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Implications of Land use and Land Cover Dynamics for Water Resources in Ghana Under Changing Climatic Conditions A Review

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Abstract: The environmental challenges anticipated are increasingly driven by shifts in land use and land cover (LULC), coupled with climate change—two pivotal factors shaping global water resources, with Ghana being no exception. These transformations influence water availability, quality, and quantity, consequently impacting agriculture, ecosystems, and human well-being. This review delves into the intricate link between LULC alterations, climate variability, and their combined repercussions on Ghana's water resources through a systematic review methodology. The study synthesizes existing literature on LULC and climate change as dual environmental influences on water systems, alongside adaptation and mitigation strategies designed to address their effects in Ghana. It explores the root causes and evolving patterns of LULC shifts, assesses climate change-induced hydrological changes, and evaluates strategic responses for managing these challenges.

Keywords: *Adaptation, Climate, Dynamics, Environment, Ghana, Hydrology, Implication, Land use, Land Cover, Mitigation, Systematic Review, Water Resource.*

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I. INTRODUCTION

Water resources play a vital role in Ghana's socioeconomic progress, supporting key sectors such as agriculture, energy, industry, and households. However, the nation faces increasing pressures due to rapid changes in land use and climate dynamics. A thorough understanding of these influences is crucial for ensuring sustainable water management practices.

Water resources in Ghana are critical for sustaining agriculture, energy production, industry, and drinking water supply (Mugagga and Nabaasa, 2016; Bieber, et al.; 2018; Bazaanah, 2019). However, changes in land use and land cover (LULC) due to agricultural expansion, deforestation, mining, and urbanization (Yaro et al., 2018; Awotwi & Anornu, 2019; Ampim et al.,2021) combined with the growing effects of climate change, pose significant risks to these water resources (Manful & Opoku-Ankomah, 2021). The conversion of forests to farmlands, urban areas, and mining sites has altered the hydrological cycle, leading to changes in water availability and quality (Aduah et al., 2017; Abungba et al., 2022). Additionally, climate change, characterized by altered rainfall patterns, temperature rise, and extreme weather events, exacerbates these challenges (Acheampong, 2021; Jewess. 2023). According to the Intergovernmental Panel on Climate Change (IPCC), West Africa, including Ghana, is one of the most vulnerable regions to climate variability, with rainfall patterns showing increasing unpredictability in recent years (IPCC, 2021). Understanding the interplay between LULC and climate change and their combined effects on water resources is critical for developing practices geared towards sustainable water management in Ghana.

This review paper assesses the implications of LULC and climate change on water resources in Ghana: between 2000 and 2024. This requires a multidisciplinary approach, combining remote sensing, climate data analysis, hydrological modeling, water quality assessment, and socio-economic studies. These methods provide comprehensive insights into how human activities and climate variability have shaped water availability, quality, and distribution across the country. Understanding these complex interactions is essential for developing effective water management strategies and mitigating the impacts of environmental changes on Ghana's water resources.

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II. METHODOLOGY

➢ *Systematic Review*

A structured review of existing research follows PRISMA guidelines (Figure 1), as outlined by Moher et al. (2010), ensuring a precise methodological approach to evaluating how land use and land cover (LULC) changes affect Ghana's water resources. Additionally, it examines the influence of a changing climate on hydrological patterns, the interaction between LULC changes and climate variability, and identifies research gaps to recommend sustainable water management strategies.

A comprehensive literature search across scientific databases, institutional reports, and grey literature was conducted using Boolean operators for precision (Table 1) (Haddaway et al., 2015). Studies were selected based on relevance, focusing on Ghana and similar West African regions, covering LULC changes, climate change, and water resources from 2000 onward. Thematic synthesis and meta-analysis were applied (Thomas & Harden, 2008; Borenstein et al., 2009**)**, incorporating GIS and remote sensing data. The PRISMA flow diagram (Figure 1) is used to ensure transparent study selection. Quality assessment followed the CASP checklists (CASP, 2018), with bias control strategies (Higgins et al., 2008), including independent double-screening and cross-referencing

Table 1 Database and Internet Search Protocol for Studies on Interlocking the impact of LULC and Climate Change on Water Resources

Search terms	**Search strategy**	**Creditability conditions**	**Databases**	**Sources**
"Land Use/Land Cover change AND water resources AND Ghana" "Climate change impact AND hydrology AND Ghana" "Deforestation AND water availability AND Ghana" "Urbanization AND water quality AND Ghana" "Climate variability AND river flow AND Ghana" Boolean operators (AND, OR) and Wildcards are used to refine searches.	Database: all terms searched as keyword as in title, abstracts & references Date: from 2000-2024	PRISMA guidelines to ensure methodological rigor. Critical Appraisal Skills Programme (CASP) checklists for assessing study robustness.	Google Scholar ScienceDirect Scopus, PubMed Web of Science GIDA, UNEP, FAO, Ghana Water Resources Commission, IPCC reports Theses, conference proceedings, government policy documents	Peer reviewed journals Institutional reports Grey literature:

➢ *Data Extraction and Analysis*

Data extraction was performed using a structured protocol (Booth et al., 2021). A standardized data extraction format was developed to capture essential details (Table 2) and this approach was followed for all the papers.

Table 2 Standardized Data Extraction Format

Study	**Year**	**Location**	**Key Findings**	**LULC Changes**	**Climate Factors**	**Hydrological Impact**
Kpoti et al.	2016	Volta Basin	Deforestation reduced water retention	Agricultural expansion	Temperature rise, erratic rainfall	Decreased river flow
Songore et al.	2020	Northern Ghana	Urbanization increased water demand	Built-up area growth	Reduced precipitation	Water scarcity issues

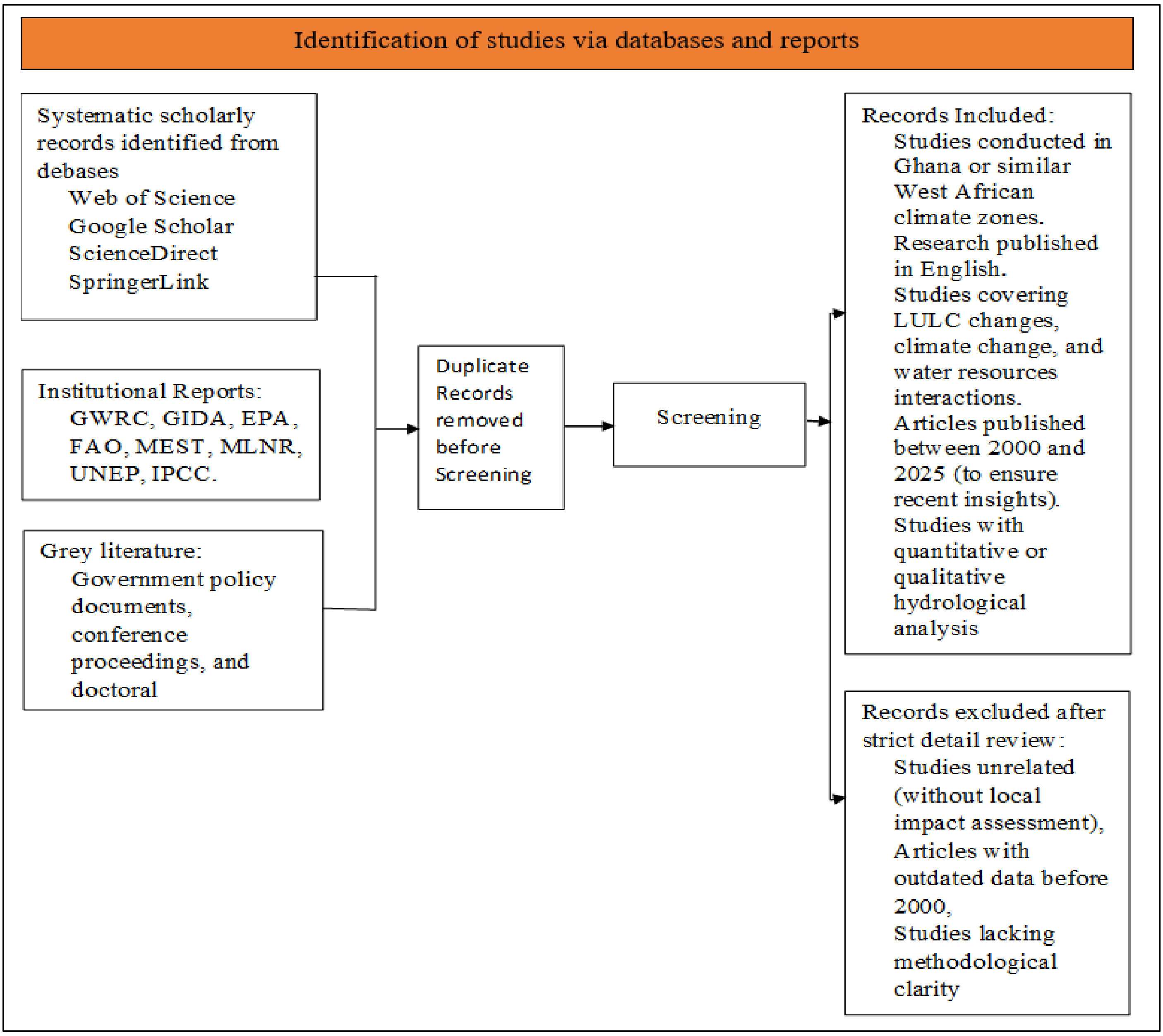

Fig 1 PRISMA Flow Diagram of the Study Selection

The PRISMA flow diagram is used to ensure transparent study selection by the Bias Control Strategies approaches involving double-screening of articles by independent reviewers, Cross-referencing studies to avoid over-reliance on specific datasets and independent verification of extracted data for consistency

III. SYNTHESIS AND INTERPRETATIONS OF FINDINGS

A systematic review approach was adopted, analyzing peer-reviewed articles, government reports, and climate change spanning the past two decades and half decades. Articles were selected based on their relevance to LULC trends, climate change impacts, and water resource management in Ghana. Key themes identified include deforestation-driven hydrological shifts, agricultural pressures on water resources, and urbanization-induced modifications in water availability and quality.

- *Ghana's Major Land use and Land Cover (LULC) Classifications*

Ghana, located in West Africa, has a total area of 238,533km^2 shared between land and water area of 227,533km^2 and 11,000km^2 respectively shown in Figure 3; (MoFA 2021; GMet, 2021). The country has a diverse landscape characterized by varied land use and land cover (LULC) types. These categories play a critical role in the nation's economy, ecology, and development. The major land use and land cover types in Ghana include agricultural lands, forests, grasslands, urban areas, and water bodies (Atwi et al., 2014; Yeboah et al., 2017; Ampim et al., 2021). Below is an analysis of these categories: Agriculture is the backbone of Ghana's economy, employing about 44% of the population (Aryeetey et al., 2007; FAO, 2024). Agricultural lands are the most extensive land use type, covering about 57% of the total land area of Ghana (FAO, 2024). These lands are mainly used for the cultivation of staple crops such as maize, cassava, yam, and plantain, as well as cash crops like cocoa, which is

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Ghana's primary export commodity, (Asibey et al., 2020). Subsistence farming is predominant in rural areas, but commercial farming is expanding, particularly in the cocoa and oil palm sectors (Orday et al., 2017).

Forests cover is approximately 21.7% of Ghana's land area (FAO, 2024), primarily in the southern part of the country, particularly in the Western, Ashanti, and Eastern regions. These forests are crucial for biodiversity conservation, carbon sequestration, and the livelihoods of many communities (Acheampong et al., 2022). However, deforestation, driven by logging, agriculture, and mining, stances a significant threat to these ecosystems (Appiah et al., 2009, Bansah, 2024). The northern part of Ghana is dominated by grasslands and Savanna, accounting for a significant portion of the country’s land cover (Braimoh et al.,2005; Ocloo et al., 2024). These areas support livestock grazing and seasonal farming (Akapali et al., 2018). The savanna ecosystem is characterized by scattered trees (Kugbe et al., 2012). The major land use and land cover types in Ghana include agricultural lands, forests, grasslands, urban areas, and water bodies and grasslands, providing habitat for diverse wildlife and supporting communities through fuelwood and non-timber forest products.

Urbanization in Ghana has been rapid, particularly in cities such as Accra, Kumasi, Tamale and Takoradi (Owusu & Yankson, 2017; Songore, 2020). Urban and built-up areas, although constituting a smaller proportion of less than 2% of the land cover, are expanding due to population growth and economic development (Addae & Oppelt, 2019; Asabere et al., 2020). This urban growth often occurs at the expense of agricultural and forested lands, leading to environmental challenges such as habitat loss and urban heat islands (Asabere et al., 2020). According to the Food and Agricultural Organization, water bodies, including rivers, lakes, and wetlands, cover about 3.6% of Ghana's total area (FAO, 2024). The Volta River system, including Lake Volta, is a prominent feature, providing water for domestic use, agriculture, and hydroelectric power generation (Gordon et al., 2013; Agodzo, 2023). Coastal wetlands and lagoons, such as the Sakumo Lagoon and the Keta Lagoon, are important for biodiversity and aid in especially, the breeding of fish and migratory birds (Lamptey & Ofori-Danson, 2014; Takyi et al., 2022; Agbeti, 2023).

The main challenges facing land use and land cover in Ghana include deforestation, land degradation, and urban sprawl. Efforts to address these challenges include reforestation initiatives, sustainable agricultural practices, and urban planning reforms. The adoption of land management initiatives, including the Ghana Forest Plantation Strategy, plays a crucial role in promoting sustainable environmental stewardship. It also aims at balancing economic development with environmental conservation. Ghana's land use and land cover types in Figure 2 reflect its rich natural resources and diverse ecosystems. Effectively managing these resources is essential for fostering sustainable progress and enhancing the quality of life for the nation’s people.

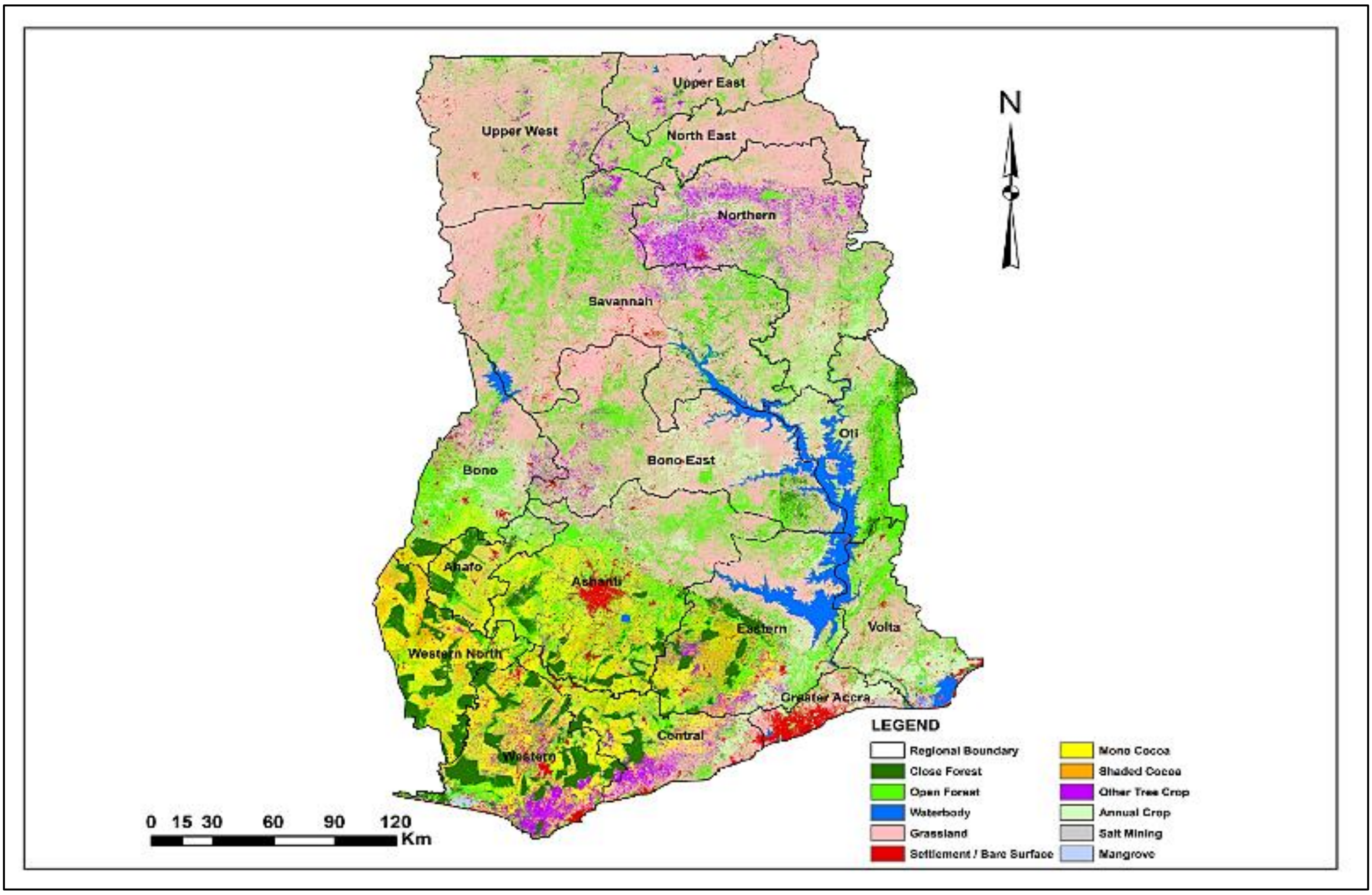

Fig 2 Map of Ghana Showing Land Cover types of Ghana Enhanced by Forestry Commission of Ghana, (FCG, 2019).

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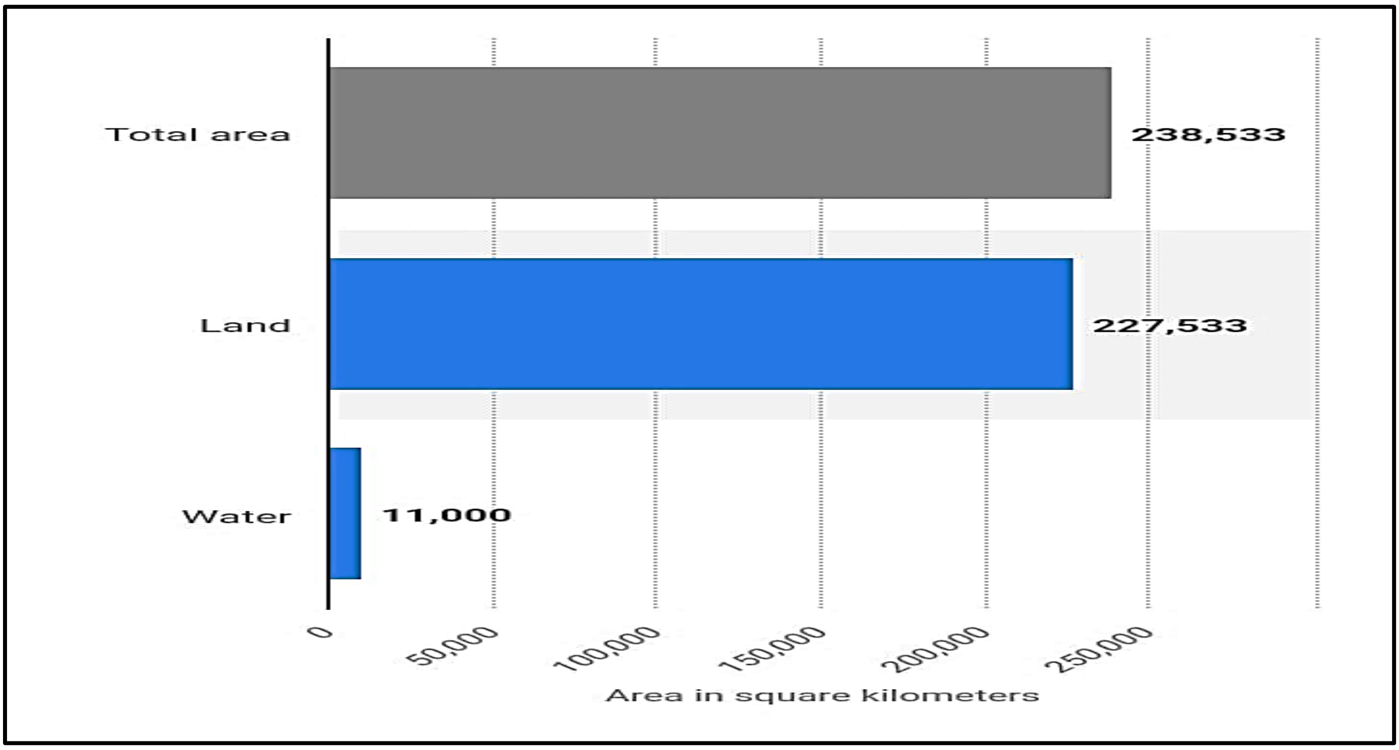

Fig 3 Ghana's Land and Water Area
Sources: Ministry of Food and Agriculture (2021); Ghana Meteorological Agency @ Statista 2024

➢ *Trend Analysis of Temperature in Ghana*

The decadal trends of average temperature in Ghana, presented in (Figure 4) showed that the average surface air temperature has varied upward per decade from 1951 to 2020. Temperature in the immediate last three decades has continued to trend in an increasing trajectory between 1991 and 2020 which is a matter of concern.

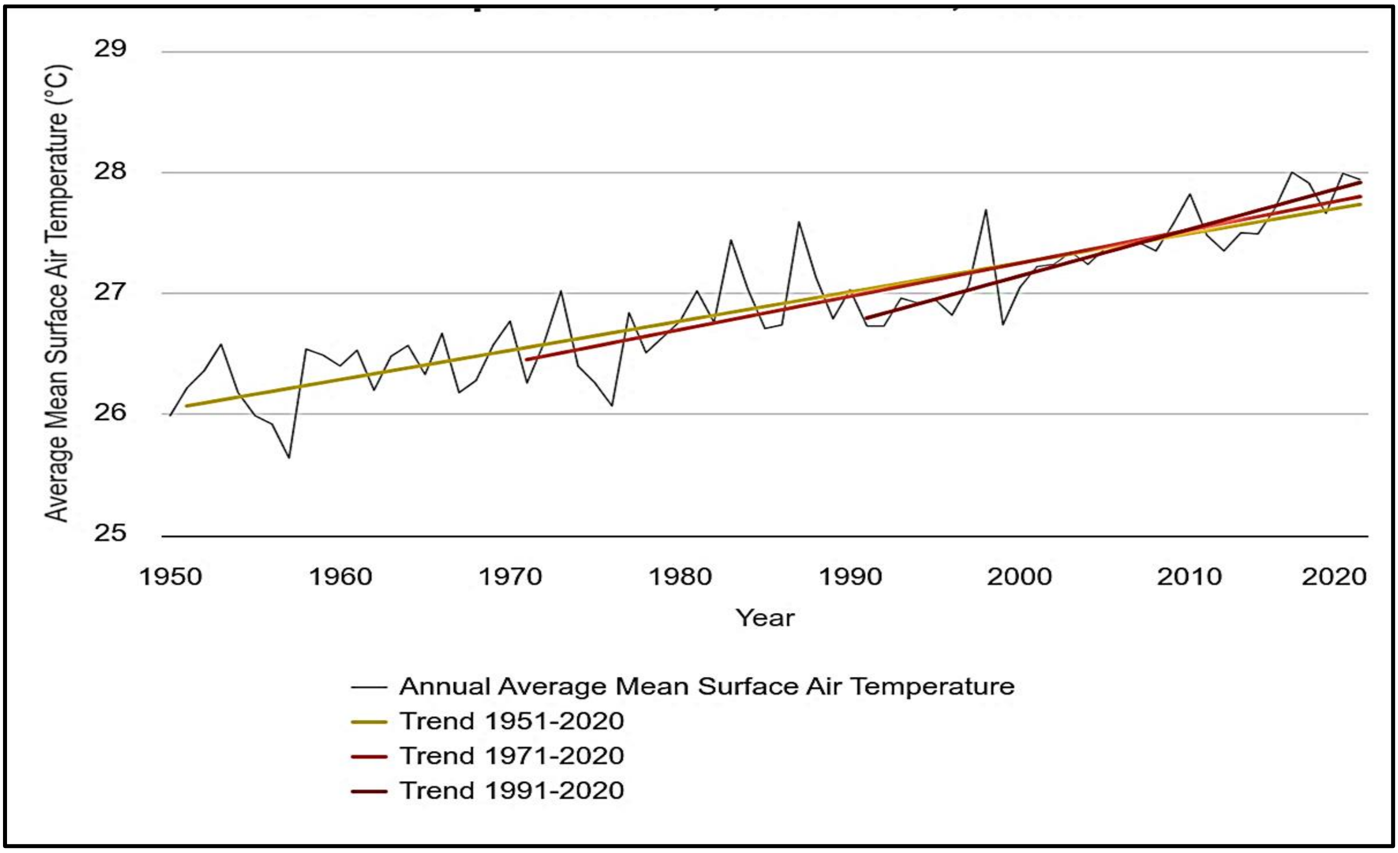

Fig 4 Average Mean Surface Air Temperature Annual Trends with Significant of Trend per Decade from 19951-2020, Ghana.
Source: World Bank Group Report (2021)

➢ *Annual Rainfall Distribution in Ghana by Region*

Ghana has witnessed an upsurge in extreme weather events such as flashes of floods and droughts. These extreme events affect both water availability and infrastructure. In Figure 5., Greater Accra has the lowest average rainfall found in the coastal zone while Upper East, North East and Northern, Volta and Oti, and Upper West regions located in the savannah zone have relatively lower average rainfall in Ghana. The Western and Western-North regions have the highest seasonal average rainfall while Eastern, Ashanti, Central and Brong Ahafo, Bono and Bono East regions in the forest zone recorded relatively higher average rainfall values in Ghana over the period.

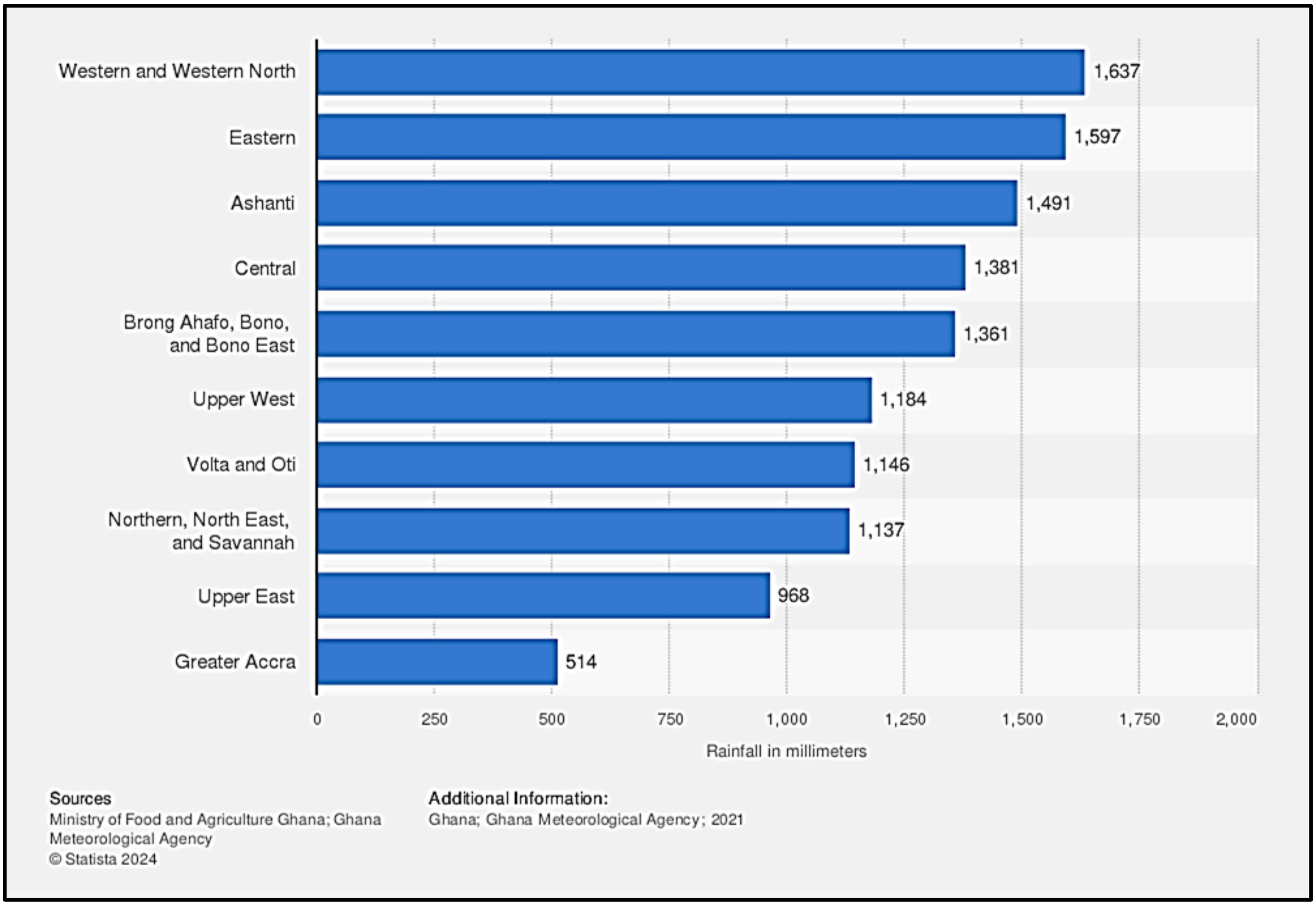

Fig 5 Annual Rainfall in Ghana by Region 2021.

IV. DISCUSSION

➢ *LULC Change Patterns in Ghana and Implications on Water Resources in Ghana*

Ghana has undergone significant land cover changes in recent decades, driven by human activities. These changes have direct implications for the hydrological cycle and water resources. Changes in land use (like deforestation, urbanization, and agriculture expansion) affect land cover and have altered the natural hydrological cycle. Studies in Ghana have shown that deforestation, particularly in regions such as the Volta Basin, leads to increase surface runoff (Kpoti et al., 2016). This can reduce water availability during the dry season, leading to water stress for agriculture and households (Kpoti et al.,2016). In Ghana, large-scale deforestation, particularly for agriculture, has significantly altered local hydrology (Aduah et al., 2017) although Ghana's economy is heavily reliant on agriculture (Diao et al., 2019). Deforestation as a result of clearing land for farming, particularly cocoa cultivation, has significantly altered the landscape (Brobbey et al., 2020). Shifting cultivation practices and monocropping deplete soil fertility, contributing to land degradation. Also, land-use changes such as the expansion of coastal agriculture, further stresses freshwater availability in regions like the Keta Basin (Sagoe-Addy & Gordon, 2019). Agriculture accounts for a significant portion of land use in Ghana, with large tracts of land being converted into cropland, particularly for cocoa, maize, and yam cultivation according to Ministry of Food and Agriculture (MoFA, 2017). This conversion of forests and wetlands into farmlands disrupts the natural water balance, affecting surface water runoff (Akhtar et al., 2021; Babaremu et al., 2024).

Rapid urban growth, particularly in cities like Accra and Kumasi, has led to the conversion of wetlands, forests, and agricultural lands into human settlements and industrial areas. This affects infiltration rates, increases surface runoff, and reduces groundwater recharge. Urbanization in Ghana is a significant driver of land use and land cover change

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(LULCC), impacting ecosystems, agricultural land, and biodiversity. The surge in population and the movement of people from rural areas to urban centers have resulted in significant changes and challenges. This has contributed into the expansion of cities like Accra and Kumasi, significantly altering natural and rural landscapes. Urban expansion in Ghana often involves converting agricultural land and forests into residential, industrial, and infrastructural areas. For instance, between 1990 and 2015, Ghana's urban areas expanded by 120%, primarily at the expense of forests and farmlands (Koranteng & Zawila-Niedzwiecki, 2015). Urban sprawl leads to habitat fragmentation and the loss of biodiversity. Natural ecosystems are replaced by impervious surfaces, rendering the land less capable to provide essential services like water filtration and carbon sequestration (Eduful, 2014). Urbanization alters water systems through increased demand, pollution, and changes in hydrology (Ampim et al., 2021). For example, cities often disrupt local water cycles and lead to the degradation of water quality, particularly where informal settlements lack adequate waste management systems (Abdallah, 2018; Kayaga et al., 2021).

Urban areas in Ghana, like elsewhere, experience increased regional temperatures due to heat-absorbing materials such as asphalt. Additionally, soil degradation occurs from the removal of vegetation, compaction, and increased runoff due to impermeable surfaces (Mercado, 2016, Gantula et al., 2023). The rising demand for urban infrastructure often conflicts with traditional land uses. Efforts to address LULCC in Ghana involve balancing urban growth with sustainable practices. Policies promoting compact city designs, urban greening, and integrated land use planning are essential but often face implementation challenges due to resource constraints and governance issues (Kleemann, 2018; Adu-Boahen et al., 2023; Kumi, 2024). By improving urban planning frameworks and enforcing land management regulations, Ghana can mitigate the adverse effects of urbanization on land use while promoting sustainable urban growth.

Small-scale and large-scale mining activities, especially in regions like Ashanti and Western Ghana, have degraded vast areas and polluted water bodies through sedimentation and chemical runoff. Mining activities, particularly gold mining, are a key force behind transformations in land use and land cover in Ghana. The country’s position as a significant gold producer has led to extensive land transformations. Mining activities, whether conducted within regulatory frameworks or outside legal boundaries, have significant environmental and socio-economic impacts. Large-scale and artisanal mining operations have led to significant deforestation. In areas such as the Asutifi North District, forests have declined from about 59,000 hectares in 1986 to 34,000 hectares by 2020, as mining sites replace natural vegetation (Gbedzi et al., 2022). Mining activities, especially surface mining, strip the land of its vegetative cover, degrade soil quality, and leave the land unsuitable for agriculture or habitation. This degradation is particularly pronounced in the Western Region of Ghana, where gold mining is most intense (Mensah et al., 2015; Gbedzi et al., 2022). Mining operations often contaminate and deplete water resources. For example, in mining zones, streams and rivers suffer from sedimentation, heavy metal pollution, and chemical contamination, affecting both aquatic ecosystems and communities reliant on these water sources (Emmanuel et al., 2018; Amengor, 2024). The increase in mining zones is evident from satellite studies (Gbedzi et al., 2022). For example, the gold mining area in the Asutifi North District expanded by approximately 13.6 km² in 2015 to 16.7 km² in 2020 (Gbedzi et al., 2022). This growth is largely driven by illegal mining, which poses challenges to environmental management and local governance (Gbedzi et al., 2022; Adu-Baffour et al., 2021; Asori et al., 2023). Mining activities often lead to the displacement of communities and conflicts over land ownership. Agricultural lands are frequently converted into mining areas, disrupting local food production systems and livelihoods (Ofosu et al., 2020; Adjei et al., 2024).

Efforts to mitigate these impacts include stricter enforcement of environmental regulations, rehabilitation of mined lands, and promoting alternative livelihoods for communities affected by mining. Sustainable mining practices and greater oversight of illegal mining operations are critical to balancing economic benefits with environmental protection and community well-being (Yeboah & Nyarkoh, 2022; Asuamah, 2023). Logging and charcoal production are major causes of forest loss, impacting evapotranspiration and watershed stability. Deforestation reduces the ability of the land to retain water, leading to increased surface runoff and reduced groundwater recharge (Owuor et al., 2016). For example, regions like the Volta Basin have experienced increased surface runoff due to the reduction in forest cover, which impacts water availability (Agodzo et al., 2023).

Ghana has one of the highest deforestation rates in West Africa, driven by illegal logging, timber harvesting, and charcoal production (Afele et al., 2022). Deforestation in the country's forest belts reduces vegetation cover, which acts as a buffer for water infiltration and evaporation processes. Consequently, deforestation accelerates soil erosion, alters watershed characteristics, and affects river flow regimes (Hansen, & Treue, 2001; MLNR, 2020).

➢ *Climate Change Impacts on Hydrology*

Shifting climate patterns create profound difficulties for water systems across the globe, affecting availability, quality, and distribution, and Ghana is no exception. As a country heavily reliant on agriculture, hydropower, and groundwater for domestic and industrial use, Ghana’s water resources are highly sensitive to climatic variations. Key manifestations of climate change in Ghana include rising temperatures, changing rainfall patterns, and increased frequency of extreme weather events such as floods and droughts. These changes directly affect the availability, quality, and distribution of water resources. Irregular rainfall patterns disrupt surface water flow and reduce groundwater recharge, leading to water scarcity in some regions. In contrast, excessive rainfall can result in flooding, which contaminates water supplies and damages water infrastructure. These challenges have profound implications for agriculture, energy

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production, public health, and overall socio-economic development, making the sustainable management of water resources a critical priority in addressing the impacts of climate change in Ghana. The country experiences significant climatic variability, with observable trends in key climatic variables.

For instance, average annual temperatures have increased by over 1°C since 1970, leading to heightened evaporation rates and reduced water availability (Effah, 2014). The increase in average temperatures across Ghana has intensified evapotranspiration, which has reduced water availability in rivers and lakes (Appiah et al., 2020). This is of particular concern for northern Ghana, where semi-arid conditions prevail, and the water demand for agriculture is high. Higher temperatures due to climate change led to increased evaporation from rivers, reservoirs, and lakes which is of great concern to water bodies that support agriculture and hydropower, as decreasing water levels impact energy production and irrigation in regions such as the Upper East and Northern regions (Amisigo et al., 2015). Additionally, temperature increases due to climate change accelerate evaporation from water bodies, further reducing the availability of water. This may affect reservoirs and rivers in key agricultural regions, which depend on consistent water levels for irrigation and crop production (Amisigo et al., 2015).

Rainfall patterns have become erratic, with decreased precipitation in some regions and an increased frequency of extreme weather events like floods and droughts. Climate models predict a decrease in precipitation and higher variability in rainfall patterns across Ghana, particularly in the Northern and Upper regions, which are already prone to droughts. This increased variability threatens the availability of water for agricultural, domestic, and industrial use (Asante et al., 2016). Owusu and Waylen (2009) utilized historical rainfall and temperature data to assess climate variability in the Volta Basin. They found that increased temperatures and reduced rainfall over the study period negatively impacted water availability, mostly during the dry season, contributing to seasonal water shortages.

Climate change has led to more erratic rainfall patterns in Ghana, with some areas experiencing prolonged dry spells while others face intense and unpredictable rains (Rademacher-Schulz et al., 2014). Northern Ghana, particularly the White Volta Basin, is seeing more frequent droughts, severely reducing water availability for irrigation and drinking (Opoku-Ankomah et al., 2020). Prolonged droughts deplete surface water sources and stress groundwater reserves. Rainfall in Ghana has become increasingly unpredictable, with some areas experiencing more intense rainfall, while others are seeing prolonged dry spells (Gbangou et al., 2020). The highest daily rainfall over Accra (244 mm) and Kumasi (168 mm) for the period 1960-2017 saw increasing trend of same over the period in Accra and a decreasing trend in Kumasi (Ansah et al., 2020). For instance, the northern regions have reported reduced annual rainfall, affecting the water supply for agriculture and livestock (Fagariba et al., 2018; Klutse et al., 2021).

In southern Ghana, sea-level rise, exacerbated by climate change, leads to saltwater intrusion into freshwater resources, particularly in low-lying areas. reduced groundwater recharge, and greater susceptibility to flooding during the rainy season (Adade, 2024). Also, coastal areas, such as the Volta Delta, are threatened by rising sea levels, resulting in saline intrusion into freshwater systems. In the coastal regions of Ghana, sea-level rise driven by climate change is increasing saltwater intrusion into freshwater systems, compounding the stresses from land cover changes, especially in low-lying areas (Effah, 2014; Magnan et al., 2019).

➢ *Interlocking Effects of LULC Change and Climate Change on Water Resources*

The combined effect of LULC changes and climate change on water resources in Ghana is multifaceted, involving complex interactions between physical, ecological, and socio-economic systems. The many effects as manifested by these factors are narrated in various ways deemed appropriate in this study. The combination of land use changes (deforestation and urbanization) and climate change intensifies water scarcity challenges. Flooding, particularly in the southern regions, has overwhelmed drainage systems, causing riverbanks to overflow, while droughts in the north have reduced water levels in rivers and reservoirs (Quaye, & Ofori, 2019).

Changes in LULC, such as deforestation and urbanization, exacerbate runoff, erosion, and sedimentation, reducing the capacity of reservoirs and rivers like the Volta and Pra (Acheampong et al., 2021). Large-scale and artisanal mining, especially for gold, has caused significant land degradation in many parts of Ghana, particularly in the Western and Ashanti regions. Mining activities, often accompanied by the destruction of vegetative cover, alter natural landscapes and result in sedimentation of water bodies, degrading water quality and reducing storage capacity in rivers and dams (Tschakert, & Singha, 2007; Armah, et al., 2013). Changes in land cover disrupt the natural hydrological cycle, altering the flow of rivers and the availability of water throughout the year. The conversion of wetlands into farmlands and urban areas reduces the ability of these ecosystems to store water and regulate river flows, leading to seasonal imbalances in water availability (Cobbinah et al., 2022). The combined effects of LULCC and climate change are intensifying water scarcity in Ghana. For example, deforestation reduces the land's ability to retain moisture, while climate change leads to more erratic rainfall and longer dry periods. In regions like the Volta Basin, these changes are leading to reduced water availability, affecting agriculture, domestic water supply, and ecosystem sustainability (Gyasi et al., 2014, Mul et al., 2016). Forest degradation reduces water retention capacity, while climate change exacerbates variability in water supply (Mul et al., 2016; Atulley et al., 2022). The two factors together pose serious threats to the sustainability of water resources, especially in catchment areas like the White Volta Basin (Atulley et al., 2022). In combination with reduced rainfall and higher temperatures due to climate change, water availability in rivers, streams, and reservoirs is declining (Obuobie et al., 2012).

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Groundwater is a critical resource, particularly in the northern regions of Ghana where surface water is scarce (Appiah, et al., 2020). However, deforestation and urbanization reduce groundwater recharge by limiting infiltration. Urbanization and agriculture lower groundwater recharge rates, while over-extraction in semi-arid regions, such as the Northern Savannah, further stresses aquifers. Studies in Ghana have shown that deforestation, particularly in regions such as the Volta Basin, leads to decreased infiltration and groundwater recharge (Kpoti et al., 2016). Moreover, the Volta Basin has experienced decreased groundwater recharge due to the reduction in forest cover, which impacts water availability (Agodzo et al., 2023). As forests are converted into farmland, less water infiltrates the soil, leading to reduced aquifer recharge, essential for sustaining water resources. Rapid urbanization in major cities such as Accra and Kumasi have contributed to decreased water infiltration (Abass et al., 2020). The conversion of forests and wetlands into farmlands disrupts the natural water balance, affecting surface water runoff and groundwater recharge (Babaremu, 2024).

Climate change, by altering rainfall patterns and increasing evapotranspiration, further reduces groundwater levels. This has serious implications for rural communities that rely on boreholes for drinking water (Owusu, and Waylen, 2020). Abungba et al. (2022) applied the SWAT model to assess the impact of agricultural expansion in the Black Volta Basin on the water resources in the basin. Their simulations showed that large-scale conversion of forest to farmland increased surface runoff and reduced groundwater recharge, exacerbating water shortages during the dry season.

Pollution from mining, agriculture (fertilizers and pesticides), and urban effluents increases turbidity and nutrient loads, causing eutrophication and biodiversity loss in aquatic ecosystems. Urbanization, particularly in Accra and Kumasi, has resulted in the loss of permeable surfaces, further exacerbating flooding and reducing the quality of water bodies due to pollution (Addae et al., 2018). Furthermore, in urbanized regions such as Accra and Kumasi have contributed to water pollution through expansive impervious surfaces, such as roads and buildings, leading to greater volumes of stormwater runoff, which carries pollutants into water bodies, degrading water quality (Abass et al., 2020). Mining, deforestation, and agricultural activities contribute to water pollution, with increased sedimentation and the introduction of contaminants such as mercury and pesticides into water bodies (Kumi et al., 2023). The increased sediment load in rivers leads to siltation, reducing water quality and the storage capacity of reservoirs (Adongo, et al.,2020).

Climate change exacerbates these impacts by intensifying rainfall events, which wash more pollutants into rivers and streams (Adongo et al., 2020). Water pollution control in Ghana is a critical issue influenced by land use and land cover changes (LULCC) and exacerbated by climate change. Key drivers include deforestation, illegal mining (galamsey), agricultural runoff, and poor waste management practices. These activities degrade water quality, impact ecosystems, and threaten public health. In mining regions, over 60% of water bodies are heavily polluted, primarily with heavy metals such as mercury and arsenic (Bessah et al., 2021). Illegal mining introduces these pollutants into rivers, making the water perilous for drinking and agriculture. For example, mercury concentrations in areas like the Pra River Basin exceed safe limits for irrigation and consumption (Asare, 2021).

Deforestation for agriculture and urbanization also compromises water sources by increasing runoff and sedimentation, which worsens pollution levels (Amuah et al., 2022). Climate change further aggravates the situation by altering rainfall patterns, reducing water availability, and increasing the concentration of pollutants during dry periods (Asante & Amuakwa-Mensah, 2014; Boateng et al., 2020). Efforts to address these challenges include implementing sustainable land and water management practices, such as reforestation of watersheds, enforcement of mining regulations, and the use of riparian buffers to protect water bodies. Integrated approaches involving community participation and stricter pollution controls are crucial for sustainable water resource management in Ghana (Owusu et al., 2016; Acheampong et al., 2016; Tang & Adesina, 2022).

Land Use and Land Cover Change (LULCC) and climate change significantly affect hydropower generation in Ghana, where hydropower provides a substantial portion of the country’s electricity (Obahoundje et al., 2017; Obahoundje & Diedhjou, 2022; Ahialey et al., 2023). LULCC, including deforestation, urbanization, and agricultural expansion, impacts river basins by altering water cycles, reducing vegetation cover, and increasing soil erosion (Ahialey et al., 2023). These changes reduce water availability and increase sedimentation in reservoirs, which can lower the efficiency and capacity of hydropower facilities (Ahialey et al., 2023).

Climate change exacerbates these issues through altered rainfall patterns, increased temperatures, and extreme weather events. Reduced and erratic rainfall can lead to lower water levels in reservoirs, affecting power generation reliability. Additionally, high temperatures exaggerate evaporation rates, further reducing water resources. These combined factors threaten the sustainability and reliability of Ghana’s hydropower sector, with cascading effects on energy supply, economic growth, and sustainable development. The percentage coverage of runoff calculated using projected rainfall and temperature means over the entire 2011-2050 period for the Bagre, Kompienga, and Akosombo facilities, 2014-2050 for Bui and 2025-2050 for Juale on Oti, Pwalugu on the White Volta, and Hermang on the Pra rivers (Amissigo et al., 2015). The percentage coverages of runoff are generally higher for the global scenarios than for the Ghana scenarios, (Amissigo et al., 2015). The results showed that on the average, the demands for the two largest facilities, Akosombo and Bui are not fully met under any of the scenerios including the wet scenarios.

Reduced water flow in rivers like the Volta threatens the Akosombo Dam, Ghana's primary source of hydropower, with implications for energy security. Reduced rainfall in the

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Volta River Basin, which feeds the Akosombo Dam, threatens hydroelectric power generation, which is one of Ghana's major energy sources (Scudder, 2012). In the Volta Basin, water levels have decreased, affecting both agricultural productivity and hydroelectric power generation (Kabo-Bah et al., 2016).

- *Policy and Management Implications*

Addressing the impacts of LULC changes on water resources requires integrated and proactive measures at both policy and community levels. Integrating water resource management into land-use planning can help mitigate the effects of deforestation and urbanization (Awotwi et al., 2019). A study by Acheampong et al. (2014) reviewed Ghana's water resource management policies and found gaps in the enforcement of regulations governing water extraction and land use, which contributed to over-exploitation of water resources in urban areas. Therefore, deliberate policies and systems for wastewater recycling and reuse in urban areas must be promoted and enforced by the responsible ministries and agencies.

Additionally, the construction of multipurpose dams that integrate water storage, flood control, and irrigation can improve water resource management. While Ghana has made some strides in water resource management, there remains a need for better integration of LULCC and climate change considerations into national and regional policies. Effective adaptation strategies, such as reforestation and improved urban planning, are necessary to mitigate the combined impacts of these environmental challenges (Awuni et al., 2023). The country has committed to the Land Degradation Neutrality (LDN) program, aiming to restore degraded forests and agricultural lands through reforestation and sustainable practices (Kumar et al., 2024). For example, the nation targets replanting 30,000 hectares of trees annually and protecting biodiversity-rich areas (Kumar et al., 2024). Projects like the Land of Opportunities (LogMe) initiative in northern Ghana combine environmental restoration with community empowerment. Over 60,000 tree seedlings have been planted, wetlands restored, and erosion controlled, improving water retention and agricultural productivity while fostering microclimates (Gichuki et al., 2019; Standturf, 2021; Kumar et al., 2024). The programs focus on sustainable income generation, such as producing grass, charcoal, beekeeping, and creating energy-efficient cookstoves. These efforts improve economic stability, especially for marginalized groups like women in the rural areas, while reducing environmental impacts (Likoswe et al., 2018; Glatzel et al., 2024).

Local communities play a critical role, with enforcement against unsustainable practices like bush burning. Women's participation in leadership and decision-making has been crucial for inclusivity and effectiveness (Koomson, 2024). By reducing land degradation, Sustainable Land Management (SLM) efforts bolster resilience against climate variability, improve food security, and enhance sustainable land use practices aligned with the UN Sustainable Development Goals (SDGs) (Sanz et al., 2017; Koughi et al., 2024). Policies that promote reforestation, afforestation, and sustainable agricultural practices can enhance water retention in soils and maintain ecosystem services according to Forestry Commission of Ghana (2018).

The Promotion of afforestation and reforestation projects, particularly in degraded watershed areas, and the implementation of agroforestry and conservation agriculture to maintain soil and water balance and the sustainable land management (SLM) in Ghana addresses the dual challenges of land-use and land-cover change (LULCC) and climate change by focusing on restoring degraded ecosystems, enhancing productivity, and fostering economic resilience. Ghana's SLM strategies demonstrate the transformative potential of integrating environmental restoration with economic and social development, creating opportunities for sustainable growth even in challenging conditions (Djenontin et al., 2018). Developing an integrated water resources management (IWRM) framework that includes real-time monitoring of water bodies and land use changes is crucial for planning and decision-making. The adoption of efficient water management techniques, such as rainwater harvesting, drip irrigation, and the use of water-saving technologies, is essential to ensure water availability for agriculture and domestic use (Adu, 2019; Assefa et al., 2019; Frimpong et al., 2023). Local communities should also be educated on sustainable water use practices. Develop policies that integrate land use planning with water resource management. Establish watershed protection initiatives and enforce regulations to prevent encroachment on wetlands and riparian zones.

Climate resilience programs in Ghana focus on mitigating the adverse impacts of climate change on water resources, which are critical for agriculture, drinking water, and energy generation. Ghana’s water resources face significant threats due to erratic rainfall, prolonged droughts, and rising temperatures, impacting both surface and groundwater availability. These programs integrate policy, community engagement, and technical solutions to build resilience in water management. Ghana has adopted Integrated Water Resources Management (IWRM) to ensure sustainable water use while minimizing conflict among sectors. This approach emphasizes coordinated development and management of water, land, and related resources. The Water Resources Commission (WRC) of Ghana oversees IWRM initiatives, including stakeholder engagement and data-driven decision-making (WRC, 2021). Investments in resilient water infrastructure, such as reservoirs, rainwater harvesting systems, and improved irrigation facilities, aim to counter water scarcity during dry periods. The Ghana Irrigation Development Authority (GIDA) implements irrigation projects to enhance agricultural productivity under changing climate conditions (GIDA, 2020). Empowering local communities to manage water resources sustainably is a cornerstone of resilience strategies. Training programs and the establishment of water user associations help in equitable distribution and efficient usage. The United Nations Development Programme (UNDP) supported the “Community Resilience through Early Warning” project, which enhanced water conservation practices in northern Ghana (UNDP, 2021).

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Ghana integrates climate considerations into national water policies through different institutions. The Ghana National Climate Change Adaptation Strategy (NCCAS) includes provisions to secure water resources against climate risks. The Ministry of Environment, Science, Technology, and Innovation (MESTI) ensures that water management aligns with broader climate adaptation goals (MESTI, 2015). But, limited funding, insufficient data for predictive modeling, and over-reliance on rain-fed agriculture exacerbate water resource vulnerabilities (Nyamekye, 2020). With this, expanding public-private partnerships, enhancing groundwater mapping, and improving climate-resilient water infrastructure are critical for long-term sustainability (World Bank, 2022).

Moreover, investing in climate-resilient water infrastructure, such as improved drainage systems, flood control measures, and dam restoration, can reduce the impact of extreme weather events on water resources according to Ghana Meteorological Agency (GMet, 2021). Regulate mining activities and adopt eco-friendly agricultural practices to reduce water pollution. Strengthen the enforcement of environmental laws to protect water bodies. Water pollution control in Ghana involves a combination of legislative frameworks, institutional efforts, community initiatives, and international collaboration to address growing challenges.

Ghana's National Water Policy emphasizes Integrated Water Resource Management (IWRM) to ensure the sustainable use of water. It incorporates mechanisms like effluent charges under the "polluter pays" principle, aiming to curb industrial and domestic pollution. However, the enforcement of existing regulations and securing adequate funding remain key challenges (Dorm-Adzobu & Ampomah, 2014; Frimpong et al., 2021). The Water Resources Commission (WRC) and Environmental Protection Agency (EPA) lead the charge against water pollution, focusing on monitoring, enforcement, and collaboration with local and international agencies. Efforts include training enforcement personnel, fostering inter-agency collaboration, and integrating water resource management into local governance (Ofori & Mdee, 2022; Adranyi et al, 2024).

Programs supported by the UN and other international organizations, like WASH (Water, Sanitation, and Hygiene), aim to improve infrastructure in schools and health facilities. These initiatives target reducing waterborne diseases and enhancing sanitation access, with plans to rehabilitate infrastructure in vulnerable regions like northern Ghana (Wuni, 2008; Adorsu-Djentuh, 2018). Climate change impacts, such as reduced water availability and quality, are a growing concern. Initiatives include mapping climate risks to water infrastructure and developing standards for resilient WASH solutions in collaboration with global partners like UNICEF (Howard et al., 2016; WHO, 2020).

Insufficient funding, inadequate enforcement of pollution regulations, and limited data on water resource quality are significant hurdles. Solutions proposed include stronger legal frameworks, expanded public-private partnerships, and innovative financing mechanisms (Tijani, 2014; Sanusi et al.; 2023; Kulwant & Yadav, 2024) These collective efforts aim to ensure the sustainable management of Ghana's water resources, balancing economic growth with environmental conservation.

Invest in remote sensing and Geographic Information Systems (GIS) to monitor LULC and water resource changes. Encourage research on the interplay between climate change, LULC, and water resources to inform evidence-based policymaking. Accurate data on rainfall, river flows, groundwater levels, and LULC patterns can guide adaptive management strategies (Acheampong et al., 2020). Hydrological data is essential for understanding water resource trends in Ghana. This includes river discharge data, groundwater levels, and precipitation records, which are available from the Water Resources Commission of Ghana and the Ghana Meteorological Agency (GMet). These datasets provide historical insights into the variability of water resources and can help identify trends linked to both LULCC and climate change.

Studies focusing on the Volta Basin and other river systems in Ghana often rely on these datasets to assess how rainfall changes and land use practices affect river flows and groundwater recharge.

Climate models and historical climate data from the Intergovernmental Panel on Climate Change (IPCC) and regional climate databases provide information on temperature and precipitation trends. These data are crucial for projecting future climate scenarios in Ghana and understanding how changes in the climate might exacerbate or mitigate the effects of LULCC on water resources.

Ghana Meteorological Agency tracks local climate patterns and assess the extent of climate change impacts on water availability, particularly in the northern parts of the country where droughts are increasingly frequent.

Government documents and policy reports from institutions like the Ministry of Environment, Science, Technology and Innovation (MESTI) and the National Development Planning Commission (NDPC) provide a context for understanding national priorities and strategies in managing LULCC and climate change. The National Climate Change Adaptation Strategy offers insights into how Ghana plans to address these environmental challenges. These reports often include data on land use policy changes, agricultural practices, and water governance frameworks, which are crucial for understanding the socio-political dimensions of environmental challenges in Ghana.

V. IDENTIFIED RESEARCH GAPS AND RECOMMENDATIONS FOR EFFECTIVE WATER RESOURCES MANAGEMENT

Addressing these issues demands a comprehensive and coordinated approach that brings together multiple strategies encompassing sustainable land management, water conservation, and climate adaptation strategies. The gap remains that there is little or no integration of climate

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modeling, hydrological assessments, and land-use planning to develop adaptive strategies. Policymakers must also focus on building resilient water infrastructure and enhancing community-based water management practices to mitigate the dual impacts of LULCC change and climate change on water resources in Ghana. Climate change is exacerbating water scarcity by altering rainfall patterns and increasing the frequency of extreme weather events. Developing climate-resilient infrastructure can help mitigate the impacts of these changes on water resources. The following water resources management approaches are recommended for efficient water usage.

➢ *Integrated Water Resources Management (IWRM)*

As a holistic approach, the interdependencies between water, land, and ecosystems is considered: By managing water resources in a coordinated manner, IWRM promotes sustainability and resilience to climate change. The IWRM framework should include:

- Stakeholder Collaboration: Involvement of government, local communities, industries, and non-governmental organizations (NGOs) in decision-making processes.
- Watershed and Basin Management: Coordinated management of water resources at the watershed and basin levels (e.g. the Volta Basin) to balance water supply and demand for agriculture, industry, and domestic use.
- Policy Integration: Ensuring that water management policies are aligned with climate adaptation, land use, and agricultural policies to minimize conflicts and inefficiencies.
- Water Use Regulation: Strengthening policies and enforcing regulations around water extraction and use can help manage overexploitation of water resources. This includes regulating groundwater extraction, improving water rights, and enforcing pollution control measures to ensure the sustainability of water resources.

➢ *Rainwater Harvesting*

Rainwater harvesting is an effective strategy for improving water availability, particularly in areas prone to water scarcity or erratic rainfall (Kumar et al., 2006). This strategy involves capturing and storing rainwater from rooftops, landscapes, and other surfaces for later use. In Ghana, rainwater harvesting can be applied in both rural and urban settings: Households can store rainwater for drinking, washing, and irrigation during dry periods. Also, rainwater can be stockpiled in farm ponds or small reservoirs for irrigation during dry spells, helping to sustain crop production and reduce the impact of droughts.

➢ *Drip Irrigation and Efficient Water use in Agriculture*

Agriculture is a major user of water in Ghana, and more efficient irrigation methods are needed to cope with water shortages. Drip irrigation, a technique that delivers water directly to the root-zone of crops in controlled quantities, can significantly reduce water wastage and increase crop productivity. This technology is particularly suited for regions with limited water availability.

Water-Use Efficiency, can be achieved through drip irrigation reduces evaporation losses, ensuring that crops receive adequate water while minimizing wastage. Promotion of Water-Conserving Crops by encouraging the cultivation of drought-tolerant and water-efficient crops can also reduce water demand in agriculture.

➢ *Wetland Conservation and Restoration*

Wetlands play a vital role in regulating water flow, maintaining water quality, and providing ecosystem services such as flood control and groundwater recharge. The conversion of wetlands into farmlands and urban areas has contributed to increased flood risk and water scarcity. Protecting and restoring wetlands can help build resilience to climate change and Flood Mitigation: Wetlands act as natural buffers, absorbing excess water during floods and releasing it slowly, thus preventing downstream flooding. Water Purification is ensured by wetlands filtering pollutants from surface runoff thereby improving water quality and reducing the need for expensive water treatment processes.

➢ *Groundwater Recharge and Management*

Groundwater is a critical source of drinking water in many parts of Ghana, especially in rural areas. However, over-extraction and reduced recharge due to deforestation and urbanization threaten groundwater levels. To adapt to these challenges, it is essential to enhance groundwater recharge. Implementing practices such as afforestation, soil conservation, and the construction of recharge wells can increase the infiltration of rainwater into aquifers, replenishing groundwater supplies. Groundwater Monitoring by the installation of groundwater monitoring systems can help track water table levels and manage water usage to prevent over-extraction and depletion.

➢ *Water-Efficient Urban Infrastructure*

As Ghana's urban areas expand, the demand for water in cities has risen, while water supply systems are often inefficient. Adaptation strategies in urban areas should focus on improving water-use efficiency and building resilient infrastructure: Green Infrastructure by incorporating green spaces, permeable pavements, and urban wetlands can help manage stormwater, reduce flooding, and enhance groundwater recharge. Water recycling and reuse by promoting water recycling and reuse in urban settings (e.g., greywater recycling for irrigation) can also reduce the pressure on freshwater resources.

➢ *Early Warning Systems and Climate-Resilient Infrastructure*

The rising occurrence of severe climatic events, including intense flooding and prolonged droughts, is becoming more prevalent due to shifting weather patterns. This calls for climate-resilient infrastructure and robust early flood warning systems: Flood Control Infrastructure by investing in improved drainage systems, levees, and floodplain management can reduce the impact of floods in high-risk areas. Creating Early Warning Systems by establishing meteorological stations and early flood warning systems can help communities prepare for extreme weather events, allowing for timely evacuation and resource mobilization.

➢ *Capacity Building and Community Participation*

Community engagement and capacity building are crucial for the successful implementation of adaptation strategies. By involving local communities in decision-making and resource management, these strategies can be designed to align with the unique conditions and requirements of the area.

Water Conservation Awareness: Educating communities on water conservation practices, such as efficient irrigation methods and reducing water wastage, helps to build local resilience to water shortages. Training Programs: Capacity-building programs can train farmers, water managers, and local leaders in sustainable water management practices and climate adaptation techniques.

➢ *Policy and Institutional Frameworks*

To ensure the effectiveness of water adaptation strategies, Ghana requires a strong policy framework that integrates climate adaptation, land use, and water resource management: Strengthening Water Policies: Updating Ghana's National Water Policy to reflect current climate change challenges will promote sustainable water management practices. Institutional Coordination: Encouraging better coordination between institutions responsible for water, agriculture, forestry, and climate adaptation is essential in order to avoid policy conflicts and ensure a comprehensive response to water challenges.

➢ *Drought and Flood Risk Management*

With the changing rainfall patterns, droughts and floods have become more common. Adaptation measures should address both risks. Drought management plans can focus on water storage, crop diversification, and alternative livelihoods to reduce dependency on water-intensive crops. Flood Risk Mapping to identify flood-prone areas and implementing zoning laws can prevent infrastructure development in high-risk areas, reducing the damage caused by floods. Floods could also be reduced by:

- Improved drainage systems: Upgrading and expanding drainage systems in urban areas can reduce flooding during heavy rainfall events and enhance water storage for dry periods.
- Multipurpose Dams and Reservoirs: Constructing or rehabilitating multipurpose dams that serve both flood control and water storage functions can provide a reliable water supply during periods of scarcity while mitigating the risks of flooding during extreme rainfall events.

VI. CONCLUSION

In conclusion, understanding the intricate relationship between climate change, hydrology, and land use dynamics is central for sustainable water resource management. The impacts of climate variability on hydrological processes are further compounded by human-induced LULC changes, leading to shifts in water availability, quality, and distribution. Climate variability continues to alter precipitation patterns, evaporation rates, and water availability, while LULC changes further exacerbate or mitigate these impacts through modifications in runoff, infiltration, and storage. This study highlights the pressing need for interdisciplinary research that integrates climate modeling, hydrological assessments, and land-use planning to develop adaptive strategies.

Addressing existing research gaps such as the long-term effects of extreme climate events and the feedback mechanisms between LULC and hydrological systems will be essential in formulating resilient and sustainable water management policies. By bridging these knowledge gaps, policymakers and stakeholders can implement science-driven solutions that ensure water security amid ongoing environmental change.

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➢ *Ethical Approval*

This review article was prepared in full compliance with ethical standards and guidelines for systematic reviews. Data referencing, analysis, and reporting were carried out with transparency and integrity, following recognized protocols throughout the process.

➢ *Declaration of Conflict of Interest*

- **Awini Robert Asaanbilla**: original draft preparation, methodology design, data curation, and writing – review and editing. Ing.
- **Prof. Boateng Ampadu and Steve Ampofo**: supervision and manuscript proofreading.

➢ *Declaration of Generative AI and AI-Assisted Technologies in the Writing Process*

In preparing this work, the authors used ChatGPT4o, Goggle Scholar and Grammarly to gather information from a variety of sources, assist with paraphrasing, and refine language. Following the use of these tools, the authors thoroughly reviewed and edited the content as needed and take full responsibility for the final publication.

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