows 2018	Outflows 2018
Basin 1	2.64	2.62	6.38	6.36	5.88	2.29
Basin 2	15.58	15.31	39.55	39.26	36.33	16.92
Basin 3	11.44	11.03	32.75	32.28	31.86	11.68
Basin 4	15.98	15.65	49.14	48.75	48.12	21.89
Basin 5	45.33	44.34	125.36	124.2	118.01	49.05
Basin 6	77.1	74.89	200.48	197.99	190.2	64.15
Basin 7	112.39	111.64	223.29	222.47	227.8	97.76
Basin 8	116.46	116.16	231.17	230.81	235.73	100.1
Average inflows/ outflows	**396.93**	**391.64**	**908.11**	**902.12**	**893.95**	**364.73**

Source: Field Data, 2021

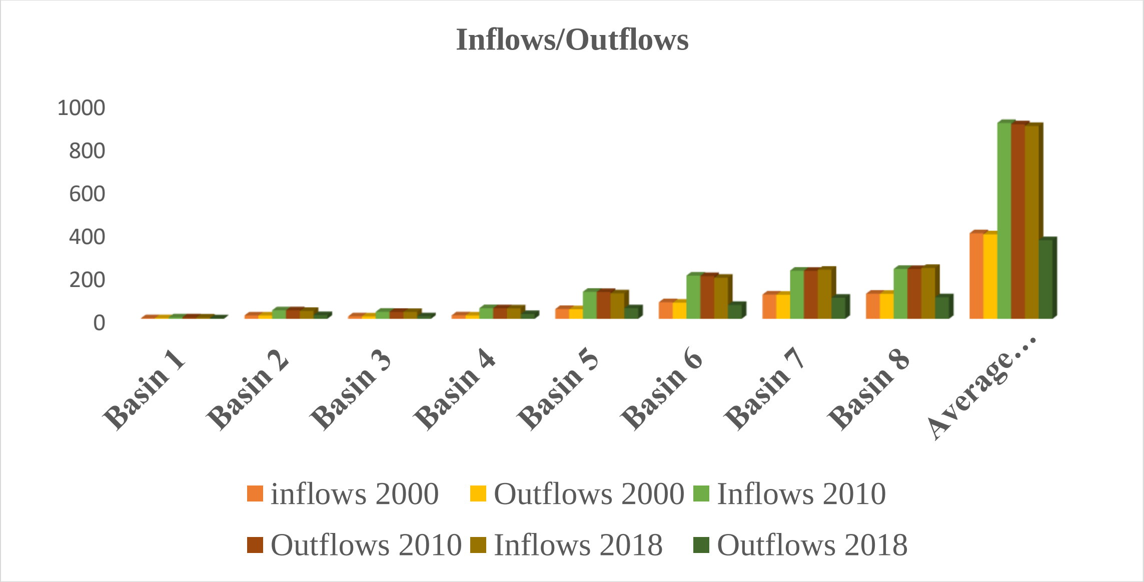

Figure 30: Graphical Representation of Inflows and Outflows for 2000, 2010 and 2018.

Source: Field Data, 2021.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Introduction

The investigation of the Oti River's hydrological response to climatic and land use/land cover (LULC) dynamics is the study's major goal. The study is focused on a section of the Oti River in Ghana, with a particular emphasis on examining trends in both climate and LULC dynamics for a 30-year period (1990-2020) using Mann-Kendall test and ArcGIS, respectively. Climate and LULC dynamics have also been simulated, and the Soil and Water Assessment Tool used to examine the impact of climate and land-use dynamics on the flow of the Oti River (SWAT). Conclusions and suggestions were made in light of the data obtained from the research objectives.

Summary of Key Findings

The first objective of the study evaluated the trends of change occurring along the Oti River as a result of Climate dynamics between 1990 and 2020. The Mann Kendall test for determining series in climatic and hydrological trends was employed. Temperature results from M-K test indicated a mean of 7,666.141 and 10,773.617 for both minimum and maximum temperature respectively. Annual temperature has consistently been high throughout the years, temperature exhibited an up and down trend from 2007 to 2011 and maintained the consistently high and increasing temperature for the rest of the years. The computed p-value of 0.106 in the M-K test was greater than the significance level alpha=0.05, suggesting that, there are no significant trends in temperature dynamics in the Oti River. Results from rainfall observations from the two stations for the 29-year period also indicated respective means of 486.879 and 1304.355. There are no much variations in the dynamics in rainfall in the two stations. The computed p-values (0.388, 0.320) for both stations are greater than the alpha value=0.05. This implies that there are no significant trends in rainfall dynamics in the Oti River catchment area.

The second research objective did a trend analysis of LULC dynamics in the Oti River catchments and its environs using ArcGIS. Landsat 5, 7 and 8 images for 1991, 2000, 2010 and 2020 were downloaded from Earthexplorer.usgs.gov/. A change detection for the periods between 1991-2000, 2000-2010, 2010-2020 and 1990-2020 was carried out. broader classifications used in the classifications includes, Open and Close Forest, Farmlands, Water and Built-up/bare lands. The results revealed that, as at 1991, Farmlands dominated the Oti catchment, followed by the open forest type of vegetation and then closed forest type. The built up/bare lands and water covered a relatively small area. There has been a change in the LULC in the area in 2000. There has been a reduction in farmlands and open forest in sq/km in 2000. Meanwhile Closed Forest, Built-up/bare lands and water increased. As a matter of, farmlands still dominated the area as at 2000. There is an indication from the 2010 results that, there has been an increase in the area covered by all the LULC classes except water. Much of the farmlands and close forest have been converted into open forest hence open forest dominated the classifications in 2010. It has been revealed from 2020 results that, several kilometers of farmlands, water and the closed forest have been lost. Majority of these lands have been converted to open forest, built-up and bare lands.

The change detection analysis for 1991-2000 revealed that, majority of farmlands were further reconverted to farmlands, followed by the reconvention of open forest lands to open forest. It was also revealed from the change analysis for 1991-2000 that, major open-forest lands were converted to closed forest during the nine-year period. a major component of the open forest was further converted into open forest, meanwhile, quite an extent of the open forest has been lost to the other classes. Farmlands dominated the area during this period. It was also revealed from the change detected for the period 2000-2010 that, several kilometers of farmlands were being lost to the other LULC classes. Most of open forest however, was being reconverted into open forest hence the reason for which open forest dominated the area during this period. water lands were also converted to Closed and Open Forest, Farmlands and Built-Up/Bare lands. Results for the period 2010-2020 indicated that open forest continue to dominate the Oti River catchment area, even though there has been a sharp decrease from 1967.73sq/km (2000-2010) to 1939.84sq/km (2010-2020). Closed forest has reduced drastically in the catchment area during this period; several sq/km of the Closed Forest has been converted into Built-Up/Bare lands, farmlands and water. Meanwhile, the area covered by water has seen a more decrease in recent times even than the previous years.

Research objectives III simulated Climate and LULC dynamics in the Oti River and their impact on flow using the Soil and Water Assessment Tool (SWAT). Results of the simulation, indicated that eight 8 soil groupings according to FAO global classification are present within the Oti River catchment. These include: Lf26-a-1442 (sandy, clay and Loamy in texture), J2-a-1327 soil type (Loamy in texture), Lp2-a-1530 soil type (Sandy-clay and loamy in texture), Lf1-1a-5591 (Loamy Sand), Lf20-1a-1436 (Sandy loam in texture), I-Lf-Rd-1264 soil type (Loamy in texture) and water.: Lf26-a-1442 dominates the watershed followed by I-Lf-Rd-1264. Lf1-1a-5591 soil type is the least among the 8 soils in the study basin.

Research objective III did a calibration and validation of climate and LULC results from the simulation to determine the impact on flow. r__CN2.mgt, v ALPHA BF.gw, v GWQMN.gw, V__DELAY.gw, r_REVAPMN.gw, r_REVAP.gw, r_RCHRG_DP.gw, r_SOL_AW.wgn, r_PCPMM().wgn, r_PR_W1().wgn are the ten 10 sensitive parameters that were used to generate the output for the model. The model also indicated four 4 of the sensitive parameters as the most sensitive parameters. These include; R__CN2.mgt, R__PCPMM(..).wgn, R__SOL_AWC(..).sol, R__REVAPMN.gw. The model also detected a t-stat value of 31.87 and p value of 0.00, for R__CN2.mgt, making it the most sensitive parameter resulting from the model.

Calibration and Validation of the model resulted into the respective Nash-Sutcliffe efficiency coefficient (NES) value 0.89 and 0.83 (good performance), a correlation coefficient R^2 values of 0.89 and 0.84 (good performance), RSR values of 0.3 and 0.4 and a PBais value of 14.8%. and 0.61% indicating a very good agreement between observed and simulated flows.

Sub-Basin Analysis of Inflows and Outflows was also carried out. Results from the Sub-Basin analysis for the Oti catchment was based on selected years (2000, 2010 and 2018). The changes in inflows and outflows were determined after the SWAT model was run. Results from the selected years revealed that, the difference between inflows and outflows is insignificant, even though the inflows of the Oti basin are slightly higher than outflows. The results also revealed that, flows (inflows and outflows) for the Oti basin increase as one move from upstream (starting from sun-basin 1) to downstream (ends at sub-basin 8), however, there has been a tremendous reduction in outflows hence increasing the extent of sedimentation and volume of water in the river.

Conclusions

It can be concluded that, Oti River is responding to climate change that has taken place between 1990-2020. The area's increased temperature is ascribed to the predominating human activities, such as farming and growing built-up areas. A surge in these activities suggests a reduction in the area's forest cover and the release of very significant amounts of greenhouse gases (GHG), which raise temperatures.

Secondly, increased temperature in the catchment is having a significant effect on the river’s inflows and outflows. The rising temperatures have altered precipitation patterns, resulting in changes in the timing, intensity, and distribution of rainfall in the catchment area.

Also, there is a decline in annual rainfall in the Oti River catchment. This is having a direct effect on the flow of the river. Decreased rainfall in the area has led to lower flows in the Oti River over the past decade.

It can again be concluded that, the Oti River is responding to the LULC changes that occurred between 1990-2020. Open forest is dominating the Oti River catchment area whiles built up/bare lands have also increased immensely. This therefore give a clue as to why runoff is detected as the most sensitive parameter in the SWAT modelling.

It is also very important to note that, the ongoing deforestation, urbanization and agricultural expansion is modifying the amount and timing of runoff and streamflow in the river. Forested areas generally have higher infiltration rates and lower surface runoff compared to urban or agricultural areas. Therefore, converting the forest areas to bare lands/built-up areas has increased surface runoff and peak flows, leading to more rapid and intense runoff events, especially during rainfall.

It can further be concluded that, changes in land use, particularly for agriculture and urbanization in the catchment area is increasing soil erosion. This has resulted in higher sediment loads in the river, leading to sedimentation and changes in channel's morphology. The extent of the river's sedimentation is the direct effect of year in year out floods communities along the river are experiencing.

Again, it can be concluded that, the changes in both climate and LULC has impacted on the flow of the Oti River between the period 1990-2020. The dominance of sandy-clay and loam in the catchment area is associated with the rapid drainage, increased runoffs and reduced ground water discharge hence the reason why initial SCS curve number for moisture condition (CN2) was found to be the most sensitive parameter that affected the model output.

Finally, it can also be concluded that the general decline in inflows in the past decade in the Oti Catchment is a direct outcome of the decrease in rainfall pattern in the catchment area, as evidenced by the rainfall results, meanwhile, the significant difference between inflows (893.95c/m) and outflows (364.73c/m) is affecting the river and its ecosystem.

Recommendations

Mitigating the impacts of climate change and land use/land cover (LULC) dynamics on the hydrological extremes of the Oti River requires a comprehensive approach that involves both adaptation and mitigation strategies. Here are some recommendations to address this problem:

First, institutions such as the Environmental Protection Agency (EPA), Ministry of Energy, Council for Scientific and Industrial Research (CSIR), Renewable Energy Association of Ghana (REAG), Ghana Climate Innovation Center (GCIC) among others can take it upon themselves to encourage the implementation of policies and practices that reduce carbon emissions, such as transitioning to renewable energy sources, promoting energy efficiency, and adopting sustainable agricultural practices.

Secondly, the Environmental Protection Agency (EPA) can reduce climate and LULC effects on the Oti River by promoting the planting of trees and restoration of degraded forests in the Oti River catchment area to enhance carbon sequestration, reduce soil erosion, and improve water retention.

In addition to the above, it is recommended that, the MMDAs and Regional Coordinating Councils found along the Oti Catchment among other NGOs encourage sustainable urban development practices, including green infrastructure, compact cities, and efficient water management systems, to reduce the urban heat island effect and minimize the impacts of urbanization on hydrological extremes.

Furthermore, it is recommended that Ghana's ministry of Agriculture promote the adoption of sustainable agricultural practices that minimize soil erosion, such as conservation tillage, agroforestry, and contour farming. This helps reduce sedimentation and nutrient runoff into the Oti River.

It is also recommended that MMDAs and institutions in charge of water resource management establish and enforce regulations to protect riparian zones along the river, which act as natural buffers against floodwaters and help maintain water quality. Limiting encroachment and preventing deforestation in these areas is crucial. land use planning strategies that consider the hydrological implications of development projects should also be implemented. MMDAs should also ensure that infrastructure development and urban expansion are carried out in a manner that minimizes impacts on the river's hydrology and avoids exacerbating flood events in the Oti Catchment.

It is also recommended that, government of Ghana; at the central and local levels Integrates water resources management into their action plans and medium-term development plans. The programmes and projects in the action plan and MTDPs should include coordinated water allocation, flood forecasting and early warning systems, and the development of water storage and retention infrastructure.

Finally, stakeholder engagement and capacity building that is involving local communities, government agencies, researchers, and other stakeholders in decision-making processes, and enhance their understanding of the impacts of climate change and LULC dynamics on the Oti River, foster cooperation and build capacity for sustainable water resources management is also a short cut to solving this problem as faced by the Oti River catchment.

Suggestions for Further Research

1. Hydrological response to bank erosion in the Oti River.
2. Projecting the impact of future climate and land use land cover dynamics on the Oti River Basin.

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APPENDICES

APPENDIX A

ANNUAL MAXIMUM TEMPRATURE -RAW DATA

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL TOTAL
1990	1057.5	999.8	1165.4	1015.1	993.4	938.3	891.9	915.5	908	978.9	993.9	1013.9	**11871.6**
1991	1058.1	990.4	1075.7	972	968.9	933.7	911.4	903.1	924.6	966.9	987.5	1017	**11709.3**
1992	1041.8	1054.5	1119.7	1031.9	1006.9	910.9	892.2	890.9	880.1	989.1	563.7	1043	**11424.7**
1993	1060	1012.7	1084	1033.9	1031.2	946.3	905.9	910.7	897.7	1010.9	1016.4	1030.5	**11940.2**
1994	1053.9	1007.6	1132.8	1028.8	1028.2	907.9	919.1	920.6	906	967.6	1007.1	1043.5	**11923.1**
1995	1075	1028.4	1127.1	1014.9	1009.9	940.8	924.6	907.3	921.2	989.2	1005.7	1033.1	**11977.2**
1996	1074.1	1049.2	1122.2	1026.2	1026.1	922.4	933.5	901.7	915.6	990.7	1031	1056.7	**12049.4**
1997	1086.6	1019.1	1103.2	1005.3	1026.1	923.6	919.9	922.3	943.7	1026.6	1028.6	1064.6	**12069.6**
1998	1079.6	1042.5	1190.1	1073.8	1048.7	937	919.2	916.6	927.4	1005.6	1053.4	1077	**12270.9**
1999	1096.9	987.2	1119.7	1036.7	1058	975.4	925.3	925.8	916.2	972.8	1012.8	1053.6	**12080.4**
2000	1060.4	1041.9	1115.5	1024.4	1041.8	933	921.6	908.1	909.8	1007.5	1037.5	1054.5	**12056**
2001	1088.1	1023.7	1148	1047.1	1052.9	945.9	927.6	900.4	900.1	1030	1044.1	1093.3	**12201.2**
2002	1084.2	1039.9	1113.7	1021	1011	936.4	943	919.7	934.2	1006.2	1030.4	1071.1	**12110.8**
2003	1094	1032.2	1148.5	1017.4	1060.2	928.3	937.9	918.4	922.3	1002.3	994.8	1040.2	**12096.5**
2004	1057.4	1036.7	1114.9	1029.3	991.2	920.2	918.1	912.7	919	1008.1	1001.9	1047.8	**11957.3**
2005	1056.1	1023.5	1107.3	1033.4	1015.5	924.2	927.1	908.8	924.9	1006.3	1024.6	1067.9	**12019.6**
2006	1079.5	1000.7	1098	1080.9	1032	972.4	945.8	916.6	910.2	1005.6	1020.6	1067.6	**12129.9**
2007	1072.4	1037.2	1129.5	1014.9	1001.3	932.6	938.2	915.9	924.7	989.3	1008.4	1045.4	**12009.8**
2008	1050.4	1055.3	1110.3	1039.7	1011.5	932.6	915.6	911.4	924.7	1002.6	1020.4	1040.3	**12014.8**
2009	1050.8	993.4	1095.9	979.9	1040.2	946.5	922.4	913	923.9	987.8	1000.4	1063	**11917.2**
2010	1099.3	1036	1134.5	1068.1	1039	973.9	951.4	943.2	917	1003.3	1001.1	1075	**12241.8**
2011	1064.4	1015.3	1136.5	1084.7	1070.4	947.8	929.9	927.9	924.4	996.9	1036	1078.8	**12213**
2012	1082.4	1027.3	1123	1016.6	1007.6	930.5	913.9	911.8	991.5	1007.4	1061.2	1124.5	**12197.7**
2013	1077.1	1031.4	950.1	936.5	918.2	892.9	990.3	1073.8	1083.3	1019.9	1105.8	1047.6	**12126.9**
2014	1067	936.5	955.3	938.3	927.7	1017.9	1048.4	1109.9	1095.7	1139.2		1023.7	**11259.6**
2015	1044.3	959.5	951.2	919.4	923.7	1008.1	1048.1	1087.1	1101.3	1031.4	1164.4	1069.4	**12307.9**
2016	1045.2	940.7	929.4	919.9	912.9	1037.6	1027.1	1063.9	1087.2	1027.3	1110.7	1028.2	**12130.1**
2017	1025	946.5	932.7	931.1	923.2	1009.8	1050.2						**6818.5**
2018													**0**
2019													**0**

ANNUAL MINIMUM TEMPRATURE -RAW DATA

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1990	692.8	652.4	794.7	764	744.7	705.4	710.2	711.9	673.2	708.3	700.2	680.8	**8538.6**
1991	661.5	687.2	784.4	731.3	750.9	722.3	709.1	704.9	687.8	705.3	683.3	629.3	**8457.3**
1992	603.5	673.7	810.9	771.6	760.5	699.3	713.7	701.6	667.7	724.1	657.9	645.1	**8429.6**
1993	605.2	664.9	750.6	765.7	775.8	713.3	725.8	715.4	673.3	724.2	721.7	657.5	**8493.4**
1994	654.8	675.8	806.2	772.8	762.3	709.6	715.5	707.6	683.4	694.5	641.7	560.4	**8384.6**
1995	578.7	631.5	795.8	752.8	750.6	701.4	725.3	710.8	686.5	719.8	666.6	668.2	**8388**
1996	679.8	716.2	809.2	760.2	767.6	702.2	716	713.1	690	703.2	646.5	687.2	**8591.2**
1997	713.3	605.1	774.7	748	760.6	709.8	717.7	716.1	708.9	735	708.6	680.6	**8578.4**
1998	643.7	674.3	819.6	807.4	793.7	712.5	735.6	692.6	701.5	730.7	708.7	681.8	**8702.1**
1999	694.8	649.3	794.2	744.7	775.3	730.9	722.5	710.7	687.2	698.9	704.6	634.3	**8547.4**
2000	716.6	626.8	767.6	755.5	777.3	709.8	711.8	700.6	692.1	722.6	713.3	624.4	**8518.4**
2001	638.7	643.8	805	760.2	786.9	711.3	731	718.5	683.9	738.3	715	697.8	**8630.4**
2002	648.4	654.1	812.5	760.8	762.3	703.9	735.9	716.8	686.1	715.6	699.4	618.2	**8514**
2003	657.7	696.5	804.2	745	786.3	712	734.1	729.8	698.8	723.8	685.4	627	**8600.6**
2004	651.4	686.7	789.8	761	763.4	700.2	708.8	722.5	686.9	728.5	700.5	717	**8616.7**
2005	595.8	714.1	800	771.2	762.5	719.3	719.7	712.6	689.6	711.4	681.7	650.2	**8528.1**
2006	703.9	699.1	777.6	784.9	772.6	727.2	742.8	728.4	692.3	741.6	644	597.4	**8611.8**
2007	604.2	682.5	782.1	748.1	753.5	715	728.2	714.9	684.4	710.4	695.1	648.9	**8467.3**
2008	578.6	662	793.2	760.7	749.3	714.1	709.2	710.2	691.6	716.7	686.9	678.1	**8450.6**
2009	620.2	709.2	802.6	741.6	774.9	717.3	718.9	730	707.6	735	673	674	**8604.3**
2010	661.5	698.2	831.8	796	795.9	750.5	737.8	733	699.1	738	711.3	684.6	**8837.7**
2011	626.7	689.6	808.9	782.5	793.8	739.8	730.9	734.6	710.8	727.9	721.8	588.2	**8655.5**
2012	604.8	700	801.2	764.6	756.6	720	732	688.3	719.1	674.7	594.7	807.1	**8563.1**
2013	773.8	782.9	729.2	736.6	718.3	682.9	721.5	655.8	607.7	695.8	781.7	769	**8655.2**
2014	780.2	714.7	739.3	741.3	709.8	731.4	696.4	657.9	693.6	829		770.6	**8064.2**
2015	794.7	726.8	751.9	736.4	706.5	735.6	737.8	589	652.2	685.2	824.6	784.8	**8725.5**
2016	781.4	725.3	736.2	728.6	705.3	757.9	727.4	681.4	604.8	693.2	802.6	758.6	**8702.7**
2017	771.6	720.7	728.7	723.5	710.6	751.4	739	781.4	725.3	736.2	728.6	705.3	**8822.3**
2018	757.9	727.4	681.4	604.8	693.2	802.6	758.6	771.6	720.7	728.7	723.5	710.6	**8681**
2019	2019		604.3	753.1	773.4	654.3	765.4	823.2	774.4	743.4	773.2	773.3	**751.4**

APPENDIX B

ANNUAL RAINFALL DATA - RAW DATA

	KETE-KRACHI	DAMBAI
YEAR	**RAINFALL**	**RAINFALL**
1990	1336.7	939.3
1991	2431.5	0
1992	970.7	859.2
1993	1003.2	895.4
1994	1199.6	564.4
1995	1680.8	464.7
1996	1545.4	0
1997	1387.9	648.9
1998	982.5	506.1
1999	1580.8	625.7
2000	1375.6	623.9
2001	915.6	418.3
2002	1453.8	627.8
2003	1423.5	748.7
2004	1500.6	742.7
2005	1498.8	945
2006	1033.3	529.4
2007	1148.6	856
2008	1853.5	1152.8
2009	1617.5	844.4
2010	1107.2	0
2011	1229.8	0
2012	1295	844.4
2013	1419	0
2014	1375.1	0
2015	993.1	0
2016	1100.9	0
2017	1280.6	0
2018	1422.4	0
2019	0	1221.7
TOTAL	39163	15058.8

APPENDIX C

FLOW DATA FROM SABARI STATION

Year	Min Q	Month	Mean Q	Max Q	Month
1959	-999	0	-999	-999	0
1960	2	3	387.917	1900	10
1961	2	3	210.75	1070	9
1962	1	3	552.583	3040	9
1963	5	4	574.417	2810	9
1964	3	3	324.083	1830	9
1965	9	3	190.583	1080	9
1966	0	4	241.333	1140	9
1967	1	3	344.083	1600	9
1968	6	2	447.333	1780	9
1969	5	3	450.333	2580	9
1970	2	4	476.833	3010	9
1971	3	3	396.75	2220	9
1972	2	3	188.167	1270	9
1973	1	4	207.667	1140	9
1974	-999	0	-999	-999	0
1975	-999	0	-999	-999	0
1976	-999	0	-999	-999	0
1977	-999	0	-999	-999	0
1978	-999	0	-999	-999	0
1979	-999	0	-999	-999	0
1980	-999	0	-999	-999	0
1981	-999	0	-999	-999	0
1982	-999	0	-999	-999	0
1983	-999	0	-999	-999	0
1984	-999	0	-999	-999	0
1985	-999	0	-999	-999	0
1986	-999	0	-999	-999	0
1987	-999	0	-999	-999	0
1988	-999	0	-999	-999	0
1989	-999	0	-999	-999	0
1990	-999	0	-999	-999	0
1991	-999	0	-999	-999	0
1992	-999	0	-999	-999	0
1993	-999	0	-999	-999	0
1994	-999	0	-999	-999	0
1995	-999	0	-999	-999	0
1996	-999	0	-999	-999	0
1997	17.878	3	348.524	1668.095	9

1998	18.352	1	680.207	2528.676	9
1999	-999	0	-999	-999	0
2000	41.626	2	349.288	1277.363	9
2001	32.301	12	374.655	1973.458	9
2002	29.582	3	273.064	1084.533	9
2003	23.345	3	493.115	2525.829	9
2004	16.28	2	383.348	2144.419	9
2005	35.23	3	333.667	1358.023	9
2006	10.409	3	266.496	1300.937	10
2007	-999	0	-999	-999	0