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ACHIEVING FOOD SECURITY THROUGH AGRICULTURAL WATER SECURITY OF SMALLHOLDER FARMERS IN GHANA.

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Abstract

Water security is a crucial element in the realm of agricultural development, significantly impacting the welfare of farmers and stakeholders throughout the agricultural supply chain. However, the connection between agricultural water security and food security has been relatively understudied. This research seeks to fill this gap by examining the influence of agricultural water security on the food security of smallholder farm households in Ghana. Using principal component analysis, the study classified farmers into two groups: those considered agriculturally water-secure (48.56%) and those agriculturally water-insecure (51.44%), with a threshold set at the 40th percentile. Employing an endogenous treatment-effect ordered probit model, the research delved into the impact of water security on household food security among smallholder farmers. The analysis revealed several critical factors influencing agricultural water security, including gender, land ownership, non-farm income, access to extension services, credit availability, membership in farmer-based organizations (FBOs), adoption of irrigation, and information sources like NGOs and the Ministry of Food and Agriculture (MoFA). These factors were identified as positively contributing to water security. Conversely, factors such as age, total livestock count, distance to water sources from the farm, and information obtained from fellow farmers hurt agricultural security. Concerning the effect of agricultural water security on food security, the study found that farmers achieving water security witnessed a significant 23% improvement in their food security status. This translated to reductions in mild food insecurity (by 0.8%), moderate food insecurity (by 6.1%), and severe food insecurity (by 17.8%). These findings underscore the importance of government and development partners' support for enhancing agricultural water security among smallholder farmers to improve overall food security.

Keywords: *Food security, Agricultural water security, Agricultural water conservation strategies;,treatment-effect ordered probit, Principal Component Analysis*
Jel Codes :*O13, Q15, C51*

1. Introduction

Water is a fundamental resource essential for sustaining life and socio-economic progress, playing a critical role in enhancing agricultural productivity and economic development (Gariba & Amikuzuno, 2019). However, the sustainable utilization of global freshwater resources has become a growing concern, exacerbated by the inherent heterogeneity in water quality and availability worldwide (FAO, 2017). The scarcity of freshwater, which constitutes only three percent of Earth's total water, poses significant challenges, especially considering that approximately 70% of it is consumed by agriculture (Jha, 2018; FAO, 2017).

Furthermore, the issue of water scarcity is intensifying on a global scale due to factors such as rapid population growth, climate change, inadequate water resource management, and pollution, exerting significant pressure on available water resources (Yadav, 2020). The projected global population growth, reaching 8.4 to 8.6 billion people by 2030, with substantial increases in Africa and Ghana, is expected to exacerbate water scarcity, particularly regarding safe drinking water (Desa, 2017; WWDR, 2018). Additionally, the demand for food worldwide is estimated to increase by 60% by 2050 (FAO, 2017), further stressing water resources as agriculture relies heavily on freshwater.

Despite having abundant water resources, Ghana faces the challenge of managing and utilizing its surface water and groundwater systems effectively (Evans, et al., 2012). The predominantly smallholder-based agriculture in Ghana, which depends on rain-fed farming, is vulnerable to climate change and erratic rainfall patterns, leading to widespread poverty, food insecurity, and malnutrition in rural communities (Mendes, et al., 2014). Various government and stakeholder initiatives have been undertaken to improve irrigation systems in Ghana, but these efforts have not yielded the desired outcomes (Dittoh, 2020). Thus, there is an urgent need for "Farmer-Led Irrigation Development" (FLID) to address water scarcity challenges (Namara, et al., 2011).

Moreover, there is a lack of empirical investigation into the water security status of household farmers and the impact of water security on food security in Ghana, highlighting a significant research gap (Sinyolo, et al., 2014). Little literature exists on water security in Ghana and its effects on food security, emphasizing the need for a comprehensive study in this area. Therefore, this study aims to investigate the effects of agricultural water security on household welfare among smallholder farmers in Ghana, using food security as a proxy for measurement. The objective is to provide valuable evidence for the development of evidence-based strategies and policies to address the complex issue of food insecurity in Ghana, with a focus on enhancing water security, agricultural productivity, and the overall well-being of smallholder farmers.

The contemporary nature of water security and its broad nature has created varying definitions of the concept among experts. This has led to the definition of the concept by experts based on their areas of expertise.

Various definitions have emerged to capture the multidimensionality of water security. For example, GWP (2000) defines water security as ensuring that every individual has access to sufficient safe water at an affordable cost to lead a clean, healthy, and productive life while safeguarding the natural environment. This definition encompasses mitigating water-related risks, addressing disputes over shared water resources, and reconciling tensions among stakeholders competing for limited resources (Beek & Arriens, 2014).

Asare (2004) offers a straightforward definition based on the ratio of water supply to water demand, achieving security when the ratio exceeds unity, signifying water surplus. UN-Water proposes a comprehensive definition, encompassing safeguarding sustainable access to adequate water quantities and quality, protecting against water-borne pollution and disasters, and preserving ecosystems, human well-being, and socio-economic development within a context of peace and political stability (UN-Water, 2013).

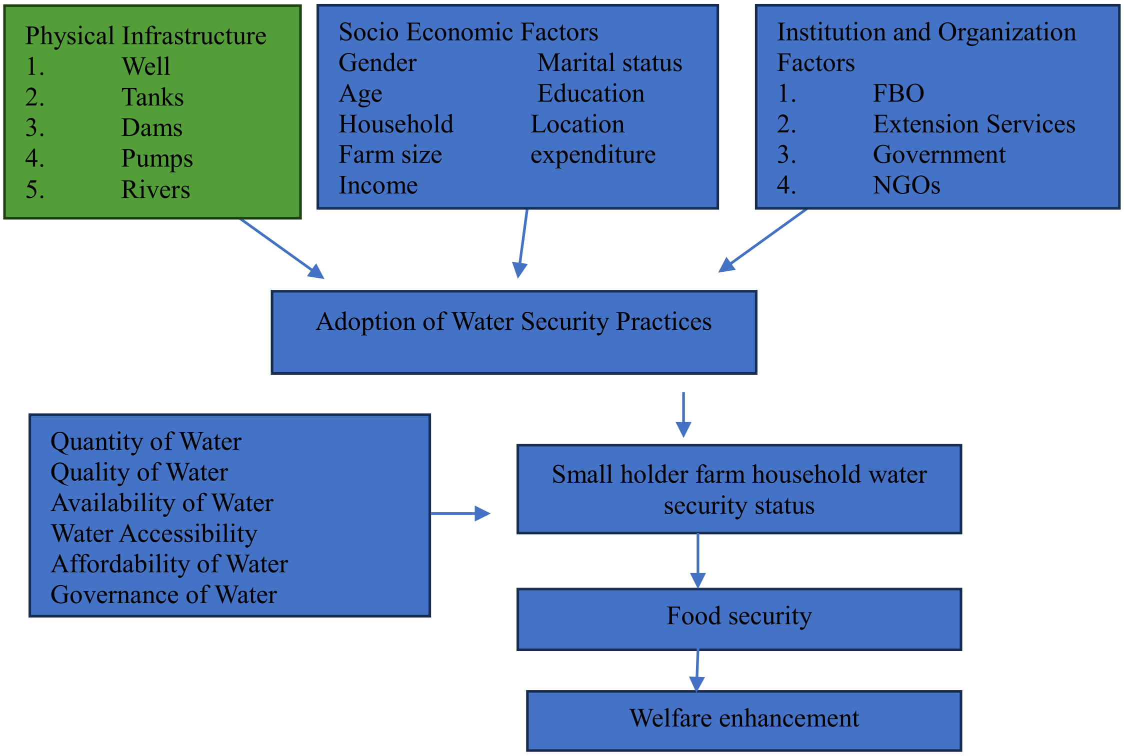
Grey and Sadoff (2007) define water security as the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies. WaterAid incorporates accessibility into this definition, defining water security as reliable access to water of sufficient quantity and quality for basic human needs, small-scale livelihoods, and local ecosystem services, while also effectively managing the risk of water-related disasters (WaterAid, 2012).

Shrestha, et al. (2018) provide a comprehensive perspective within UNESCO's International Hydrological Program's Strategic Plan, defining water security as the capacity of a population to protect sustainable access to tolerable quantities of acceptable quality water for sustaining livelihoods, human well-being, socio-economic development, protection against water-borne pollution and water-related disasters, and preservation of ecosystems, all within a climate of peace and political stability. This definition underscores the intricate interconnectedness and interdependence of various sectors and dimensions at local, national, regional, and global scales (Moumen, et al., 2019).

The challenge lies in reconciling these diverse definitions and perspectives to create a comprehensive framework for addressing water security on a global scale.

1.2 Relationship between Agricultural Water Security and Food Security

The concept of consumer utility theory was employed to explain the interconnections and relationships between water security and food security (Michael & Becker, 1973). Water remains a crucial input in agricultural production, and access to water incentivizes a farmer to invest in high-yielding crop varieties or entirely new high-value crops. This, in turn, enhances employment opportunities, stabilizes income, and improves the consumption patterns of a farmer (Namara, et al., 2010).



Source: (Sinyolo, et al. (2014) and Gain,et al. (2016))

Figure 1. Conceptual Framework of Water Security

Mudhara et al. (2014) argued that uncertainties regarding water availability on a farm can discourage the farmer from investing in improved inputs and technologies, potentially resulting in negative consequences. In simpler terms, when a farmer is certain about water availability and accessibility on the farm, it serves as a motivation for them to invest in inputs that enhance productivity.

Figure 1 depicts a framework adapted from the works of Sinyolo, et al. (2014), Gain, et al. (2016), and was also based on Goal Six of the Sustainable Development Goals(SDG). Sinyolo, et al. (2014) employed this framework to illustrate how physical or infrastructural factors, socioeconomic factors, and institutional or organizational factors affect household water security diagrammatically. Furthermore, it establishes the link between household water security and high productivity, demonstrating its interconnections with food security.

A farmer possesses specific characteristics that influence their decisions regarding the adoption of certain practices related to water security. These features include age, gender, management skills, household size, education, and farming experience, among others. Additionally, these farmer-specific factors and a farmer's decision regarding water security practices are significantly influenced by external factors such as technology, climate and macro policies, among others. The farm-specific factors (such as farm size, crop type, and soil type), institutional and organizational variables within the country (including input subsidies, extension services, and market access), and biophysical or agroecological location factors (like rainfall, and temperature) are principal external factors influencing a farmer's decision to allocate resources to water security practices..

Taking into account specific farm characteristics such as soil quality, land size, technology, soil type, and water availability, and guided by the objective of maximizing profit (Foster and Rosenzweig, 2010), a farmer determines whether to cultivate a particular crop. Assuming the farmer is a rational economic agent, this decision is driven by the goal of maximizing profit or utility, while considering inputs, including water security. In accordance with the principle of utility maximization, a farmer's production function establishes a technical relationship between inputs, including the status of water security, and the resulting output or achievement.

A farmer has the option to embrace water security practices to ensure water security. This implies that as the farmer adopts water security practices, they are more likely to achieve water security. To qualify as a water-secure farmer, certain criteria must be met, including having access to an adequate quantity of water, water of acceptable quality, accessibility to the water source, the availability of water, and affordability of the water (Khan, et al., 2020). The implication here is that once the farmer achieves water security, the agricultural productivity of the farmer will increase, leading to improvements in food security and subsequently enhancing household welfare (Cofie, 2022).

2. Methods and Materials

2.1 Description of the Study Area

The study area encompasses the Guinea Savannah, Sudan, and Rainforest agroecological zones of Ghana. Ghana's savannah zone is a geographical region situated in the northern part of the country, extending from its northern boundary to the central region. In the Sudan and Guinea Savannah zones, the rainfall pattern is unimodal (MOFA, 2016). The wet season typically occurs between April and October, with an annual precipitation range of 800 to 1,200 millimeters (MOFA, 2016). Conversely, the dry season spans from November to March, characterized by reduced rainfall and higher temperatures. The rainforest zone in Ghana is characterized by tropical rainforests featuring dense canopies and a wide variety of tree species (Abbam, al., 2018). The climate in Ghana's rainforest zone is commonly described as humid and equatorial, characterized by elevated temperatures and consistent rainfall throughout the year. Annual precipitation ranges from 1,500 to 2,500 millimeters, creating a moist environment that sustains diverse plant and animal life (MOFA, 2016). Figure 2 depicts the map of the study area.

Source: Google earth

Figure 2. Map Showing the Selected Agro-Ecological Zones and the Study Communities.

2.2 Sample Size Determination and Sampling Approach

Utilizing Yamane's formula (Yamane, 1967) as shown in Equation [1], the initial sample size was estimated, resulting in a sample size of approximately 494. However, 7 observations had to be excluded due to incomplete responses, which ultimately reduced the sample size to 487 observations. This determination of the sample size was predicated on the total farm household population of 2,368,218 across the three regions (GSS, 2019)

$$n = \frac{N}{1+N(e^2)} = \frac{2{,}368{,}218}{1+2{,}368{,}218\left(0.045^2\right)} = \frac{2{,}368{,}218}{1+4795.6415} = 493.72 \approx 494 \qquad (1)$$

where n is the sample size, N is the population size (2,368,218), and e is the margin of error (4.5%).

The study employed a multistage sampling procedure to select the respondents. In the initial stage, the study deliberately chose the Northern, Upper East, and Ashanti regions of Ghana for comparative analysis. This choice was made due to variations in climate conditions, with the Northern and Upper East regions being less conducive to potential agricultural production and productivity compared to the Ashanti region. In contrast to the Ashanti region, the Northern and Upper East regions experience relatively dry weather, characterized by a single rainy season from May to October (MoFA, 2021). Moving to the second stage, the study purposefully selected six districts, with two districts chosen from each of the three regions, specifically focusing on districts with significant large-scale irrigation schemes. For the third stage, three communities were randomly chosen from each district, resulting in a total of eighteen (18) communities included in the study. Lastly, in the fourth stage, the study employed a proportionate-to-size random sampling approach to select 30-35 rice farm households from each community.

2.3 Empirical Technique

2.3.1 Principal Component Analysis

Principal Component Analysis (PCA) was utilized to construct the agricultural water security index. To rank farmers' perceptions regarding the components of agricultural water security, a Likert scale was employed, and from this ranking, the principal component analysis was conducted to derive the agricultural water security index. Garson (2008) suggests that there should be a minimum of 10 cases for each item in the instrument used as a component. This is commonly referred to as Garson's rule of 10. With a sample size of 487 selected for this study, it was deemed sufficient as it adhered to Garson's rule of 10, given that there were 17 components of water security, requiring a minimum of 170 cases according to the rule.

PCA is a technique widely utilized in multivariate statistics to reduce data dimensionality while retaining essential information (Achia, et al., 2010). Many authors have previously used PCA to construct asset-based poverty indices (Howe, et al., 2012), making it a suitable choice for developing the water security index based on farmers' perceptions. Farmers' perceptions, which often influence their investment and production decisions, were assessed using a "yes" or "no" Likert scale concerning statements reflecting various aspects of water security (Crewett, et al., 2008). These responses formed the basis for assessing perceived water security and constructing the water security index.

Polychoric correlations were utilized to derive six components instead of Pearson correlations. The selection of polychoric correlations was based on their robust nature in handling continuous and linearly related variables, as highlighted by Holgado–Tello, et al. (2010). The PCA method, employed for index generation, is deemed more robust, possibly owing to its capacity to efficiently capture underlying correlations and relationships among individual ratings (Sinyolo, 2013). The PCA process identified six primary principal components: resources, accessibility, capacity, water use, governance, and environment, with subcomponents designed to contribute to the satisfaction of each main component. The standard deviations of the variables played a crucial role in PCA, with those having higher standard deviations carrying more weight in the analysis (Howe, et al., 2012).

Eigenvalues associated with the water security indicators in each component represented their respective weights, indicating their influence on determining the component score. Components were arranged in descending order of explained variance, with PC1 capturing the highest variance, followed by PC2, PC3, and so on, each explaining a decreasing proportion of the variance (Morrison, 2005). PCA proved to be most effective when dealing with correlated variables and cases where variable distributions exhibited variability across instances (Vyas, et al., 2006).

2.3.2 Endogenous Treatment-Effect Ordered Probit Model.

Assessing the effect of water security on household food security for smallholder farmers requires employing an econometric model that extends beyond the binary framework. This study utilizes evaluation models that leverage non-observational or non-experimental data. A notable challenge associated with such data is the presence of sample selection bias, as highlighted by Heckman (1979).. Dealing with sample selection bias is crucial, as inherent characteristics alone do not guarantee that some households will be food-secure, regardless of their water security status. Estimations concerning water security are susceptible to distortion due to the potential presence of endogeneity. Elements such as reverse causality (simultaneity bias), omitted variables, and measurement errors are factors that can contribute to endogeneity (Wooldridge, 2010).

To address these issues, various methods such as the Heckman sample correction, propensity score matching (PSM), endogenous switching regression models, and generalized propensity score (GPS) matching within a continuous treatment framework are commonly employed to mitigate selectivity bias (Asfaw, Di Battista et al., 2016). Nevertheless, these models are better suited for unordered outcome variables. Given that the outcome variable (i.e., the level of food insecurity) is ordered, this study employs a treatment-effect ordered probit regression model developed by Gregory (2015) and previously utilized in research by Mabe, et al. (2021). Following Gregory (2015), The selection equation, which depicts the treatment model examining the factors influencing water security among smallholder farmers, is defined in equation (2).

$$\begin{array}{rl} water\ security = & 1\ if\ WS_I^* = Z_i\delta + \delta_i > 0 \\ & 0\ if\ WS_I^* = Z_i\delta + \delta_i \leq 0 \end{array} \quad (2)$$

$$\text{FOOD SECURITY(FS)} = \begin{array}{c} 1\ if\ -\infty < X_i\beta + V_i \leq \mu_1 \\ 2\ if\ \mu_1 < X_i\beta + V_i \leq \mu_2 \\ J - 1\ if\ \mu j - 1 < X_i\beta + V_i \leq \mu J \\ J\ if\ \mu J < X_i\beta + V_i \leq \infty \end{array} \quad (3)$$

Let cut parameters to be estimated as j = 1, 2, ..., J, representing possible food security categories as shown in equation 3. For the ith household, $FS *_i$ in equation 3 is the latent food security variable, and X_i is a set of variables explaining the variation in household food security status. β is a parameter to be estimated, and V_i is the error term for the outcome equations. In addition to the vector of explanatory variables in the Water Security equation (Equation (2)), access to water security information was used as an instrument for the treatment variable (WS). The key assumption is that farmers' access to water conservation practices information can directly influence their decision to employ such practices but has no direct effect on food security. Thus, access to information from MOFA, NGOs, and colleague farmers, as well as water source from dam irrigation adoption, were included in the water security equation but not the outcome food security equation. In this study, a treatment estimator with ordered probit outcomes was utilized. A latent factor framework was employed to handle any joint normality violations in the error terms $\varepsilon_{i\ and}\ V_i$ formed by a factor structure in the treatment and outcome equations. The underlying assumption of this model is that the factors determining the ordered outcome differ between the treated and untreated groups. However, inconsistent estimates may result if this assumption is not entirely met. To address this, Halton-based sequences, drawn from the distributions of latent factors that are unobserved but affect the adoption of water security practices and food insecurity levels, were employed. As recommended by (Mabe, et al. 2021), the advantages of Halton sequences encompass the domain of distribution, reduction of variances, and reduction of computational time. The estimators of the two equations (2) and (3) were obtained through likelihood simulation techniques.

2.3.2.1 Average Treatment Effect: ATE and ATT

The effect of treatment on an outcome is conveyed through its treatment effects, which examine how households would have fared (in terms of food security) if they were water insecure. Like many impact evaluation studies, this research computed two treatment effects: the average treatment effects (ATE), as outlined in equation 4, thus the probability difference between experiencing an outcome with and without treatment. Additionally, the average effect of treatment on the treated (ATT) parameter can be defined as the treatment effect on households that were agriculturally water secure. Thus, ATT represents the difference in the response variable (food security outcomes) of the treated group (agricultural water secure) with and without treatment, as expressed in equation 5. Following Christian A. Gregory (2015), the ATE specification with a treatment-effect ordered probit structure is presented in equation 4 as:

$$ATE_j^{WS} = \frac{1}{N}\frac{1}{S} \sum_{i=1}^{N} \sum_{s=1}^{S} \quad [\![\Phi\{\mu_k - (X_i\beta + \Phi + \lambda\eta_{is})\} - \Phi\{\mu_{k-1}(X_i\beta + \Phi + \lambda\eta_{is})\}] - [\Phi\{\mu_k - (X_i\beta + \lambda\eta_{is})\} - \Phi\{\mu_{k-1} - (X_i\beta + \lambda\eta_{is})\}] \tag{4}$$

For ATT, it can be specified in equation 5 as:

$$ATT_j^{WS} = \frac{1}{N}\frac{1}{S}\Sigma \frac{1}{E\{\Phi(Z_i\delta)\}} \sum_{S-1}^{S} \Phi\,(Z_i\delta + \eta_{is}) \times [\Phi\{\mu_k - (X_i\beta + \Phi + \lambda\eta_{is}) - \Phi\{\mu_{k-1}(X_i\beta + \Phi + \lambda\eta_{is}\}] - [\Phi\{\mu_k - (X_i\beta + \lambda\eta_{is})\} - \Phi\{\mu_{k-1} - (X_i\beta + \lambda\eta_{is})\}] \tag{5}$$

In this instance, where k = 1, . . . k, k = J + 1, and J represents the number of outcome categories (food security).$\mu_0 = -\infty \; and \; \mu k = \infty, \Phi$ is the standard normal cumulative distribution.

2.4 Food Security Measurement

This study employs the Household Food Insecurity and Access Scale (HFIAS) as an indicator of household food security within the study area, the assessment utilized a measure developed by the Food and Nutrition Technical Assistance II (FANTA) in collaboration with Tufts and Cornell universities and others from 2001 to 2006, HFIAS Built on a succinct questionnaire, this instrument encompasses both behavioral and psychological dimensions of insufficient food access, encompassing situations where resource constraints result in reduced meal frequency or diminished food quality. Importantly, HFIAS distinguishes between the physical and psychological facets of food insecurity, which influence health and well-being rendering it versatile for use in both urban and rural settings(Ballard, et al., 2013),. Its concise nature facilitates seamless integration into comprehensive household surveys

HFIAS comprises nine questions that assess food access issues over the past 30 days, ordered to reflect increasing severity levels: anxiety, insufficient quality, and inadequate intake (Coates, et al., 2007). Interviewees express the occurrence frequency—whether never or rarely, sometimes, or often—of each scenario over the past month. The collected responses contribute to generating a continuous or discrete food security index.. Each of the nine questions is scored from 0 to 3, with 3 indicating the highest frequency. The cumulative HFIAS score ranges from 0 to 27, representing the extent of food availability insecurity experienced by an individual. Elevated scores signify increased food insecurity within a household, while lower scores indicate the opposite. The research categorizes households into groups such as "food-secure," "mildly food-insecure," "moderately food-insecure," and "severely food-insecure" (Coates, et al., 2007).

3.0 Results and Discussions

3.1 Descriptive Statistics of Continuous and Categorical Variables

Table 1 presents an overview of descriptive statistics, illustrating mean variations in outcomes, as well as household and farm characteristics, between agricultural water-secure and agricultural water-insecure farmers. Noticeable distinctions emerge between these two groups across several dimensions, including farmer age, years of education, tropical livestock units, proximity of farms to water sources, farm sizes, dependency ratios, fertilizer application, and labor utilization.

Table 1. Summary Statistics of Continuous Variables

	Pooled		Water secure		Water insecure		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	t-test
Age	43.355	14.701	48.486	16.737	41.945	13.782	3.49***
Years in education	3.834	6.233	2.793	4.95	4.82	7.114	3.63***
Household size	9.181	7.311	9.472	7.412	8.904	7.217	-0.85
Tropical livestock unit	1.294	4.423	0.920	1.828	1.649	5.895	1.82*
Farm distance to a water source	4.800	18.813	1.852	4.411	7.596	25.617	3.404***
Dependency ratio	0.7022	0.245	0.672	0.259	0.731	0.228	2.652**

Source: Author’s calculation based on Field data, 2023

For the entire sampled farmer population in the study region, the mean age is 43.3 years, and the average years of education amount to 3.8 years. The results in Table 1 demonstrate that the mean age of agricultural water-secure farmers is 48.5 years, which is significantly higher than that of agricultural water-insecure farmers at 41.95 years. This indicates an aging farming demographic in the study area, with a comparatively higher proportion of aging farmers among those classified as water secure. Conversely, agricultural water-insecure farmers exhibit significantly higher levels of education compared to their water-secure counterparts. On average, water-insecure farmers have spent 4.8 years in education, while agricultural water-secure farmers have spent 2.79 years. Remarkably, this points to a trend where younger farmers are pursuing higher levels of education compared to their older counterparts.

The results further reveal that the mean livestock ownership for the sampled population in the study region is 1.294 units. Specifically, water-insecure farmers possess an average of 1.649 livestock units, significantly surpassing the average of 0.920 livestock units owned by agricultural water-secure farmers. This indicates that water-insecure farmers allocate time and effort to livestock rearing as a supplementary income source alongside crop cultivation.

Upon examining Table 1, it becomes evident that the average distance between farms and water sources is 4.8 km. The outcomes reveal that agricultural water-secure farmers have shorter average distances between their farms (1.852 km) and water sources, which is significantly less than the distance for agricultural water-insecure farmers (7.596 km) to their respective water sources. This indicates that the greater distance of water sources from the farms of water-insecure farmers contributes to their water insecurity. Table 1 indicates a dependency ratio of 0.7. Agricultural water-insecure farmers, however, have a dependency ratio of 0.731, which is significantly higher than that of agricultural water-secure farmers, who have an average dependency ratio of 0.672.

Table 2 offers a comprehensive overview of categorical variable statistics for both water-secure and water-insecure farmers. Distinct disparities are evident between these two groups across various aspects, including land ownership, vehicle possession, year-round farming engagement, access to extensions, membership in farmer-based organizations (FBOs), participation in non-farm jobs, irrigation adoption, reliance on dam water sources, and geographical zones inhabited.

Table 2. Summary Statistics of Continuous Variables

		Pooled		**Water secure**		**Water insecure**		
Variable	Category	freq.	%	freq.	%	freq.	%	chi^2
Sex	Male	362	74.33	184	77.64	178	71.20	2.64
	Female	125	25.67	53	22.36	72	28.80	
Marital status	Married	377	77.41	186	78.48	191	76.40	0.30
	Not married	110	22.59	51	21.52	59	23.60	
land ownership	Own	324	66.53	169	71.31	155	62.00	4.73**
	Do not own	163	33.47	68	28.69	95	38.00	
vehicle ownership	Own	151	31.01	63	26.58	88	35.20	48.67**
	Do not own	336	68.99	174	73.42	162	64.80	
Farm all-year-round	Yes	74	15.20	27	11.39	47	18.80	5.18**
	No	413	84.80	210	88.61	203	81.20	
Extension access	Yes	187	38.40	101	42.62	86	34.40	3.47*
	No	300	61.60	136	57.38	164	65.60	
FBO membership	Member	284	58.32	152	64.14	132	52.80	6.43**
	Non-member	203	41.68	85	35.86	118	47.20	
Credit access	Yes	125	25.67	67	28.27	58	23.20	1.64
	No	362	74.33	170	71.73	192	76.80	
Small-scale farmer	Yes	339	69.61	171	72.15	168	67.20	1.41
	No	148	30.39	66	27.85	82	32.80	
Medium-scale farmer	Yes	137	28.13	61	25.74	76	30.40	1.31
	No	350	71.87	176	74.26	174	69.60	
Large-scale farmer	Yes	11	2.26	5	2.11	6	2.40	0.05
	No	476	97.74	232	97.89	244	97.60	
Radio ownership	Own	424	87.06	211	89.03	213	85.20	1.58
	Do not own	63	12.94	26	10.97	37	14.80	
Non-farm job	Yes	54	11.09	36	15.19	18	7.20	7.88***
	No	433	88.91	201	84.81	232	92.80	
Irrigation adoption	Adopter	196	40.25	123	51.90	73	29.20	26.07***
	Non-adopter	291	59.75	114	48.10	177	70.80	
Access to dam water	Yes	215	44.15	90	37.97	125	50.00	7.14***
	No	272	55.85	147	62.03	125	50.00	
Guinea savannah	Resident	213	43.83	120	50.63	93	37.35	4.04*
	Non-resident	274	56.17	117	49.37	157	62.65	
Sudan Savannah	Resident	152	31.21	59	24.89	93	37.20	8.70***
	Non-resident	335	68.79	178	75.11	157	62.80	
Rainforest	Resident	123	25.26	58	24.47	65	26.00	8.58***
	Non-resident	364	74.74	179	75.53	185	74.00	

Source: Author's calculation based on Field data, 2023

The findings highlight that 66.53% of the sampled population in the study possessed agriculturally viable land. Notably, 71.31% of water-secure farmers owned land, while only 62% of water-insecure farmers could claim land ownership. This emphasizes that land ownership is more prevalent among water-secure farmers, marking a notable distinction within the study area.

Vehicle ownership is relatively low (31.01%) among farmers in the study region. However, water-insecure farmers demonstrate a higher vehicle ownership rate at 35.20%, compared to the 26.58% ownership rate among water-secure farmers. This variance could be attributed to water-insecure farmers needing to cultivate larger plots, likely due to their limited ability to cultivate only once a year.

Engagement in year-round farming is modest within the studied farmer population, with only 15.2% of all farmers involved in year-round farming. Among them, 18.80% of water-insecure farmers engage in year-round farming, surpassing the 11.39% among water-secure farmers. This discrepancy signifies a significant difference between agricultural water-secure and water-insecure farmers concerning year-round farming.

In terms of institutional factors, 38.40% of farmers in the study region access extension services, with a notably higher rate among agricultural water-secure farmers (42.62%) compared to water-insecure farmers (34.40%). This implies that extension services are more attractive to water-secure farmers, likely for the exchange of innovations and technologies to enhance productivity. This contradicts the findings of Andani, Abdulai, et al. (2023), which suggest that seasonal farmers have three times more access to extension services.

According to Table 2, 58.32% of the farmers who were sampled are members of farmer-based organizations. Among these organizations, a higher membership rate of 64.14% was found among agricultural water-secure farmers compared to water-insecure farmers, who had a membership rate of 52.80%. This indicates that practices leading to agricultural water security are influenced by membership in farmer-based organizations.

Additionally, only 11.09% of all sampled farmers participated in non-farm activities. A greater percentage of water-secure farmers (15.19%) engage in non-farm activities, significantly more than the rate among water-insecure farmers (7.2%). This suggests that most farmers concentrate primarily on farming, rather than pursuing other income-generating opportunities.

The adoption of irrigation stands at 40.25% among all sampled farmers, with a notably higher adoption rate (51.90%) among agricultural water-secure farmers compared to water-insecure farmers (29.20%). Moreover, 44.15% of all sampled farmers have access to dam water sources, and an interesting observation is that approximately 50% of water-insecure farmers access dam water, surpassing the 37.97% among water-secure farmers. Geographically, the Sudan savannah zone accommodates 31.21% of sampled farmers, while the rainforest zone houses 25.26%. Among agricultural water-secure farmers, 24.89% reside in the Sudan savannah zone, and 24.47% in the rainforest zone. In contrast, 37.20% of water-insecure farmers are in the Sudan savannah zone, and 26% reside in the rainforest zone.

3.2 Determination of Agricultural Water Security Index.

Table 3 shows that out of the six extracted components, only four were retained using the Kaiser criterion. These four components had eigenvalues greater than one (1), and therefore were considered significant. The retained principal components, presented in Table 3, explain 89.42% of the variance in the data. PC1, PC2, PC3, and PC4 explain 45.95%, 17.41%, 16.40%, and 9.66% of the variation, respectively.

Table 3 illustrates that almost all the variables in PC1 exhibit dominance and move in the same direction, with only two variables showing an opposite trend. PC1 suggests that agricultural water-secure farmers perceive water as reliable, sufficient in quantity, satisfactory in terms of quantity, affordable, with willingness to pay, and a history of consistent payments. Additionally, they feel secure in their water usage rights, express satisfaction with water use regulations, and find water to be consistent, adequate for other needs, and of satisfactory quality. However, variables such as "Will never fail to pay," "Crop lost to drought," and "Crop lost due to flood" were perceived as less dominant among the water security factors. Registered water usage and satisfaction with water management maintenance were not considered dominant factors among agricultural water-secure farmers. This implies that farmers do not necessarily need to be registered, satisfied with maintenance management, or experience crop losses due to erosion, flood, or drought to be considered water-secure. PC2, PC3, and PC4 had fewer water security variables that dominated. PC2 had two dominant variables, namely "Registered water user" and "Water maintenance management satisfaction," while PC3 had three dominant variables related to crop losses due to soil erosion, flood, and drought, leaving the other dimensions relatively less dominant. PC4, on the other hand, did not have any dominant variables. Consequently, PC1 was utilized to generate the agricultural water security index because it explained the highest variation (approximately 45.95%) and encapsulated most of the water security components.

Table 3. Water Security Index Generation PCA Results

	Principal components			
Indicators	**PC$_1$**	**PC$_2$**	**PC$_3$**	**PC$_4$**
Water is reliable	0.66	0.02	-0.23	0.28
Water is sufficient	0.71	-0.05	-0.05	0.26
Water quantity satisfaction	0.72	-0.10	-0.05	0.16
Ability to pay	0.59	0.21	-0.01	-0.47
Willingness to pay	0.59	0.18	0.17	-0.51
Never failed to pay	0.70	0.18	0.14	-0.45
Water use rights security	0.76	-0.10	-0.09	0.05
Will never fail to pay	0.49	0.09	-012	-0.01
Water use rights and regulations satisfaction	0.52	0.45	-0.11	0.02
Water consistency	0.76	-0.12	-0.08	0.19
Water is sufficient for other needs	0.73	-0.18	-0.07	0.12
Water quality satisfaction	0.71	-0.10	-0.10	0.17
Crop lost drought	0.12	0.17	0.67	0.10
Crop lost due to flood	0.26	0.06	0.80	0.05
Crop lost due to soil erosion	0.11	0.03	0.82	0.27
Registered water user	-0.15	0.84	-0.14	0.36
Water maintenance management satisfaction	-0.09	0.96	-0.11	0.02
Eigen value	5.47	2.07	1.95	1.15
% of variance explained	45.95	17.41	16.40	9.66

Source: Author's calculation based on Field data, 2023

The water security index was computed by retaining factor loadings with eigenvalues equal to or greater than one, and the cumulative variance explained by these factors was calculated from the eigenvalues. Households were categorized based on whether their water security index fell within or above the 40th percentile, with a code of 1 representing agricultural water security and a code of 0 indicating water insecurity (Sinyolo, 2013). This binary classification facilitated the use of probit analysis to identify factors influencing water security. Based on this categorization, 51.44% of household farmers interviewed were water insecure, while 48.56% of the respondents were considered agriculturally water secure. This summary is presented in table 4:

Table 4. Number of Respondents According to Their Agricultural Water Security Status

Agricultural water security status of household farmers	Freq.	Percent
Water insecure	250	51.44
Water secure	236	48.56
Total	486	100

Source: Author's calculation based on Field data, 2023

3.3 Determinants of Water Security

The initial equation of the ordered probit model with an endogenous treatment examines the factors influencing a farmer's agricultural water security, and the findings are presented in Table 5. Variables such as gender, land ownership, non-farm income, access to extension services, access to credit, membership in farmer-based organizations (FBOs), adoption of irrigation, information from NGOs, and the Ministry of Food and Agriculture (MoFA) were identified as positively affecting the adoption of agricultural water security. Conversely, factors such as age, total livestock count, distance to water sources from the farm, and information from fellow farmers were found to have a negative influence on the adoption of these strategies.

The gender variable displayed a significant positive influence on agricultural water security, indicating that male farmers are more likely to be agriculturally water secure. This observation aligns with the results reported by Sileshi, Kadigi et al. (2019), suggesting that male-headed households tend to adopt Soil and Water Conservation practices that make them agriculturally water secure more readily than their female counterparts. This may be due to males' dominance in the local farming sector, making them more inclined to embrace practices that enhance water security. Age was also found to exert a significant negative influence on agricultural water security. This suggests that younger farmers are more likely to be agriculturally water secure compared to their older counterparts, possibly because older farmers might prioritize other family responsibilities over investing in water security activities. This contradicts the finding reported by Mango, Makate et al. (2017), which indicated that age positively influences the adoption of conservation measures to achieve water security in the study areas of Chinyanja Triangle, southern Africa. Furthermore, the results in Table 5 indicate that land ownership positively affects agricultural water security. Farmers who own land are more likely to invest in water security on their land, contrasting with farmers who do not own land, as they might face obstacles in making such investments to become water secure. This result is consistent with the findings reported by Tenge, De Graaff et al. (2004), which indicated that insecure land tenure has a negative influence on water conservation strategies in West Usambara highlands, Tanzania.

Income derived from non-farm activities significantly and positively influenced agricultural water security. Sileshi, Kadigi, et al. (2019) found that farmers who participated in off-farm activities as alternative sources of income were less likely to be water-conserved in Ethiopia. This contradicts these findings. Farmers who earn income from non-farm activities are more inclined to be water secure, likely due to their ability to invest their non-farm income in practices that enhance water security.

Interestingly, the total livestock count exhibited a significant negative correlation with the adoption of water security. Farmers with larger livestock numbers are less likely to be water secure, possibly due to the time and attention demands of livestock management, which may reduce their interest in water security. This finding contradicted the findings of Belachew, Mekuria et al. (2020), which indicates that livestock holding increased by one TLU, and the likelihood of a farmer becoming water-secure in the northwest Ethiopian highlands increased by 0.42%. However, the findings are in tandem with the findings of Sileshi, Kadigi et al.

(2019), which indicated that livestock influences water conservation measures by smallholder farmers in Ethiopia.

Institutional factors, including access to extension services, credit availability, and FBO membership, were found to have a significant and positive influence on water security. This suggests that farmers with access to credit and extension services, as well as FBO membership, are more likely to be agriculturally water secure. These findings imply that education on water security, access to credit for investment in water security, and guidance from FBOs contribute to farmers' decisions to become agriculturally water secure. The result in Table 5 confirms the findings reported by Wordofa, Okoyo et al. (2020), which indicated that FBO membership positively influenced farmers to conserve water in Eastern Ethiopia.

The distance between farmers and water sources was identified as a significant negative factor influencing water security. Farmers located far from water sources are less likely to engage in agricultural water security due to the increased cost and effort required to access water. In such cases, farmers might opt to prioritize their existing situation over investing in water security.

Lastly, the source of information also plays a role in farmers' decision-making regarding water security. Information from NGOs and MoFA was positively associated with water security, while information from fellow farmers had a negative association. This could be attributed to farmers' greater trust in information from official sources compared to information from peers. The adoption of irrigation was a significant and positive factor influencing agricultural water security strategies. Farmers who adopt irrigation are more likely to prioritize water security, as the continued use of irrigation necessitates the availability of water. This inclination encourages agricultural water security. Overall, the findings suggest that various socio-economic and institutional factors influence farmers' decisions to achieve agricultural water security.

3.5. Factors Affecting Food Security.

The correlation between agricultural water security and household food insecurity access score is statistically significant at the 1% level, implying the presence of selectivity bias in agricultural water security, which has been corrected. This result also suggests that certain unobserved factors in agricultural water security are correlated with the error terms of household food security. The factors that have significant effects on food security include gender, age, household size, land ownership, the non-farm income of farmers, access to extension services, access to credit, distance of water sources from the farm, and farmers who live in zone three (3).

The results table 5 indicate that male-headed households are more likely to achieve food security than female-headed households. This is attributed to male-headed households' ability to pool resources, engage in non-farm activities, and increase household income, ultimately enhancing food security. The model results support the initial expectations of this study, suggesting that male-headed households are better positioned to ensure household food security.The findings presented in Table 5 establish a clear relationship between a farmer's age and their food security status. Younger farmers are shown to be more likely to attain food security, indicating that their energy and willingness to adopt modern technologies and innovative practices contribute to increased production. Young and energetic household heads can also manage larger farms compared to their older counterparts, who may face physical limitations. Conversely, the results reveal that older farmers are more susceptible to food insecurity, often allocating funds for health issues and subsequently selling their agricultural produce to cover medical expenses. This outcome aligns with previous research findings, such as Abu, Soom et al. (2016), which identified a significant negative correlation between age and food security in Nigeria, suggesting that food security tends to decline with age.

Table 5. Estimation of the (Ordered Probit with Endogenous Treatment)

	Selection		Food security	
Variable	Coeff.	Robust Std. Err.	Coeff.	Robust Std. Err.
Sex	0.461***	0.151	0.403***	0.125
Age	-0.018***	0.005	-0.276*	0.160
Educ	-0.116	0.138	0.050	0.108
Household size	0.004	0.011	0.254*	0.111
Ownership land	0.451**	0.166	0.281*	0.135
Vehicle ownership	-0.217	0.151	-0.110	0.113
Nonfarm income	0.366*	0.221	0.334*	0.167
Tropical total livestock	-0.047***	0.010	0.031	0.095
Extension access	0.518***	0.139	-0.273*	0.141
FBO Membership	0.289*	0.128	-0.011	0.113
credit access	0.474**	0.162	0.216*	0.131
Rainwater Harvesting	0.051	0.130	0.026	0.104
Both season	-0.048	0.215	0.214	0.180
Distance water source to farm	-0.034***	0.011	-0.752***	0.175
zone2	0.084	0.214	-0.267	0.184
zone3	-0.033	0.240	-0.257*	0.110
small scale	-0.414	0.494	-0.482	0.477
medium scale	-0.449	0.474	-0.681	0.465
No children school			-0.024	0.026
Momo account			0.090	0.124
remittances			0.160	0.317
lndependency			0.220	0.346
Marital status			-0.065	0.131
Lnhousehold Income			-0.031	0.047
info_source_ngo	0.301*	0.133		
info_source_mofa	0.326**	0.118		
info_source_farmer	-0.392**	0.139		
water_source_dam	0.250	0.222		
irrigation_adoption	0.834***	0.222		
_cons	-0.407	0.620		
cut1	-2.064	0.825		
cut2	-1.081	0.852		
cut3	-0.524	0.870		
corr(e.agricwatersecurity_sstatus,e.HFIA)	0.618***	0.186		
Observations	487			
Wald chi2(25)	129.02			
Log pseudolikelihood	-862.029			

Source: Author's calculation based on Field data, 2023

The size of the household has a positive and significant impact on the food security of Ghanaian farmers. The results in Table 5 demonstrate that food security increases by 25.4% with an increase in household size while holding other factors constant. This suggests that easy access to affordable family labor contributes to increased food production and reduced labor costs. The presence of more household members means a greater source of family labor available to work on the farm, resulting in enhanced food productivity. This finding aligns with prior research, such as that of Abu, Soom et al. (2016), which found that an increase in household size positively affects the food security of rural households in Nigeria.

Furthermore, an increase in land ownership, non-farm incomes, and access to credit significantly and positively impacts the food security of household farmers in Ghana. The results indicate that food security status is positively affected by increased access to credit, land ownership, and income from non-farming jobs. This implies that farmers who own land can make long-term investments in their land to boost productivity, thereby enhancing food security. Access to credit and income from non-farm jobs provides farmers with the necessary liquidity to acquire agricultural inputs promptly, leading to increased productivity and potentially improving food security. These findings align with the expectations of this study.

Conversely, the food security status of household farmers is significantly and negatively influenced by increased access to extension services, far distances to water sources from the farm, and prolonged residence in the rainforest zone. The extended stay in the rainforest zone and increased access to extension services negatively impact household food security, deviating from the initial expectations of this study. However, the far distance of water sources from the farm aligns with the study's expectations, as it negatively affects food security among household farmers.

3.6 Description of Food Security According to Farmers' Water Security Status

Table 6 indicates that 75% of agricultural water-secure farmers are food-secure, compared to 67.2% of water-insecure farmers who are food-secure. This suggests that agricultural water-secure farmers have better food security, implying a positive effect of agricultural water security on food security. The findings also reveal that only 25% of water-secure farmers are food-insecure, whereas 32.8% of water-insecure farmers are food-insecure, indicating that agricultural water-insecure farmers experience higher levels of food insecurity compared to agricultural water-secure farmers. The water security of household farmers plays a crucial role in their ability to operate successfully and contribute to household food security. This highlights the need for effective interventions by the government and all relevant stakeholders to ensure that farmers have access to water security, ultimately bolstering food security.

Table 6. Food security status of farmers according to their water security Status

AWSS	food secure	food insecure	Total
AWI	168(67.20)	82(32.80)	250(100)
AWS	177(75.00)	59(25.00)	236(100)
Total	345(70.99)	141(29.01)	486(100)

Source: Author’s calculation based on Field data, 2023

3.7 Effect of Agricultural Water Security on Food Security

The findings in Table 7 suggest that when a farmer achieves agricultural water security, there is a potential for a 23% improvement in their food security status compared to when they are agricultural water insecure. This finding is consistent with Cofie, (2022) who indicated that Access to water in its various forms is fundamental to maintain food security. In practical terms, this implies that agriculturally water-secure farmers have a higher likelihood of reducing their levels of mild, moderate, and severe food insecurity by 0.8%, 6.1%, and 17.8%, respectively. This outcome is notably more favorable than what water-insecure farmers might experience. This finding is consistent with the findings reported by Sinyolo, Mudhara et al.

(2014) which indicates that perceived water security has a positive impact on household food consumption per adult equivalent in South Africa.

Table 7. Effect of Agricultural Water Security on Food Security

Status	**ATT**	**Std. Err.**
*p*1 (food secure)	0.230***	0.004
*p*2 (mildly food insecure)	-0.008	0.006
*p*3 (moderately food insecure)	-0.061***	0.002
*p*4 (severely food insecure)	-0.178****	0.005

Source: Author's calculation based on Field data, 2023

4. Conclusion and Policy Recommendation

This paper was designed to investigate the impact of water security on the food security of smallholder farmers. Agricultural water security has received limited attention in the literature on agricultural productivity. The study examined the relationship between agricultural water security and the food security of farmers in Ghana, and the results demonstrated that farmers who have water security are also more likely to be food secure. The study also explored the determinants of water security, revealing that factors such as gender, age, household size, land ownership, non-farm income, access to extension services, access to credit, distance to water sources from the farm, and farmers living in Zone Three (3) influence the water security of smallholder farmers.

The study presents empirical evidence highlighting the positive effect of water security on food security. Recognizing the importance of water security in enhancing agricultural productivity and overall well-being, key stakeholders—including the government through the Ministry of Food and Agriculture (MoFA), development partners, and private enterprises—should prioritize water security at the household level. The policy framework designed to support this approach should be strengthened, with a particular focus on reaching farmers across the country, especially those in regions heavily reliant on rainfed agriculture.

In the short term, partnerships can be established with entities such as private rice processing companies, agricultural marketing firms, and financial institutions to engage farmers in contract farming and related activities. These collaborations would provide farmers with access to improved water security measures and technical expertise, thereby enhancing their productivity. Agricultural extension agents play a crucial role in this endeavor by intensifying their outreach to farmers and offering guidance on effective water security and sound agronomic practices tailored to specific agroecological zones. Importantly, these initiatives should be customized to meet the unique needs of farmers within their respective regions, avoiding a one-size-fits-all approach.

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