International Scholars Journals

African Journal of Agriculture ISSN 2375-1134 Vol. 12 (3), pp. 001-013, March, 2025. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

The Economics of Sustainable Water Resource Availability for Food Production in Ghana

Daniel Ofori[1], Amatus Gyilbag[2], Komla Ben Kakraba[3], Mitchell Dodzi Morvey[4] & Francis Xavier Kabir Mwinkon[5]

[1]Kumasi Technical University, Department of Entrepreneurship and Finance, Ghana. [2]Takoradi Technical University, Ghana. [3]University of Energy and Natural Resources (UENR), Sunyani, Centre for Climate Change and Gender Studies (3CGS), Ghana. [4]Kumasi Technical University, Procurement officer (Snr), Ghana. [5]Odomaseman Senior High School, Sunyani, Ghana.

Abstract

Received 14 January, 2025; Revised 10 February, 2025; Accepted 16 February, 2025; Published 13 March, 2025

Water bodies in Ghana are being ‘’poisoned’’ by illegal mining in water bodies and also in the forest reserves; thus polluting river bodies and amplifying the crisis of the country. However, the water-agriculture nexus is poorly understood as researchers tend to focus more on agricultural sector. This research aims at gaining a comprehensive understanding of the relationship between agricultural water resource management practices and their effects on food production. Food production (FoPin), food export (FoE), and food import (FoI) served as the dependent variables, whereas the independent variables include Gross National Expenditure (GNE), Rainfall (RNF), Temperature (TEMP), Water Productivity (WPT), Gross Fixed Capital Formation (GFICFN), Foreign Direct Investment (FDINI), and arable land (ArL). The research utilizes time series data from 1973 to 2022. The numerical data included in the study was sourced from the World Bank (2024). The inquiry centers on assessing the stationarity of variables through the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The research utilises an Autoregressive Distributed Lag (ARDL) model as the econometric method to evaluate the relationships among the variables of interest. The empirical findings of this study indicate that Water Productivity (WPT) possesses a positive coefficient, demonstrating a correlation in the same direction as the dependent variables. This connection was shown to be statistically insignificant at 1% level. The study recommends that policy-makers ensure measures to improve water – agriculture nexus, water availability and sustainability in the midst of changing climate and illegal mining activities in the country.

Keyword: Sustainable Water, Food security, Food Import & export, ARDL, Economic Growth, Ghana.

1.0 Introduction

The global water crisis poses significant threats to food security, economic development, and environmental sustainability. Though a renewable resource, the availability of water is limited and variable. Water is a vital input for agricultural production, and its scarcity has far-reaching consequences for food availability, rural livelihoods, and national economies (FAO, 2017). Agricultural sector alone accounts for 85% of global water consumption, making it the largest user of this critical resource (WWAP, 2019); and this is projected to double by 2050 as irrigated area is expected to rise by a factor of 1.9. The global food system faces increasing pressure to produce more food with less water, while also addressing the environmental and social implications of agricultural

Corresponding Author. E-mail: nyarkobenson55@gmail.com

intensification (Rockström et al., 2010). This underscores the intricate relationship between water and food security (World Bank, 2016). In recent decades, it has been reported that climate change, population growth, and urbanization are the primary drivers of water scarcity, exacerbating the water crises and facilitating food security. According to the UN reports, global water demand is likely to exceed supply by 40% by 2030 (UN, 2015). Therefore, sustainable water resource availability for food production is critical in achieving SDG 2 (Zero Hunger).

In Africa, climate change is amplifying water stress by changing patterns of water availability. The water available is generally under threat, and green water for agriculture is expected to further shrink drastically by 2050 due to the increasing demand and weak adaptation to climate hazards (Burney et al., 2013). Although Africa experiences the highest depth of food deficit, only about 4-6% of the total land of Africa is irrigated (Burney et al., 2013). In East African (Ethiopia, Kenya, Tanzania and Uganda) for example, only 2% of the four countries' cultivated area is under irrigation (FAO, 2025). Interestingly, despite a small annual increase in total irrigated area in most parts of Africa, there are reported poor efficiency rates of irrigation systems within the continent (Falkenmark, 2015). Irrigation facilities are poorly constructed and they easily succumb to external shocks (Rockström & Falkenmark, 2015). Local farmers lack water management techniques and thus endure the recurring incidence of flooding and suffer the consequences of droughts that follow the flooding. There is the need for a sustainable water resource use in Africa, harnessing the potentials and opportunities in climate hazards to boost agricultural production (Fujiie et al., 2011). Efficient water management policy, focusing on maximization of water use and water productivity should be prioritized in order to meet the food demand of the growing population.

In Ghana, the agricultural sector is largely rain-fed, making it susceptible to climatic fluctuations (MoFA, 2018). However, about 60% of the population depends on agriculture for survival. According to the World Food Summit, agricultural sector utilizes over two-thirds of the water extracted from rivers and other freshwater sources (FAO, 2023), thus increasing the stress on the scarce natural resource. Subsequently, rural communities rely on untreated wastewater for farming (Akudugu et al., 2020). It has been reported that water used for small-scale and commercial farming are sourced from dams, streams, lakes, ponds, and groundwater that do not meet recommended standards for irrigation (Douti et al., 2021). More importantly, the rising population growth rate and the expansion of the Ghanaian economy have heightened the need for water. Though the Water Resources Commission and Ministry of Food and Agriculture of Ghana have been playing varied roles in formulating policies that encourage sustainable water utilization, these policies are poorly implemented due to poor planning and change of government. Within the research community, there is limited attention on the quality of irrigation water and the associated public health concerns (Amuah et al., 2022). This resulted in a paucity of information on the economics of sustainable water resource management for food security. Recently, many researchers in Ghana have called for a coherent and sustainable water resource management framework for food security (Akudugu, 2020; Amuah et al., 2022). It is therefore, critical to explore the economics of sustainable water resource availability for food production in Ghana, examining the current state of water resources, the impact of water scarcity on agricultural productivity, and the potential strategies for improving water use efficiency and ensuring sustainable food production. This study seeks to fill this gap by developing a sustainable water resource availability package to ensure food security in Ghana.

1.1 Statement of the Problem

Ghana's agricultural sector, which accounts for approximately 20% of the country's GDP and employs about 50% of the workforce (MoFA, 2018; Mwinkom *et al.,* 2020), is heavily reliant on water resources. However, the country is facing significant challenges in ensuring sustainable water resources availability for food production. Climate change, growth in population, and inadequate water management practices have led to water scarcity, affecting agricultural productivity and food security (Kasei, *et al.,* 2016; Owusu *et al.,* 2017). Although climate change has significantly affected food production, a thorough examination of water resource concerns and their implications for food security remains underexplored in the literature. The Ministry of Food and Agriculture in Ghana established the Ghana Irrigation Development Authority as a directorate to devise, develop, and execute irrigation and drainage strategies for year-round agricultural output in Ghana (Ministry of Food and Agriculture-Ghana, 2021). Despite the establishment of twenty-two irrigation projects encompassing 6,505 hectares, there is a notable absence of adequate maintenance strategies to guarantee the sustainability and operational efficacy of these initiatives. The United Nations (2021) reported that 90% of the people in semi-arid northern Ghana relies on rain-fed agriculture for their livelihood.

The significance of water management in agricultural production has been emphasized by prominent institutions like the World Bank; for example, World Bank (2022) and the Organisation for Economic Co-operation and Development (2021) illustrated that effective water management is essential for food sustainable production. This is due to the fact that, in the absence of water, farmers cannot cultivate their crops or sustain their livestock. While this problem has been examined in certain areas of Ghana, there is a paucity of research regarding the influence of water resources on agricultural output. It therefore, critical to examine the impact of agricultural water resources on food production and investigate their implications on food importation and exportation within the country.

1.2 Objective of the research

This research aims to analyses the economics of sustainable water resource availability in agricultural food production in Ghana and to assess the influence of water resource management on food exports and imports.

2 Literature Review

2.1 The Principle of Agricultural Water Utilization

Agricultural water use seeks to optimize water utilization, enhance agricultural yield, and reduce water wastage. It is a crucial element of sustainable agriculture and aids in the efficient utilization of water resources in farming. Water management, as defined by Water Conservation and Management (WCM), includes the policy policies and actions implemented to sustainably manage agricultural water resources in order to safeguard farming operations. It encompasses procedures like irrigation, which aims to deliver water to crops through several methods including surface irrigation, sprinkler irrigation, or drip irrigation. The objective is to supply plants with the appropriate quantity of water at the optimal moment to enhance crop growth and maximise harvest production. Water conservation is a practice that entails minimizing water losses and optimizing water use efficiency. Techniques such as mulching, which entails covering the soil with organic materials, can aid in moisture retention and diminish evaporation. Methods such as constructing small reservoirs or implementing rainwater collection systems can assist farmers in obtaining water under arid conditions (Kumar *et al.,* 2022). Theory of Integrated Water Resource Management Integrated water resource management is a concept that advocates for the integrated sustainability of water resources. It considers multiple social, economic, and environmental issues. To achieve sustainable, fair, and effective water resource utilisation, a comprehensive integrated water resource management system is essential, embodying a holistic approach. Ghana adhered to the official international guidelines (WSSD Plan of Implementation) and conventions established by ECOWAS for the development of Integrated Water Resources Management (IWRM) through national planning. Since the inception of Integrated Water Resources Management (IWRM) in 1990, Ghana has established commendable legal, political, and institutional frameworks to support its implementation (Mensah, 2010). The management of water resource issues is interdisciplinary. To attain the plan's objectives, a collaborative effort will be required to impact additional industries. Integrated Water Resources Management (IWRM) is exceptionally efficient in managing agricultural water resources and enhancing food output. The method encompasses the full water cycle, from source to consumption, and necessitates the coordination of diverse parties and sectors. In agriculture, Integrated Water Resources Management (IWRM) fosters sustainable water utilisation by amalgamating water management approaches with land use, crop selection, and irrigation methodologies. This holistic strategy optimises water availability, enhances water quality, and increases agricultural output, thereby contributing to food security and sustainable development.

2.2 Impact of water Scarcity on Food Production

Water scarcity can significantly impact agricultural productivity and food security. A study by Owusu *et al.* (2017) found that water scarcity reduced maize yields by up to 40% in Ghana. Another study by Danso *Abbeam et al.* (2019) found that water scarcity increased the cost of production for farmers, reducing their profitability. The objective of food production is to guarantee a sufficient and sustainable food supply for the expanding world population. Agriculture involves the cultivation of crops and the rearing of livestock for food production. This encompasses actions such as cultivating, tending, and harvesting crops, in addition to rearing livestock for meat, dairy, and eggs. Farmers employ several methods, including crop rotation, pest management, and soil conservation, which encompass the transportation of food from agricultural sites and processing facilities to markets, grocery shops, restaurants, and eventually customers.

2.3 Economic Benefits of Sustainable Water Resources Management

Sustainable water resources management can have significant economic benefits for food production in Ghana. A study by Awuni et. at. (2018) found that investing in irrigation infrastructure can increase agricultural productivity by up to 50% percent. Another study by Amoah et, al. (2020) posits that implanting water-saving technologies can reduce water waste by up to 30%. Effective distribution networks guarantee the prompt delivery of food to consumers while reducing food waste. Food production is affected by elements such as climate, technology, market demand, and government policy. Sustainable and responsible food production strategies seek to reduce environmental impact, preserve natural resources, and emphasize food safety and quality. Food production is a multifaceted and vital process that necessitates the collaboration of several stakeholders to guarantee a dependable and sustainable food supply. Climate-smart agriculture is a concept that emphasizes sustainable farming practices to tackle the problems presented by climate change (Adu-Gyamfi et al., 2020;

Dansi et al., 2019., Owusu et al., 2018). Its objective is to augment agricultural productivity, bolster resilience to climate variability, and diminish greenhouse gas emissions.

2.4 Challenges to Sustainable Water resources Management

Despite the economic benefits of sustainable water resources management, there are several challenges to its implementation in Ghana. These include inadequate funding, lack of institutional capacity, and limited access to water-saving technologies (Kasei et al (2016). Climate change poses a significant danger to food yield and, consequently, global food security. The agricultural food sector contributes one third of global greenhouse gas emissions (World Bank, 2023). The substantial rise in food production is attributable to the expansion of the agricultural sector, resulting in increased emissions. Climate Smart Agriculture (CSA) is a proposed solution to tackle climate-related agricultural issues. This hypothesis was formulated by the World Bank as an element of the Climate Change Action (2021-2025). This concept seeks to address three significant issues: global food security, climate change adaptation, and substantial reduction in greenhouse gas emissions. The theory addresses these objectives through three methods. It specifically addresses climate change within the agricultural food system and systematically assesses the synergies and trade-offs between productivity, adaptation, and mitigation. Ultimately, it includes many strategies and technology designed to enhance ecological conditions and cattle management (World Bank, 2023). This theory underscores three major pillars. Adaptation entails the adoption of strategies that assist farmers in adjusting to fluctuating climate circumstances, including the utilization of drought-resistant crop types, enhancement of water management, and execution of soil conservation procedures. Mitigation also emphasizes the reduction of greenhouse gas emissions originating from agricultural practices. It encompasses strategies such as optimizing fertilizer application, implementing agroforestry systems, utilizing renewable energy sources, and fostering resilience to develop farming systems capable of withstanding climate-related shocks and pressures. The approach encompasses crop diversification, the implementation of effective water management measures, and the promotion of sustainable land management practices. Through the adoption of climate-smart agriculture, farmers may not only alleviate the adverse effects of climate change but also enhance sustainable food production and environmental integrity.

2.1 Empirical Analysis

Acheampong, et al., (2018), evaluated the efficacy and influence of agricultural water management strategies in small reservoirs (SRs) in northern Ghana. A sample of 328 vegetable farmers was utilized, and a participatory rating approach employing a 5-point Likert scale was implemented to evaluate the efficacy of SRs in providing various livelihood benefits; additionally, an endogenous switching regression model was applied. The study indicated that the majority of the SRs are either ineffective or underutilized, failing to provide numerous advantages. The study indicated a mere 3% increase in the income of vegetable farmers engaged in irrigated vegetable production utilizing SRs compared to the counterfactual scenario; nevertheless, this difference is statistically insignificant.

In a study conducted by Osei-Adu (2018), evaluating and examining the impact of agricultural interventions on food security in northern Ghana. Data was obtained from more than 20 governmental and non-governmental organisations, and a systematic review was employed to evaluate the aggregate evidence about the impact of development activities. The research indicated that numerous interventions were executed in Northern Ghana during the study period. Moreover, access to excellent extension services, training, and capacity building was emphasized as a significant intervention option. Mensah-Bonsu (2017) examined the influence of variables on land and water management practices among smallholder maize farmers in Ghana. The study utilized a sample size of 292 maize producers. The study utilized count models and observed that farmers implementing three land and water management methods get the highest average productivity levels. The research indicated that access to extension services, loans, and farmers' experiences with food shocks are significant influencing factors. In their study, Agyeman et al., (2020), Ghana needs to adopt efficient water management practices including implementing conservation agriculture practices, such as mulching and crop rotation, which can help reduce water losses and improve soil health.

3 Methodology

3.1 Specification of the theoretical model

This study adheres to the Water-Energy-Food Nexus theory of food production (HOFF, 2011), which highlights the interdependence of water, energy, and food systems, and aims to examine the trade-offs and synergies among them. The theory emphasizes that food production is affected by energy, which facilitates the transportation, production, and distribution of food, and serves as fuel for machinery used in water treatment, as well as water, which is crucial for food production, forestry, and fisheries throughout the entire agro-food supply chain. In accordance with the study of Acheampong, Balana, Nimoh, & Abaidoo (2018), the food production function is revised to incorporate water productivity. This is ascribed to the Integrated Water Management theory, which illustrates that water productivity is essential to the food sector. The food production function is delineated in Equation 1 as follows:

$FoPin_t = f(GNE_t, RNF_t, TEMP_t, WPT_t, GFiCFn_t, FDINI_t, Arl_t)$……………………………………………1.

In this context, $FoPin_t$, GNE_t, RNF_t, $TEMP_t$, WPT_t, $GFiCFn_t$, $FDINI_t$, and Arl_t denote food production, gross national expenditure, rainfall, temperature, water productivity, gross fixed capital formation, foreign direct investment, and arable land, respectively.

Equation (3.1.1) is articulated in the log-linear regression format as: $\ln FoPint = \alpha 0 + \beta 1 \ln GNEt + \beta 2 \ln RNFt + \beta 3 \ln TEMPt + \beta 4 \ln WPTt + \beta 5 \ln GFiCFnt + \beta 6 \ln FDINIt + \beta 7 \ln ArLt + \varepsilon t$ 2

The study also investigated the influence of water resources on food exports. To accomplish this, the dependent variable in equation (1) is substituted with food export (FoE):

$\ln FoEt = \alpha 0 + \beta 1 \ln GNEt + \beta 2 \ln RNFt + \beta 3 \ln TEMPt + \beta 4 \ln WPTt + \beta 5 \ln GFiCFnt + \beta 6 \ln FDINIt + \beta 7 \ln ArLt + \varepsilon t$ ……………………………………………….3

The dependent variable in equation 3 is substituted by Food Import (FoI) as part of the objectives. The corresponding regression model is defined below:

$\ln FoIt = \alpha 0 + \beta 1 \ln GNEt + \beta 2 \ln RNFt + \beta 3 \ln TEMPt + \beta 4 \ln WPTt + \beta 5 \ln GFiCFnt + \beta 6 \ln FDINIt + \beta 7 \ln ArLt + \varepsilon$ …………………………………………………………..4

The elasticities of the variables concerning $FoPin_t$, FoEt, and FoIt are denoted as β1, β2, β3, β4, β5, β6, and β7. The logarithmic transformation eliminates outliers and large coefficients. Elasticities are crucial as they illustrate the responsiveness of dependent variables—food production, food exports, and food imports—to independent variables such as gross national expenditure, rainfall, temperature, water productivity, gross fixed capital formation, foreign direct investment, and arable land. The research utilized annual time series data collected on Food Production Index (FoPin), Food Exports (FoE), Food Imports (FoI), Gross National Expenditure (GNE), Rainfall (RNF), Temperature (TEMP), Water Productivity (WPT), Gross Fixed Capital Formation (GFiCFn), Foreign Direct Investment (FDINI), and Arable Land (ArL) from 1973 to 2022 (World Bank, 2023).

3.2 Measurement and Description of variables

3.2.1 Dependent variable

In this study, the dependent variable is assessed by three methods: the food production index. These variables encompass indexes of edible food crops that are nutrient-rich. Coffee and tea are removed due to their lack of nutritious content, yet being consumable. Food export refers to the sale and transportation of food products from one country to another. The export of food is a crucial component of global trade, enhancing the economies of exporting countries and assisting importing nations in fulfilling their food requirements. Food importation refers to the process of bringing food products from foreign countries into the domestic market for consumption or resale. This involves procuring food from international suppliers and transporting it across borders to meet the demands of the importing nation's populace. Food imports may encompass grains, fruits, vegetables, meat, dairy products, seafood, prepared meals, and beverages. These methodologies have been employed in the literature: an Econometric Analysis of Food Security and Associated Macroeconomic Variables in Malaysia: A Vector Autoregressive Approach (VAR) as a proxy for food production (Applanaidu, 2014) was adopted.

3.2.2 Independent variable

Gross national expenditure (GNE) plays a significant role in agricultural investment theory, as it represents the total amount of money spent by the nation’s government, businesses, and citizens on goods and services, including agricultural products. Research has shown that government expenditure on agriculture has a positive impact on agricultural productivity and production. A study published in Journal of Economic and Administrative sciences found that government expenditure on agriculture in Ghana had a significant positive effect on agricultural production (Sogah et. al., (2024). The study incorporated GNE in its estimations and quantified it as the aggregate of household final consumption spending, general government final consumption expenditure, and gross capital formation. The incorporation of the GNE is elucidated by Agricultural Investment Theory, which posits that government spendings positively influenced food production (Asuming-Brempong, et. al., 2022; Owusu et al., 2022; FAO, 2022). Rainfall is another component incorporated into the modelling. Rainfall refers to the precipitation of water droplets descending from atmospheric clouds to the Earth's surface. It is a crucial component of the Earth's hydrological cycle, aiding in the replenishment of freshwater resources, sustaining ecosystems, and affecting meteorological patterns and climate. In alignment with the principle of Agro-Ecological Zoning (AEZ), we deemed it necessary to incorporate rainfall into our research, as referenced in the study: The Impact of rainfall variability on agricultural production is a pressing concern, particularly in regions with high reliance on rainfed agriculture. Changes in rainfall patterns and temperature can significantly affect crop yields, quality, and overall agricultural productivity (Kamara *et al.* 2022; Mwinkom et al., 2022).

In our research, we used water productivity as a variable due to its direct relevance to the study's issue. Water productivity is determined by dividing GDP at constant prices by the total yearly water withdrawal. The Water-Energy-Food Nexus theory, as elucidated in earlier portions of the study, illustrates the correlation between water productivity and food production. The additional variables incorporated to assist in ascertaining the trajectory of food production are: Gross Fixed Capital Formation. Gross fixed capital formation encompasses land enhancements; acquisitions of plant, machinery, and equipment; and the development of infrastructure such as roads, trains, schools, offices, hospitals, private residences, and commercial and industrial edifices.

Foreign Direct Investment (FDI). Foreign direct investment refers to the net inflows of capital aimed at obtaining a lasting managerial stake (10 percent or more of voting stock) in an enterprise functioning in an economy distinct from that of the investor. The total comprises equity capital, retained earnings, additional long-term capital, and short-term capital as indicated in the balance of payments. This data illustrates net inflows (new investment inflows minus disinvestment) in the reporting economy from foreign investors, divided by GDP. Additionally, arable land, as defined by the FAO, including land utilized for temporary crops (with double-cropped areas counted once), temporary meadows for mowing or grazing, land designated for market or kitchen gardens, and land that is temporarily fallow, was incorporated into our variables. Land forsaken due to changing cultivation is excluded.

Estimation Technique

To ascertain the trustworthiness of estimated parameters in time series analysis, it is essential to perform preliminary tests on the utilized variables. Consequently, the stationarity characteristics are examined to prevent the estimation of a misleading regression. The stationarity is evaluated via the Augmented Dickey-Fuller and Phillips-Perron tests, as detailed in section 3.4.1. Consequently, the ARDL econometric estimation method was utilized to examine the relationship among the variables in question.

Stationary Test

Augmented-Dickey-Fuller (ADF)Test

The ADF exam enhanced the Dickey-Fuller test. The ADF was developed to address situations where error terms may be correlated, given that most macroeconomic variables might be interconnected and exhibit similar trends (Dickey & Fuller, 1979). The ADF test presumes that the error terms are random noise devoid of correlation. The ADF test mitigates autocorrelation by incorporating an extra lagged term of the dependent variable in the calculation.

The above statement may function as a fundamental definition of the ADF stationarity test.

$\Delta Xt = \alpha 1 + \alpha 2t + \alpha 3Xt{-}1 + \sum \beta 1\ \Delta Xt{=}i + \varepsilon t$ 4.1 $i{=}1$

X is the time series variable, t signifies the time trend variable, and _1, _2, and _3 denote the computed parameters. The first differencing operator has been identified. The symbol I denotes the estimated parameters for the differenced values of the lagged variables. The alternative hypothesis positing the absence of a unit root is juxtaposed with the null hypothesis asserting the presence of a unit root (3=0) by equation (3.4.1). The series has a unit root; therefore, it is non-stationary if the null hypothesis is rejected and stationary if the null hypothesis is accepted.

The-Philips-Perron (PP)Test

Philips-Perron (1988) introduced the PP test as a more precise technique for assessing stationarity in time series data. The ADF test is adjusted by non-parametric modifications to the test statistics that address autocorrelation and heteroscedasticity in the error terms. The variations in the calculated regression can also be verified as just noise. The straightforward PP test is outlined as follows:

$\Delta X_{t-1} = \alpha_0 + \beta X_{t-1} + \varepsilon_t$ 4.2

This study examines the null hypothesis from Equation (3.4.2) with the alternative hypothesis, which posits the absence of a unit root. If the investigation does not reject the null hypothesis, the series is non-stationary and possesses a unit root. If the null hypothesis is rejected, it indicates that the series does not possess a unit root.

The Autoregressive Distributed Lag (ARDL) MODEL

The study employed the ARDL econometric estimation method to assess the long- and short-term impacts of Gross National Expenditure (GNE), rainfall, temperature, Gross Fixed Capital Formation, water productivity, Foreign Direct Investment, and arable land on the Food Production Index, food exports, and food imports. The ARDL methodology is employed due of its several advantages. Pesaran *et al.* (2001), assert that time series data may be stationary at level, denoted as I (0), after the first difference, or both. This method is appropriate for research with limited sample sizes, as it is sufficiently flexible to be utilized even when the integration order of the variables is uncertain prior to the cointegration test. Detailed description of the ARDL model can be found in appendix 1.

ARDL Model Diagnosis

A range of diagnostic assessments was conducted to guarantee the results' robustness and reliability. The Ramsay RESET test was employed to verify the accuracy

Table 1: Summary of variables measurement and description.

Variable	Measurement	A Priori Expectation
Dependent		
Food Production Index	production yield	
Food Export	metric tonnes	
Food Import	metric tonnes	
Independent		
Gross National Expenditure	U.S dollars	Positive
Rainfall	Millimetres	Negative
Temperature	degree Celsius	Positive
Water Productivity	GDP in constant prices/total water withdrawal	Positive
Gross Fixed Capital Formation	net acquisition of valuables	Positive
Foreign Direct Investment	net inflows from foreign investment/ GDP	Positive
Arable Land	% of land area	Positive

of the functionality. The Jarque-Bera test was employed to evaluate the normality of residuals in the ARDL model. The Breusch-Godfrey test was employed to assess serial correlation, whereas the Breusch-Pagan-Godfrey test was utilized to evaluate heteroscedasticity.

Findings and Discourse

The dependent variables in the statistics presented in table 4.1 are FoPin, FoE, and FoI, with mean values of 3.851, 3.717, and 2.538, respectively. The maximum values found are 4,793 for FoPin, 4,495 for FoE, and 3,155 for FoI, respectively. FoPin possesses a minimum value of 2.962, FoE has a minimum value of 2.766, and FoI has a minimum value of 1.371. The standard deviation for FoPin is 0.615, for FoE it is 0.508, and for FoI it is 0.399. The mean rate of Gross National Expenditure (GNE) was 4.694, with a standard deviation of 0.060. The variable ranges from a minimum of 4.553 to a maximum of 4.831. Water productivity (WPT) exhibited maximum and minimum values of 3.876 and 2.729, respectively. The mean value of the variable was 3.167, while the standard deviation was 0.318. The mean and standard deviation of the rainfall variable are 4.560 and 0.99, respectively. A minimum value of 4.232 and a maximum value of 4.739 were recorded. The average temperature was 3.315, with a standard variation of 0.017. The maximum recorded value was 3.345, while the minimum was 3.278. The mean of Gross Fixed Capital Formation is 2.538, with a standard deviation of 0.773. A maximum of 3.367 and a minimum of 0.428 were documented. The average FDINI is 0.255, with a maximum of 2.248 and a minimum of -3.094, resulting in a standard deviation of 1.198. The mean and standard deviation for ARL were 2.618 and 0.344, respectively, with a high of 3.037 and a minimum of 2.011. All variables were documented with a consistent observation of 50.

Unit Root Examination

The fluctuation of time series variables across time renders the idea of stationarity essential. If the series is non-stationary, the persistence of shocks will be infinite, leading to erroneous term estimates. This study employed the ADF and Phillips-Perron tests to determine whether the series is continuous and stationary with the trend. The subsequent data were acquired and presented Table 4.2A and 4.2B. The results in the displayed table indicate the stationary characteristics of the tested series. Only rainfall (RNF) exhibits stationarity at levels as per the Augmented Dickey-Fuller (ADF) test. The null hypothesis, which posits the non-existence of a unit root, was rejected at the 5% significance level. Consequently, the metrics of food production, food export, food import, gross national expenditure, temperature, water productivity, gross fixed capital formation, foreign direct investment, and arable land exhibit significance at the first difference, confirming their non-stationarity. Philips Perron indicates that water productivity and rainfall remain constant at certain levels. All other variables exhibit identical characteristics in both testing.

Table 2. Descriptive Statistics results.

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
LNGNE	50	4.694	.060	4.553	4.831
LNWPT	50	3.167	.318	2.729	3.876
LNRNF	50	4.560	.099	4.232	4.739
LNARL	50	2.618	.344	2.011	3.037
LNTEMP	50	3.315	.017	3.278	3.345
LNFOE	50	3.717	.508	2.766	4.495
LNFOI	50	2.538	.399	1.371	3.155
LNFOPIN	50	3.851	.615	2.962	4.793

Results and Discussions

Short Run Estimates

Using Food production index, food export and food import as proxy, the study estimates the effects of the independent variables: GNE, RNF, TEMP, WPT, GFICFN, FDINI, ArL on foodproduction in Ghana. The test's results have been provided in table 4 below.

The ARDL Cointegrating form was employed to investigate the link between the dependent variable, Food Production, and the several independent variables: GNE, RNF, TEMP, WPT, GFICFN, FDINI, and ArL. The results indicate that the coefficient of GNE is negative and statistically insignificant at the 1 per cent level across all three models. This implies that if gross national expenditure (GNE) is increased in a period, we will experience a fall in food production, food export and food import levels in the short run. In an adverse movement of GNE in the short run, the will be a rise in food production, food export and food import levelsas a response. This discovery shifts the focus away from GNE and onto other factors that may have a greater impact on food production, export, and import. There are various other factors that, in addition to Gross National Expenditure (GNE), can have a substantial impact on food production, export, and import. Here are some of the main factors: soil quality, agricultural practices, technology and innovation. These findings of the movement of food production are in line with existing empirical evidence. For example, Akoto and Osei (2020) concluded that government expenditure which has a significant impact on agricultural development. This finding implies that increasing government expenditure alone may not necessarily lead to increased food production in Ghana.

The estimated coefficient of rainfall is negative and statistically insignificant at the 1 percent level across all models in the short-run table. According to this coefficient, an increase in rainfall statistics by that metric will result in a decrease in the food production index and the levels of food exports and imports, respectively. Opposing reactions are expected to occur if rainfall data decrease over the period. This demonstrates that any country reliant exclusively on rainfall for agricultural water is likely to experience short-term failure during periods of excessive rainfall. Nonetheless, other characteristics and situations are anticipated to exert a more significant influence on food production, export, and import levels, warranting attention in future study and policy deliberations. Numerous factors beyond precipitation can significantly influence the food production index, food exports, and food imports. These elements encompass a range of economic, social, technological, and environmental concerns. Price levels and fluctuations, agricultural technology, and labour availability. Extreme rains can lead to soil fertility loss and damage infrastructure, including food storage facilities, so negating any favorable effects on food production (Mondal, 2021).

Temperature as shown reported to have a negative and significant relationship with all the dependent variables in the in the short run, which implies that higher temperature levels hinder the growth and development of crops leading to decreased yields and relatively lower quality of produce which extensively diminishes food export and import levels. Conversely, water production exhibits negative negligible correlations with both food imports and food exports. An augmentation in water productivity, as shown by its coefficient value, will indirectly facilitate a drop in the levels of the two dependent variables equivalently in the short term. Enhancing water productivity by improved irrigation practices, crop selection, and soil management can substantially elevate food output, consequently positively impacting food exports and diminishing the necessity for food imports. Molden (2010). Gross fixed capital formation exhibits a favourable correlation with food output in the short term. Its significance is contingent upon various conditions, as it may

Table 3 A: Unit root tests results.

Variables	Levels: Intercept	Levels: Trend and Intercept	First Difference: Intercept	First Difference: Trend and Intercept	Decision
Augmented Dickey–Fuller (ADF)					
LNFOPIN	-1.762	-2.064	-3.709***	-2.781	I (1)
LNFOE	-1.141	-3.847**	-4.788***	-4.729***	I (1)
LNFOI	-2.541	-3.847**	-9.039***	-9.168***	I (1)
LNGNE	-3.077**	-3.560**	-6.306***	-5.594***	I (1)
LNRNF	-6.349***	-2.807	-6.251***	-6.191***	I (0)
LNTEMP	-1.696	-6.486***	-7.833***	-7.774	I (1)
LNWPT	1.519	-3.813**	-3.604***	-5.448***	I (1)
LNGFICFN	-1.709	-3.065	-6.986***	-6.907***	I (1)
LNFDINI	-1.756	-2.308	-6.872***	-6.800***	I (1)
LNARL	-1.824	-0.506	-6.494***	-6.972***	I (1)
Table 3 B	Phillips- Perron (PP)				
LNFOPIN	0.418	-3.247*	-8.548***	-8.842	I (1)
LNFOE	-0.855	-3.711**	-8.837***	-8.780***	I (1)
LNFOI	-2.523	-3.487**	-9.039***	-9.241***	I (1)
LNGNE	-2.992**	-2.807	-10.362***	-12.977***	I (1)
LNRNF	-6.356***	-6.499***	-23.662***	-23.960***	I (0)
LNTEMP	-2.071	-3.809**	-10.038***	-10.209***	I (1)
LNWPT	0.499	-5.033***	-3.510***	-5.422***	I (0)
LNGFICFN	-1.684	-2.243	-6.991***	-6.909***	I (1)
LNFDINI	-1.756	-2.308	-6.955***	-6.865**	I (1)
LNARL	-1.829	-0.505	-6.520***	-6.970***	I (1)

Note(s): (1) The values of t-statistics are reported. (***), (**) and (*) denote the MacKinnon (1996) one-sided p-value estimates different from zero at the 1, 5 and 10% significance levels, respectively. (2) Lag length isselected automatically based on Akaike information criterion (AIC) for all variables at levels and first differences. The Autoregressive Distributed Lag (ARDL) Bounds Test is used in the study to check for along-term association between the series.

may occasionally be inconsequential. Gross fixed capital can be substantial when investments are directed towards modern agricultural technologies, such as irrigation systems and storage facilities. Conversely, it may be negligible in labor-intensive food production, like small-scale farming, where investment in fixed assets is minimal and food production occurs in the short term. It is adversely correlated with food exports and food imports. This relationship indicates that the dependent variables fluctuate inversely in response to gross fixed capital formation. This indicates that GFCF exerts no significant influence on food trade activities, highlighting the necessity for a more refined understanding of the determinants affecting food exports and imports, with targeted and efficient capital expenditures in the agricultural and food industries. Policymakers should proceed with caution when drawing conclusions from the negative yet insignificant coefficient. It may be necessary to focus on enhancing the efficiency and effectiveness of GFCF, ensuring that investments directly benefit the agricultural and food sectors.

The analysis of the variables - food production, food export, food import, and Foreign Direct Investment (FDINI) in the study reveal that the coefficient of FDINI is both positive and statistically significant, indicating an increase in foreign direct investment due to the rise in food output, food exports, and food imports. This finding supports the Food and Agriculture Organisation (FAO) study indicating that agricultural investments can generate a wide range of benefits such as higher productivity, increased food availability (FAO, 2014). Moreover, the findings for the examined variables—food production, food export, food import, and arable land (ARL as a percentage of land area)—demonstrate that the coefficient of ARL is both

Table 4: Short run test results.

Variable	Model 1	Model 2	Model 3
D(LNGNE)	-0.409(0.311)	-4.824(1.038) ***	-1.459(0.959)
D (LNGNE (-1))		-3.277(1.105) ***	
D(LNRNF)	-0.024(0.118)	0.324(0.383)	0.679(0.375)
D (LNRNF (-1)	-0.051(0.101)	-0.942(0.329) **	
D (LNRNF (-2))	0.099(0.086)	-0.255(0.326)	
D (LNRNF (-3))		0.475(0.374)	
D(LNTEMP)	-4.685(1.368)	-3.773(4.662)	-5.150(3.906)
D (LNTEMP (-1)	3.208(1.373) **	4.255(4.406) ***	
D(LNWPT)	0.533(0.379)	-3.016(1.312) *	-2.795(1.279)
D(LNGFICFN)	-0.048(0.040) **	0.590(0.217) **	-0.389(0.122)
D (LNGFICFN (-1))	0.004(0.036) **	-0.039(0.116)	0.195(0.101)
D (LNGFICFN (-2))	-0.048(0.040) **	0.590(0.217) **	-0.389(0.122)
D (LNGFICFN (-1))	-0.048(0.040) **	0.590(0.217) **	-0.389(0.122)
D (LNGFICFN (-1))	0.004(0.040) **	-0.039(0.116)	0.195(0.101)
D (LNGFICFN (-2))	0.099(0.030) **	-0.323(0.111)	
D (LNGFICFN (-3))		-0.128*(0.088)	
D(LNFDINI)	0.011(0.020)	0.005*(0.056)	-0.211(0.060)
D (LNFDINI (-1))	-0.045(0.019) **	0.049(0.063)	0.060*(0.053)
D (LNFDINI (-2)	0.085(0.026) ***	0.209(0.100) **	
D (LNFDINI (-3))		-0.289(0.065) ***	
D(LNARL)	1.507(0.577)	3.763(1.901) *	0.275(1.390)
CointEq (-1)	-0.494(0.156) ***	0.455(0.138) ***	-0.652(0.139)

positive and statistically significant. As per the Food and Agricultural Organisation of the United Nations, arable land is a critical aspect for food security and sustainable development. The FAO asserts that arable land is essential for food production, and its availability is a significant factor influencing agricultural productivity. A research published in the Journal of Agricultural Economics indicated that a 1% increase in arable land resulted in a 0.6% increase in food output.

Long Run Estimates

Long run result focuses on analyzing the long-term relationships between variables to determine if they move together in the same direction over an extended period. This type of analysis helpsin understanding the equilibrium or stable relationships between the variables in the long term.This section shows the results of the long run in the table 4.

The test result indicates a negative and insignificant long-term effect on the variables of food production, food export, food import, and gross national expenditure (GNE). This signifies that the gross national expenditure on food production, imports, and exports exhibits an inverse connection, indicating that an increase in gross national expenditure results in a further decline in the levels of all dependent variables. This unforeseen outcome suggests that GNE is either not being allocated effectively to enhance food production, export, and import, or that it is displacing resources or investments that would otherwise support these sectors. Empirical research investigating the correlation between Gross National Expenditure (GNE) and food-related factors such as food production, food export, and food import might yield significant insights; (Smith & Johnes, 2018).

In the long term, rainfall is inversely correlated with food production; nevertheless, this correlation is statistically negligible. This outcome signifies that when precipitation levels rise, food production quantities diminish. Excessive rainfall may lead to flooding, adversely affecting crops, while insufficient rainfall can induce droughts. Both extremes adversely impact food output. Conversely, prolonged periods of heavy rainfall correlate positively with both food exports and imports, resulting in increased quantities of both over time. Several empirical studies have examined the correlation between precipitation and agricultural trade, encompassing food exports and imports. A study from (Dell, Jones, & Olken, 2012, Ali & Mohamed, 2024) posit that rainfall positively correlates with food exports and imports in the long term. Moreover, temperature adversely affects all dependent variables in the long term due to interruptions in food production, export volumes, and the availability and cost of imported commodities resulting from alterations in global production patterns induced by temperature fluctuations. The adverse effects of elevated temperatures on food imports over time may result from abrupt increases in temperature that lead to arid land, desiccated water bodies, and accelerated spoilage of perishable goods during transit, ultimately diminishing both the quantity and quality of food production as well as the volumes of food exportation and importation.

Furthermore, the coefficients (0.209, 0.874, 0.254) indicate favorable long-term associations between water productivity and all three dependent variables. This indicates that they progress in the same direction while also being influenced by additional factors that affect their linkages. Consequently, an enhancement in water productivity will result in a significant increase in the food production index, as well as in food imports and exports. Subsequent data from the study indicates that gross fixed capital formation (GFICFN) exhibits negative correlations with food production and food imports. An increase in gross fixed capital formation will diminish food output and food imports in the long term, whereas a decrease in gross capital formation will enhance food production and the volume of food imports. There exists a substantial and favorable correlation between gross fixed capital formation and food exports in the long term, suggesting that both variables move in tandem.

The analysis of the variables: food production, food export, food import, and Foreign Direct Investment (FDINI) reveals that the coefficient of FDINI is negative and statistically insignificant in models one and two, although significant in model three. The correlation among foreign direct investment (FDI), the food production index, and food exports can be elucidated by many economic, structural, and contextual aspects. Here are few critical factors to contemplate: Concentrating on high-value crops, regulatory barriers, and resource distribution challenges. However, the relationship indicates that when foreign direct investment (as a proportion of GDP) rises, all three dependent variables decline, signifying an inverse correlation among the variables. An empirical study examines the determinants of FDINI in West Africa, indicating that FDI is frequently allocated to extractive industries rather than agricultural. The sectoral emphasis indicates that FDINI's influence on food production and exports may be constrained. Anyanwu and Yameogo, 2015.

Ultimately, arable land exhibits a positive and significant correlation with food production and food import factors over the long term. This clearly indicates that arable land is essential for food production and import; thus, an increase in arable land correlates with more food availability for import over an extended duration. Conversely, arable land possesses a negative coefficient and is statistically negligible to food exports. This study indicates that although arable land is essential for agricultural output, its direct influence on food exports may be eclipsed by more significant issues, like inefficiencies in land use, prioritization of domestic consumption, and inadequate infrastructure. Consequently, any expansion of arable land will diminish food exports and vice versa.

4 Conclusions and recommendations

4.1 Conclusions

This study focused on assessing sustainable water resources and their influence on crop yield and the overall food production in Ghana. The results of the study reveal a long-term negative correlation between Ghana's temperature and food production, indicating that food production generally declines in response to increasing temperatures. Findings from the study highlights the extent of a vast arable land in Ghana, which can support agricultural productivity. Strong evidence from the study revealed a positive association between Ghana's food production and Water Productivity (WPT). This indicates an increased food production that stems from improved water productivity.

The economics of sustainable water resources use in agriculture is crucial for Ghana’s food security, economic growth, and environmental sustainability. The country’s agricultural sector, which accounts for a significant portion of its GDP and employment, is heavily reliant on water resources. However, the increasing demand for water, climate change, and inefficient use of water resources threaten the sustainability of agricultural production. In conclusion, the economics of sustainable water resources use in agriculture in Ghana is critical for the country’s sustainable development. By adopting sustainable water management practices and policies, Ghana can ensure the long-term viability of its agricultural sector, improve the livelihoods of farmers, and promote environmental sustainability.

4.2 Recommendations

As part of the top development agenda, priority should be given by the Government to empower efforts on implementing the Integrated Water Resources Management (IWRM) program to sustain and enhance the quality and availability of water for agricultural use. Moreover, programmes aimed at sensitizing stakeholders across all sectors through trainings and workshops must be encouraged by the Government. This can equally be conducted through governmental support for research and the spread of suitable water-saving technologies and irrigation management practices to enable users adapt to climate smart technologies for economic sustainability. Farmers and food production agents in Ghana are urged to implement greenhouse cultivation for certain crops, particularly vegetables. To sum it all, Governments should strengthen institutions and structures for water resources management and increase investment in water infrastructure and research and development. The integration of foreign modern technology in food production processes is a strategic component in economic sustainability. Also, the strategic use of grants, foreign aid and investments from international organizations into the agriculture sector would enhance food production in the country.

Declaration

Conflict of Interest: The authors declare that they have no competing interest.

References

Acheampong, D. Balana, B., B. Nimoh, F., & Abaidoo R., C. (2018). the effectiveness and impact of agricultural water management interventions in small reservoirs in northern Ghana. Agricultural Water Management, Volume 209, 163-170.

Akoto, Y., & Osei, K. (2020). *Gross national expenditure: Trends and implications for development*. Journal of Economic Studies, 47(4), 567-589.

Akudugu, M.A., Millar, K.K., & Akuriba, M.A. (2020). The Livelihoods Impacts of Irrigation in Western Africa: The Ghana Experience. Sustainability 2021, 13, 5677. https://doi.org/ 10.3390/su13105677

Ali, Y., H. & Mohamed, A., M. (2024). Dynamic impacts of economic and Environmental performances on agricultural productivity in Somalia: Empirical Evidence from ARDL technique.

Amoah, P. Kuwornu, J. K. M., & Osei- Aidam, Y. (2020). Assessing the impact of water0saving technologies on maize production in Ghana. Agricultural Water Management, 241, 106384. Doi:10.1016) /j. agwat.2020.106384.

Agyemang, S. A., Ratinger, T., & Bavorová, M. (2022). The impact of agricultural input subsidy on productivity: The case of Ghana. The European Journal of Development Research, 1-26.

Amuah, E.E., Amanin-Ennin, P. & Antwi, k. (2022). Irrigation water quality in Ghana and associated implications on vegetables and public health. A systematic review. Journal of Hydrology Volume 604, 127211. https://doi.org/10.1016/j.jhydrol.2021.127211

Anyanwu, J. C., & Yameogo, N., D. (2015). What Drives Foreign Direct Investments into West Africa? An Empirical Investigation. African Development Review, 27(3), 199-215.

Asuming-Brempong, S., & Dansi, A. (2022). Agricultural Investment, Food Production, and Government Spending: Evidence from Ghana. Journal of Agricultural Economics, 73(2), 437-455. Doi: 10. 1111/1477-9552.12441.

Awuni, J. A., & Teye, J. K. (2018). Economic viability of irrigation development in Ghana. Journal of Agricultural Economics, 69(2), 437-454. Doi: 10.1111\1477-9552-12263.

Burney, J.A., Naylor, R.L., & Postel, L.S. (2013). The case for distributed irrigation as a development priorityin sub-Saharan Africa. Proc. Natl. Acad. Sci. USA 110 (31),

Dansi, A. Adu-Gyamfi, P. & Kuwornu, J. K. M., (2019). Assessing the impact of Climate-Smart Agriculture on Farm Household income in Ghana. Sustainability, 11 (11), 2911. Doi: 10.3390/su11112911.

Dell, Jones, & Olken. (2012). Temperature Shocks and Economic Growth: Evidence from the Last Half Century. American Economic Journal: Macroeconomics, 4(3), 66-95.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of estimators for autoregressive time series with a unit root. Journal of the American Statistical Association 74:427–4.

Donkor, E., Owusu, V., Owusu-Sekyere, E., & Ogundeji, A. A. (2018). The adoption of farm innovations among rice producers in Northern Ghana: Implications for sustainable rice supply. Agriculture, 8(8), 121.

Falkenmark M. 2015). Growing water scarcity in agriculture: future challenge to global water security. Phil Trans R Soc A 371: 20120410. http://dx.doi.org/10.1098/rsta.2012.0410

FAO, (2022). Agriculture investment and Food Security. Food and Agriculture organization of the United Nations, Rome: FAO.

FAO, 2015. AQUASTAT database. ⟨http://www.fao.org/nr/water/aquastat/main/ index.stm⟩. (Accessed 22 April 2015

FAO, 2025). Water and One Health. https://www.fao.org/one-health/areas-of-.

Food and Agriculture Organization. (2023). Food Production: The Critical Role of Water.FAO.

Food and Agricultural Organization (FAO). (n.d.). World Food and Agriculture Statistical year book 2023

Fujiie, H., Maruyama, A., Fujiie, M., Takagaki, M., Merrey, D.J., Kikuchi, M. (2011). Why invest in minor projects in sub-Saharan Africa? An exploration of the scale economy and diseconomy of irrigation projects. Irrig. Drain. Syst. 25, 39–60.

Farsund, A. A., Daugbjerg, C., & Langhelle, O. (2015). Food security and trade: Reconciling discourses in the Food and Agriculture Organization and the World Trade Organization. Food Security, 7, 383-391

Hoff, H. (2011). *Understanding the Nexus: Background Paper for the Bonn 2011 Conference:The Water, Energy and Food Security Nexus*. Stockholm Environment Institute.

Kamara, A, Turay, A., Bangura, M., Sessay, S., & Jalloh, M., B. (2022). Assessing the impacts of rainfall variabiliyu on agricultal production in Sierra Leone, Journal of Agricultural Science, 160(3), 236-247.

Kasei, R. A., & Oteng, F. (2016). Assesing the impact of Climate Change on water resources in Ghana. Journal of Hydrology. 537, 345-355. Doi: 10. 1016\j. jhydrol. 2016.03.055.

Kumar, P., Sharma, S., & Kumar, V. (2022). Small reservoirs and rainwater harvesting for sustainable agriculture: A review. Journal of Hydrology, 612, 128104. Doi: 10. 1016/j.jhydrol. 2022.128104.

Ministry of Food and Agriculture-Ghana. (2021). Facts and Figures; Agriculture in Ghana. Ministry of Food and Agriculture- Ghana.

Mekouar, M. A. (2021). 15. Food and Agriculture Organization of the United Nations (FAO). Yearbook of International Environmental Law, 32(1), 298-304.

Mekouar, M. A. (2014). Food and Agriculture Organization (FAO). Yearbook of International Environmental Law, 24(1), 587-602.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural water management*, *97*(4), 528-535.

Mondal, P. (2021). *The impact of rainfall patterns on agricultural productivity*. International Journal of Agricultural Sustainability, 19(2), 130-145.

Mwinkom, F. X. K., Damnyag, L., Abugre, S., & Suhiyini, S. A., (2020). Factors affecting climate change adaptation among smallholder farmers in northern Ghana. Journal of Environmental Science and Health, Part B, 55(1), 53-63, doi: 10.1080|03601234.2019.1700534.

Obour, P. B., Arthur, I. K., & Owusu, K. (2022). The 2020 maize production failure in Ghana: A case study of Ejura-Sekyedumase municipality. Sustainability, 14(6), 3514.

Owusu, S., Cofie, O., Mul, M., & Barron, J. (2022). The significance of small reservoirs in sustaining agricultural landscapes in dry areas of West Africa: A review. Water, 14(9), 1440

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). *Bounds testing approaches to the analysis of level relationships*. Journal of Applied Econometrics, 16(3), 289-326.

Philips Perran (PP) 1988. The unit root tests like augmented Dicky Fuller (ADF)

Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K., ... & Bengio, Y. (2022). Tackling climate change with machine learning. ACM Computing Surveys (CSUR), 55(2), 1-96.

Smith, J., & Jones, A. (2018). Public expenditure and agricultural productivity: Evidence from developing countries. *Journal of Agricultural Economics, 69*(2), 230-245. The Organization for Economic Co-operation and Development. (2021). Measuring Progress in Agricultural Water.

Sogah, E., Tuffour, J.K., Mawutor, J.K.M. & Gborse, F.C. (2024). The relationship between external debt and agriculture GDP growth in Ghana: an ARDL cointegrating bound testing approach. Cogent Economics & Finance Volume 12, 2024 - Issue 1. doi.org/10.1080/23322039.2024.2330426

Sogah, E., Tuffour. J. K., Mawutor, J. K. M., & Gborse, C. F. (2024). The relationship between external debt and agriculture GDP growth in Ghana: an ARDL cointrgrating bound testing approach. Cogent economice & finance 12 (1), 2330426, 2024.

The Organization for Economic Co-operation and Development. (2021). Measuring Progress in Agricultural Water.

UN (2015). World Water Development Report 2015: Water for a Sustainable World. Paris: UNESCO.

World Bank. (2022). The Irrigation Operator of the Future: Toolkit.

World Bank (2016). High and Dry: Climate Change, Water, and the Economy. Washington, D.C.: World Bank.

World Bank. (2023). Building Climate Resilient Food Systems in Africa. World Bank Group, World Development Indicators, (2021).