

Article

Water–Climate Nexus: Exploring Water (In)security Risk and Climate Change Preparedness in Semi-Arid Northwestern Ghana

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Abstract

Water insecurity, intensified by climate change, presents a significant challenge globally, especially in arid and semi-arid regions of Africa. In northern Ghana, where agriculture heavily depends on seasonal rainfall, prolonged dry seasons exacerbate water and food insecurity. Despite efforts to improve water access, there is limited understanding of how climate change preparedness affects water insecurity risk in rural contexts. This study investigates the relationship between climate preparedness and water insecurity in semi-arid northwestern Ghana. Grounded in the Sustainable Livelihoods Framework, data was collected through a cross-sectional survey of 517 smallholder households. Nested ordered logistic regression was used to analyze how preparedness measures and related socio-environmental factors influence severe water insecurity. The findings reveal that higher levels of climate change preparedness significantly reduce water insecurity risk at individual [odds ratio (OR) = 0.35, $p < 0.001$], household (OR = 0.037, $p < 0.001$), and community (OR = 0.103, $p < 0.01$) levels. In contrast, longer round-trip water-fetching times (OR = 1.036, $p < 0.001$), water-fetching injuries (OR = 1.054, $p < 0.01$), reliance on water borrowing (OR = 1.310, $p < 0.01$), untreated water use (OR = 2.919, $p < 0.001$), and exposure to climatic stressors like droughts (OR = 1.086, $p < 0.001$) and floods (OR = 1.196, $p < 0.01$) significantly increase insecurity. Community interventions, such as early warning systems (OR = 0.218, $p < 0.001$) and access to climate knowledge (OR = 0.228, $p < 0.001$), and long-term residency further reduce water insecurity risk. These results underscore the importance of integrating climate preparedness into rural water management strategies to enhance resilience in climate-vulnerable regions.

Keywords: water–climate nexus; water insecurity; climate change preparedness; semi-arid Ghana; rural livelihoods; climatic stressors; Sustainable Livelihoods Framework



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1. Introduction

Water security refers to the reliable availability of an acceptable quantity and quality of water to sustain health, livelihoods, ecosystems, and production, alongside the ability to manage water-related risks to people, environments, and economies [1]. In contrast, water insecurity refers to the lack of reliable access to sufficient, safe, and affordable water necessary for sustaining well-being, livelihoods, and socio-economic development [2–4]. It encompasses both physical scarcity and institutional or socio-economic barriers that prevent

equitable access to water resources [5]. Water insecurity manifests through inadequate availability, poor quality, seasonal variability, and high effort or time required to obtain water, often resulting in negative health, livelihood, and psychosocial outcomes [6].

Water insecurity remains one of the most critical global sustainability challenges of the 21st century, particularly as climate change intensifies the frequency and severity of hydrological extremes such as droughts and floods [6]. Globally, over 2 billion people lack access to safely managed drinking water, a figure projected to increase due to rising global temperatures and changing precipitation patterns [7]. Climate-induced disruptions to the hydrological cycle are particularly pronounced in arid and semi-arid regions, where seasonal variability exacerbates the mismatch between water availability and demand [8].

Africa is among the continents most vulnerable to the impacts of climate change on water resources [9]. This vulnerability is heightened by the region's high dependency on rain-fed agriculture, rapid population growth, and limited infrastructure for water storage, distribution, and reuse [9]. Studies have shown that climate variability significantly impacts water systems and rural livelihoods across the region [2–4,9]. For instance, research in East and West Africa has demonstrated how recurrent droughts, erratic rainfall, and infrastructural limitations increase household vulnerability to both food and water insecurity [10–13]. Despite the growing body of research on water security in sub-Saharan Africa (SSA), much of the existing literature remains concentrated on large river basins or urban centers, often overlooking rural and semi-arid zones where the interplay between climate change and water access is most severe [14–16].

In Ghana, water insecurity is a developmental concern, especially in the northern part of the country, where climate variability is more severe [17]. The northern regions experience a unimodal rainfall pattern, resulting in a long dry season that lasts up to seven months annually [17]. Although various governmental and non-governmental interventions have improved water infrastructure and access, including boreholes and small-town water systems [17,18], these measures often do not address climate-related risks or ensure sustainability in these areas. The persistence of seasonal water scarcity suggests deeper systemic issues [17]. In particular, the capacity of local households and communities to prepare for and adapt to climate stressors remains underexplored. Moreover, the human cost of water collection, particularly in terms of time, effort, and health risks borne by women and children, remains underexplored in climate adaptation discourse.

Northwestern Ghana, one of the climate-stressed and least developed parts of Ghana, characterizes these challenges [17]. The region faces prolonged dry seasons (6–7 months annually), minimal surface water, and increasingly unpredictable rainfall. Rural households depend on shallow wells, boreholes, and seasonal streams, which often dry up or become unsafe during the dry season [19]. The predominant reliance on rain-fed agriculture further compounds the vulnerability of households to climatic shocks [17,19–21]. Women and children are particularly affected by gendered roles in water collection and management [5,10,22]. While studies have examined water access and agricultural resilience in the region [19,22–24], limited empirical research exists on how climate change preparedness affects water insecurity risk at multiple levels—individual, household, and community.

This study fills this critical gap by examining the nexus between climate change preparedness and water insecurity risk in northwestern Ghana. The main objective of this study is to investigate the extent to which climate change preparedness reduces water insecurity risk across individual, household, and community levels in the semi-arid context of the Upper West Region. Specifically, the study seeks to

1. Assess the levels of climate change preparedness among rural households;
2. Examine the relationship between preparedness and water insecurity risk;
3. Identify socio-environmental factors that exacerbate or mitigate water insecurity.

Against this backdrop, the study hypothesizes that rural households with higher levels of climate change preparedness experience a significantly lower risk of severe water insecurity in semi-arid northwestern Ghana. This study contributes to the academic literature and practical policymaking. By empirically demonstrating the protective effects of climate preparedness on water security, this study provides a pathway for more resilient rural water systems. The findings offer evidence-based insights for stakeholders, including local governments, Non-governmental Organizations [NGOs], and development agencies, on designing and implementing climate adaptation strategies tailored to semi-arid contexts. This study advances our understanding of the water–climate nexus in vulnerable settings and underscores the importance of integrating preparedness into broader water security and climate resilience frameworks in Ghana and across SSA.

2. Theoretical Framework

This study is grounded in the Sustainable Livelihoods Framework (SLF) [25]. The SLF highlights that livelihoods are shaped by multiple factors—at individual, household, and community levels—and offers insight into how these factors influence vulnerabilities and adaptive capacities in response to environmental stressors [26].

The SLF identifies several key components (livelihood assets, vulnerability context, livelihood strategies, outcomes, and their interconnections) fundamental to understanding water security as a vital component of livelihoods. Firstly, it categorizes livelihood assets into human, social, natural, physical, and financial capital [27]. Human capital, which encompasses individuals' skills, knowledge, and experience, is pivotal in empowering farmers to make informed decisions about water management [28,29]. Our study highlights that perceived climate preparedness is a significant predictor of water security; thus, enhancing human capital through education and training is vital. When farmers gain a deeper understanding of climate dynamics, they are better equipped to devise effective coping strategies for water-related challenges [30,31].

Social capital is another critical component of the SLF, referring to the relationships and networks that facilitate cooperation and the sharing of resources. Strong community cohesion and the exchange of local knowledge significantly influence water security. By fostering social networks, smallholder farmers can enhance their collective capacity to respond to water shortages, ultimately reducing their vulnerability to such challenges [32]. Natural capital, particularly water availability, is integral to the livelihoods of these farmers. The SLF underscores the need for the sustainable management of natural resources, as adverse climatic events—like droughts and floods—can severely affect water availability and, consequently, the livelihoods dependent on it [33].

The framework also emphasizes the importance of physical capital, which includes the infrastructure necessary for efficient water access and management, such as water supply systems and irrigation. Investment in this physical infrastructure is crucial, as our results indicate it significantly reduces farmers' time retrieving water. Financial capital also plays a significant role, as access to financial resources allows households to invest in alternative water supply solutions, like rainwater harvesting systems or water treatment technologies [33]. Financially stable households can better mitigate the effects of water insecurity by implementing adaptive strategies [34].

Furthermore, the SLF recognizes that livelihoods operate within a vulnerable context influenced by external factors, including economic, political, environmental, and social dynamics [25]. Climate variability, particularly the impact of droughts and floods on water availability, exemplifies a critical vulnerability factor [35]. This framework highlights that stressors can diminish livelihood options and exacerbate smallholder farmers' pressures.

Understanding the context of vulnerability is essential to identifying risks that threaten water security and require adaptive responses.

Lastly, the SLF outlines various livelihood strategies that individuals and households develop to enhance their livelihoods and mitigate risks. These strategies may involve diversifying income sources, investing in water-saving technologies, or engaging in community-level initiatives like forming cooperatives for water resource management. Our study reveals significant relationships between specific water management practices, such as treating water and receiving early warnings, and improved water security, reflecting the adaptive strategies farmers can use to counteract vulnerability. Ultimately, the outcomes derived from these efforts are tied to the sustainability and resilience of livelihoods. When smallholder farmers manage water insecurity effectively, it improves livelihood outcomes, such as food security, economic empowerment, and environmental sustainability. Moreover, the long-term residency of individuals within a locality contributes to their knowledge of local water management practices, demonstrating how positive outcomes can reinforce adaptive capacities and resilience within communities.

3. Materials and Methods

3.1. Study Context

The study was conducted in the Upper West Region [UWR], located in the northwestern part of Ghana [17]. Covering an area of approximately 18,476 square kilometers, the region is located between longitudes $1^{\circ}36'$ and 3° west and latitudes $9^{\circ}48'$ and 11° north (Figure 1). With a population exceeding 901,500, the region is primarily rural, and approximately 80% of its residents depend on subsistence agriculture for their livelihoods [17]. The UWR stands out as one of Ghana's poorest areas, with a Multidimensional Poverty Index (MPI) score of 0.348, significantly exceeding the national average of 0.112 [36]. More than 65% of the region's population lives in multidimensional poverty, with high rates in districts such as Wa West (61.9%), Wa East (48.7%), and Nadowli-Kaleo (40.6%), where this study was conducted [36]. The UWR is formally classified as part of the tropical savanna (Aw) zone under the Köppen climate classification [37]. However, due to its prolonged dry season, limited water availability, and increasing exposure to environmental stressors such as bushfires, droughts, dry spells, floods, heat waves, storm surges, new pests, diseases, and erratic rainfall, the region is often described in practical terms as functionally semi-arid. These factors exacerbate insecurities related to water, food, nutrition, energy, and health [19,22,38]. For instance, the region experiences a unimodal rainfall pattern with an average annual rainfall of between 700 and 1050 mm [38]. Approximately 80% of the population in the region depends significantly on ecosystem services or nature-based activities, which are adversely affected by climate change [39]. Climate variability also affects water sources, causing the drying of water sources and reduced groundwater recharge, affecting rural communities dependent on wells, streams, and boreholes, further compounding household vulnerability [19,22,37]. The district's limited and old water infrastructure exposes the region to water insecurity [17,18]. Vulnerability resulting from climate change exacerbates the negative impacts on livelihoods, encompassing human, social, physical, financial, and natural capital [25]. As an institutional response, the Ghana National Climate Change Policy (NCCP) and National Adaptation Plan (NAP) provide comprehensive guidelines for Ghana's climate change adaptation, with a specific focus on strengthening institutional arrangements, developing effective monitoring and evaluation systems, and implementing priority adaptation programs across various sectors [40]. However, the decentralized implementation of these plans and policies is challenged by limited institutional capacity, inadequate funding, and poor climate information services [41,42]. This study, therefore, explores the integration of climate preparedness into water management.

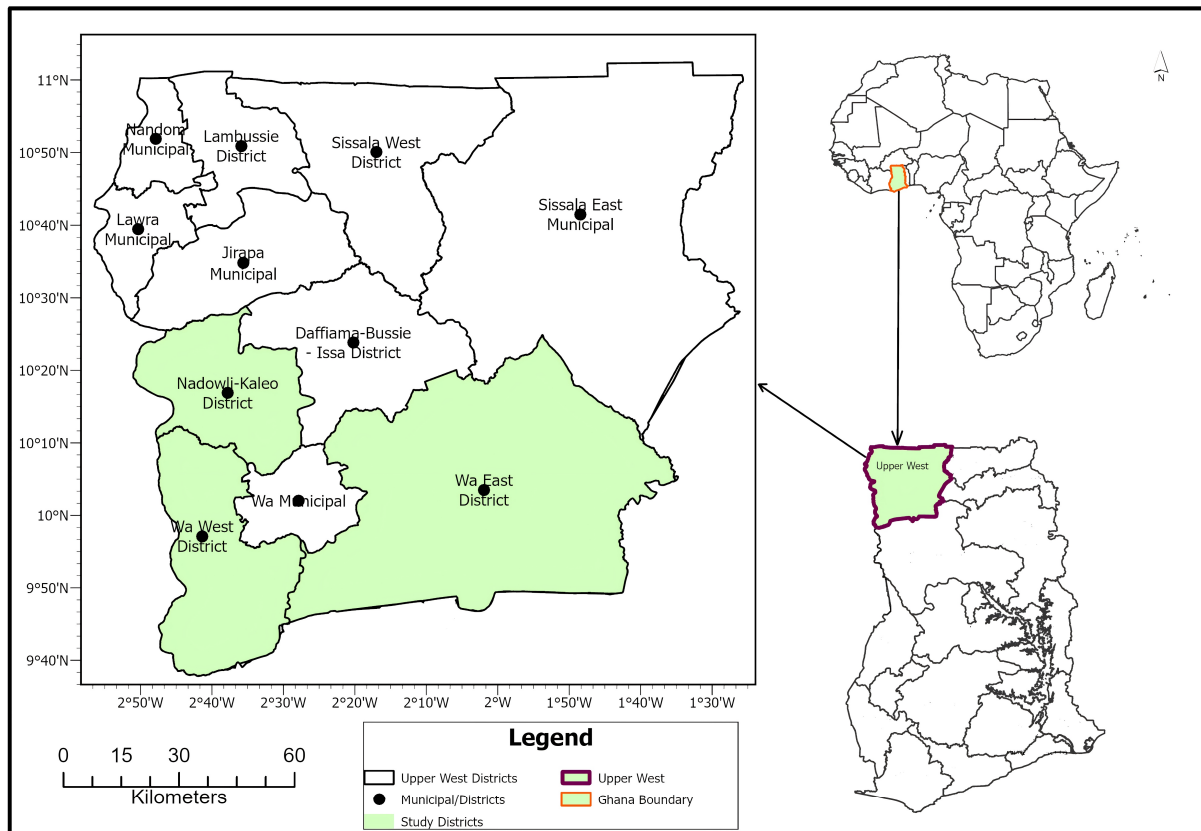


Figure 1. Map of Ghana's UWR showing the study districts (authors' construct).

3.2. Data Collection

This study is part of a larger investigation into the impact of the Community Resource Management Area (CREMA) on improving livelihoods and enhancing climate change resilience in the Upper West Region of Ghana. The sampling and data collection procedures have been published elsewhere [43]. The study received ethical approval (Project ID: 121340) from the Non-Medical Research Ethics Board (NMREB) at the University of Western Ontario, Canada.

3.3. Measurement of Variables

The outcome variable is household water insecurity. To measure this, we utilized the Household Water Insecurity Experience (HWISE) Scale [44]. This scale comprises 12 questions about the water-related difficulties experienced by households in the past month (Figure 2). These questions address emotional distress (such as worry, anger, and shame), disruptions in hygiene practices (e.g., water for washing or bathing), difficulties in consumption (such as inadequate water for drinking or needing to adjust food intake due to limited water availability), and other disturbances related to water. The responses were categorized into four options: "never" (0), "rarely" (1–2 times) (1), "sometimes" (3–10 times) (2), and "often and always" (over 10 times) (3). The scores were then summed up, ranging from 0 to 36. Households with HWISE scores 0 = water-secure, 1–18 = moderately water-insecure, and 19–36 = severely water-insecure. The HWISE Scale is widely used in different categories [10–13,44,45].



Figure 2. The 12 dimensions of the Household Water Insecurity Experience (HWISE) Scale.

The focal independent variable is “perceived climate change preparedness”, defined in line with the World Meteorological Organization’s conceptualization of preparedness as an individual’s or household’s self-assessment of their ability to anticipate, plan for, and respond to the impacts of climate change [46]. Climate change preparedness (CCP) encompasses proactive actions aimed at reducing vulnerability, enhancing resilience, and improving adaptive capacity in the face of climatic hazards. To operationalize this concept, respondents were asked to rate their level of preparedness to address key climate-related stressors experienced in their communities, including droughts, floods, pests and diseases, erratic rainfall, dry spells, and storm surges, within the past 12 months. Responses were categorized into three self-assigned levels, each with practical implications on the ground: Poor (0): This indicates households that had taken little to no action to prepare for climate-related hazards. In practice, these households lacked contingency plans, had limited knowledge of climate risks, or had no access to resources for coping with such events. Satisfactory (1): This represents households that had undertaken some level of preparedness, such as basic knowledge of risks, informal household-level strategies (e.g., storing water or food), or participation in community discussions, but lacked more formal or comprehensive plans. Good (2): This reflects households actively engaged in preparedness activities, including adopting resilient farming practices and accessing support programs to reduce climate-related vulnerabilities. This categorization captures not only self-perception but also reflects observable behaviors and coping strategies reported by respondents during the survey and field observations. Other scholars have used these measurements in similar contexts [47]. In line with the existing literature on climate change, water security, and the smallholder context [10–13,34,47–51], we accounted for various individual, household, and community predictors (refer to Table 1). For example, an asset-based method was utilized to measure household wealth by converting the ownership of 35 items—ranging

from agricultural tools and durable goods to livestock—into binary variables (1 = owned, 0 = not owned). These assets included tractors, farm equipment, mobile phones, water pumps, refrigerators, and various animals such as cattle, goats, and poultry. A Principal Component Analysis (PCA) was conducted on these variables to develop a composite wealth index. Based on their index scores, households were then grouped into five wealth quintiles—poorest, poorer, middle, richer, and richest. Also, early warning refers to formal or informal information received by households in advance of climate-related hazards, specifically droughts, floods, storm surges, erratic rainfall, and dry spells. These warnings are disseminated through multiple channels, including radio broadcasts, community sensitization programs led by NGOs, messages from the Ghana Meteorological Agency, and, in some cases, traditional knowledge shared by community elders. Respondents were asked whether they had received any such early warnings related to these stressors within the past 12 months, providing insight into household-level access to climate risk information. Again, water borrowing refers to the practice of households temporarily obtaining water from neighbors, relatives, or other nearby households during periods of water scarcity. This informal coping mechanism is common in the study area, particularly during droughts, dry spells, or other disruptions to regular water access. Respondents were asked whether their household had engaged in water borrowing within the past 12 months as a measure of household-level coping strategies for water insecurity.

Table 1. Predictors of water insecurity and SLF theoretical relevance.

Predictor Category	Predictor	Coding	SLF Capital/Dimension	Theoretical Relevance
Focal Independent Variable	Perceived climate change preparedness	(0 = poor preparedness, 1 = satisfactory preparedness, 2 = good preparedness)	Human Capital/Vulnerability Context	Measures adaptive capacity and awareness, influencing resilience to shocks.
	Age of primary farmer	Continuous	Human Capital	Age may affect experience, labor capacity, and decision making.
Individual-Level Covariates	Education	(0 = no formal education, 1 = formal education)	Human Capital	Education enhances knowledge, preparedness, and adaptive practices.
	Gender	(0 = male, 1 = female)	Human/Social Capital	Gender roles influence water access and responsibilities.
	Marital status	(0 = single, 1 = married, 2 = divorced/widowed/separated)	Social Capital	Marital status can affect household structure and decision making.
	Marital structure	(0 = monogamy, 1 = polygamy)	Social Capital	Affects household dynamics and resource allocation.

Table 1. *Cont.*

Predictor Category	Predictor	Coding	SLF Capital/Dimension	Theoretical Relevance
Household-Level Covariates	Time spent on round trip fetching water (min)	Continuous	Physical/Natural Capital	Reflects access to water infrastructure and source availability.
	Distance to water source (km)	Continuous	Physical/Natural Capital	Indicates proximity and physical effort to obtain water.
	Water-fetching injuries (monthly count)	Continuous	Human Capital	Health impact and physical risk associated with water collection.
	Water struggles due to availability (monthly count)	Continuous	Natural Capital	Frequency of water stress events due to environmental scarcity.
	Water borrowing in the past months	(0 = no, 1 = yes),	Social Capital	Indicates reliance on social networks for coping.
	Subjective water storage facility	1 = good, 2 = poor	Physical Capital	Quality of infrastructure for water storage and management.
	Water treatment	(0 = yes, 1 = no)	Physical/Human Capital	Hygiene behavior and infrastructure availability.
	Household size	(0 = 1–4, 1 = 5–8, 2 = 9+),	Social Capital	Larger households may face more pressure on water resources.
	Household wealth	(0 = richest, 1 = richer, 2 = middle, 3 = poorer, 4 = poorest)	Financial Capital	Economic capacity to invest in water access and adaptation.
	Household decision making	(0 = male head, 1 = female head, 2 = joint decision making)	Social Capital	Gendered power dynamics affect resource allocation and adaptation.

Table 1. *Cont.*

Predictor Category	Predictor	Coding	SLF Capital/Dimension	Theoretical Relevance
Community-Level Covariates	Climatic stressor experience	(0 = no experience, 1 = droughts, 2 = floods, 3 = other climatic stressors experienced (storm surge/erratic rainfall/dry spells/pests/diseases))	Vulnerability Context/Natural Capital	Indicates exposure to climatic shocks affecting water security.
	Received early warnings	(0 = no, 1 = yes)	Human/Social Capital	Measures institutional support and preparedness systems.
	Climate/disaster action plans	(0 = no, 1 = yes)	Structures/Processes	Institutional readiness to manage climate-related water risks.
	Climate knowledge support systems	(0 = no, 1 = yes)	Human/Social Capital	Access to climate information enhances adaptive capacity.
	Years residing in locality	(0 = 10 or less, 1 = 11–20, 2 = 21–30, 3 = 31–40, 4 = 41–50, 5 = 51–60, 6 = 61+)	Social Capital	Place attachment and local knowledge of environmental changes.
	Geographic location	(0 = Nadowli-Kaleo, 1 = Wa East, 2 = Wa West).	Natural/Contextual Variable	Captures spatial variability in water access and climate exposure.

3.4. Data Analysis

The analysis used a three-stage approach: univariate, bivariate, and multivariate. The univariate analysis calculated descriptive statistics and summarized key sample characteristics. Given that the dependent variable, “Water Insecurity”, is an ordered categorical variable, the study employed ordered logistic regression (OLR) at both the bivariate and multivariate stages of analysis. OLR is suitable for modeling ordinal outcomes as it preserves the natural ranking of the response categories while estimating the influence of predictor variables. This approach allowed for the examination of how socio-demographic-, household-, and community-level factors are associated with the likelihood of households experiencing varying levels of water insecurity. At the bivariate level, the analysis focused solely on “Water Insecurity” as the dependent variable, with different variables serving as independent variables to predict the various influences on severe water insecurity experience. At the multivariate level, this study employed nested multiple OLR to predict severe water insecurity at the individual (Model 1), household (Model 2), and community (Model 3) levels while continuously controlling for preparedness (the focal independent variable) and the different covariates. The analysis was strengthened by a likelihood estimation method for calculating odds ratios (ORs), where values greater than one ($OR > 1$) or less than one ($OR < 1$) indicated a higher or lower likelihood of smallholder farmers

experiencing severe water insecurity, respectively. The OLR formula used in this analysis is expressed as follows [52]:

$$\log \frac{P(Y_{ij} \leq 1)}{(1 - P(Y_{ij} \leq 1))} = a_0 + \sum_{k=1}^{p-1} (a_{jk} X_{ijk} + V_{ij}, C = 1, \dots, \Omega - 1)$$

where $(Y_{ij} \leq 1)$ denotes the likelihood of an event occurring, $(1 - P(Y_{ij} \leq 1))$ characterizes the likelihood that the event will not happen, α_{jk} represents the coefficient element, X_{ijk} denotes the determining variables, $k = 1$ shows the initial, $p - 1$ shows the final explanatory variables, and α_0 and $\Omega - 1$ are intercept components. V_{ij} characterizes the different terms in the model [52]. We utilized a likelihood estimation method to calculate the odds ratios [52] for households reporting water insecurity. The OLR coefficients are shown as odds ratios. Odds ratios exceeding one (ORs > 1) show a higher likelihood of experiencing severe water insecurity, and odds ratios below one (ORs < 1) demonstrate a lower likelihood [50]. We examined the regression model for multicollinearity by utilizing the Variance Inflation Factor (VIF). The VIF values for all variables were below 2.0, with a 1.30 VIF average, indicating minimal multicollinearity in the multiple regression model. The model's reliability was further evaluated using the R-squared, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). The final model achieved an R-squared of 0.42, signifying that it accounted for 42% of the variance in water insecurity outcomes, and the AIC (257.087) and BIC (375.274) suggested a good model fit. This comprehensive analysis was conducted using Stata 19.

4. Results

4.1. Univariate Results

Table 2 shows the demographics of smallholder farmers in Ghana regarding water insecurity. The average water insecurity score was 7.54, with 41.59% of farmers categorized as water-secure, 40.43% as moderately insecure, and 17.99% as severely insecure. Regarding preparedness, 35.40% reported poor preparedness, 50.68% satisfactory, and 13.93% good. Most primary farmers were male (62.86%), married (77.37%), and had no formal education (71.95%), with an average age of 44 years. On a household level, farmers spent an average of 28.5 min fetching water, located about 2.36 km from the source. They reported an average of 5.53 water-fetching injuries and 6.22 struggles with water availability per month. Community-level data showed that many farmers experienced climatic stressors, with floods affecting 33.85% and droughts 26.31%. Additionally, 71.95% had not received early warnings about climate events, and 81.24% reported that their communities did not have climate or disaster action plans. These results highlight significant challenges in water security and the need for better climate adaptation support for farmers in Ghana.

Table 2. Demographic characteristics of smallholder farmers' water insecurity experience in Ghana.

Predictor Categories	Predictors	Percentage (%) / Mean $\pm$ SD
Dependent Variable	Water insecurity	7.541 $\pm$ 9.443
	Water secure	41.59
	Moderately water insecure	40.43
	Severely water insecure	17.99

Table 2. *Cont.*

Predictor Categories	Predictors	Percentage (%) / Mean $\pm$ SD
Focal Independent Variable	Preparedness	
	Poor	35.40
	Satisfactory	50.68
	Good	13.93
Individual-Level Covariates	Age	44.372 $\pm$ 14.080
	Education	
	No formal education	71.95
	Formal education	28.05
	Gender	
	Male	62.86
	Female	37.14
	Marital status	
	Single	10.83
	Married	77.37
	Divorced/widowed/separated	11.80
	Marital structure	
	Monogamy	61.70
	Polygamy	38.30
	Time spent on round trip to fetch water (minutes)	28.487 $\pm$ 29.400
	Distance to water source (km)	2.357 $\pm$ 3.104
	Number of water-fetching Injuries (counts per month for the past year)	5.526 $\pm$ 3.751
	Water struggles due to availability (counts per month for the past year)	6.215 $\pm$ 3.223
	Water borrowing in the past months	
	No	35.01
	Yes	64.99
Household-Level Covariates	Subjective water storage facility	
	Good	38.30
	Poor	61.70
	Water treatment	
	Yes	48.55
	No	51.45
	Household size	
	1–4	26.89
	5–8	43.71
	9+	29.40
	Household wealth	
	Richest	20.89
	Richer	17.60
	Middle	19.92
Community-Level Covariates	Poorer	16.63
	Poorest	24.95
	Household decision making	
	Male head	76.98
	Female head	15.09
	Joint decision making	7.93
	Climatic stressors experienced	
	No experience	5.61
	Droughts	26.31
	Floods	33.85

Table 2. *Cont.*

Predictor Categories	Predictors	Percentage (%) / Mean $\pm$ SD
Community-Level Covariates	Other climatic stressors experienced (storm surge/erratic rainfall/dry spells/pests/diseases)	34.24
	Received early warnings	
	No	71.95
	Yes	28.05
	Community-level climate and disaster action plans	
	No	81.24
	Yes	18.76
	Climate knowledge support systems	
	No	73.69
	Yes	26.31
	Years of residing in the locality	
	10 or less	9.67
	11–20	17.02
	21–30	21.28
	31–40	16.83
	41–50	14.89
	51–60	14.51
	61+	5.80
	Geographic location	
	Nadowli-Kaleo	23.40
	Wa East	32.30
	Wa West	44.29

Note: Kilometers (km).

4.2. Bivariate Results

The bivariate results are shown in Table 3. The bivariate analysis assessed the factors influencing severe water insecurity among smallholder farmers in Ghana. The primary independent variable, preparedness, demonstrated a strong protective effect. Smallholder farmers who reported good preparedness were less likely (0.394 ± 0.108 , $p < 0.001$) to experience severe water insecurity compared to those who reported poor preparedness. Household-level factors also played a crucial role. Each additional minute spent fetching water was associated with increased odds of experiencing water insecurity (1.009 ± 0.002 , $p < 0.001$) compared to those who spent less time. Likewise, each additional unit increase in the travel distance to fetch water (1.058 ± 0.010 , $p < 0.001$) and a higher number of water-fetching injuries per month (1.032 ± 0.023 , $p < 0.01$) were linked to a greater risk of severe water insecurity. Smallholder farmers who had borrowed water in the past month (1.536 ± 0.267 , $p < 0.001$) were more likely to confront severe water insecurity than those who had not. Poor water storage facilities (1.722 ± 0.294 , $p < 0.001$) and a lack of water treatment (2.679 ± 0.459 , $p < 0.001$) further worsened severe water insecurity. Regarding household wealth, both poorer (1.241 ± 0.339 , $p < 0.05$) and the poorest (1.647 ± 0.399 , $p < 0.001$) households faced increased odds of severe water insecurity compared to the wealthiest households. At the community level, smallholder farmers who experienced climatic stressors such as droughts (1.365 ± 0.577 , $p < 0.05$), floods (2.311 ± 0.957 , $p < 0.01$), and other extreme weather events (5.762 ± 2.406 , $p < 0.001$) had a significantly heightened risk of severe water insecurity. Conversely, those who received early warnings (0.566 ± 0.106 , $p < 0.001$) and accessed climate knowledge support systems (0.367 ± 0.073 , $p < 0.001$) were less likely to experience severe water insecurity compared to those without these supports. Additionally, longer residency in the area appeared protective; individuals

who had lived there for 21–30 years (0.454 ± 0.147 , $p < 0.01$) and 51–60 years (0.495 ± 0.171 , $p < 0.001$) were less likely to experience severe water insecurity compared to those who had lived in the locality for 10 years or less. Geographically, farmers in Wa East were more likely (1.649 ± 0.367 , $p < 0.01$) to face severe water insecurity compared to those in Nadowli-Kaleo.

Table 3. Bivariate ordered logistic regression predicting smallholder farmers' severe water insecurity experience in Ghana.

Predictor Categories	Predictors	OR $\pm$ SE	[95% CI]
Focal Independent Variable	Preparedness (ref: poor)		
	Satisfactory	0.871 ± 0.157	0.612–1.240
	Good	0.394 ± 0.108 ***	0.230–0.675
	Age †	0.995 ± 0.006	0.984–1.007
Individual-Level Covariates	Education (ref: no formal education)		
	Formal education	0.949 ± 0.173	0.664–1.357
	Gender of primary farmer (ref: male)		
	Female	1.140 ± 0.195	0.815–1.594
	Marital status of primary farmer (ref: single)		
	Married	0.980 ± 0.257	0.586–1.639
	Divorced/widowed/separated	1.241 ± 0.429	0.630–2.444
	Marital structure of primary farmer (ref: monogamy)		
	Polygamy	1.004 ± 0.169	0.721–1.398
	Time spent on round trip to fetch water † (minutes)	1.009 ± 0.002 ***	1.003–1.014
	Distance to water source (km)	1.058 ± 0.010 ***	1.038–1.078
	Number of water-fetching injuries † (counts per month for the past year)	1.032 ± 0.023 **	1.086–1.079
	Water struggles due to availability † (counts per month for the past year)	0.928 ± 0.044	0.845–1.019
	Water borrowing in the past months (ref: no)		
	Yes	1.536 ± 0.267 ***	1.092–2.161
Household-Level Covariates	Subjective water storage facility (ref: good)		
	Poor	1.722 ± 0.294 ***	1.231–2.407
	Water treatment (ref: yes)		
	No	2.679 ± 0.459 ***	1.914–3.748
	Household size (ref: 1–4)		
	5–8	0.956 ± 0.195	0.640–1.428
	9+	1.118 ± 0.243	0.730–1.714
	Household wealth (ref: richest)		
	Richer	0.832 ± 0.220	0.495–1.398
	Middle	0.970 ± 0.249	0.586–1.606
	Poorer	1.241 ± 0.339 *	0.726–2.121
	Poorest	1.647 ± 0.399 **	1.024–2.649
	Household decision making (ref: male head)		
	Female head	1.452 ± 0.337	0.921–2.288
	Joint decision making	1.878 ± 0.591	1.013–3.483

Table 3. Cont.

Predictor Categories	Predictors	OR $\pm$ SE	[95% CI]
Community-Level Covariates	Climatic stressors experienced (ref: no event experience)		
	Droughts	1.365 $\pm$ 0.577 *	0.596–3.128
	Floods	2.311 $\pm$ 0.957 **	1.025–5.206
	Other climatic stressors experienced (storm surge/erratic rainfall/dry spells/pests/diseases)	5.762 $\pm$ 2.406 ***	2.542–13.063
	Received early warnings (ref: no)		
	Yes	0.566 $\pm$ 0.106 ***	0.391–0.819
	Community-level climate and disaster action plans (ref: no)		
	Yes	1.163 $\pm$ 0.241	0.775–1.746
	Climate knowledge support systems (ref: no)		
	Yes	0.367 $\pm$ 0.073 ***	0.248–0.542
	Years of residing in the locality (ref: 10 or less)		
	11–20	0.642 $\pm$ 0.216	0.332–1.243
	21–30	0.454 $\pm$ 0.147 **	0.239–0.860
	31–40	0.875 $\pm$ 0.295	0.451–1.698
	41–50	0.576 $\pm$ 0.197	0.294–1.126
	51–60	0.495 $\pm$ 0.171 ***	0.252–0.974
	61+	0.548 $\pm$ 0.243	0.229–1.309
	Geographic location (ref: Nadowli-Kaleo)		
	Wa East	1.649 $\pm$ 0.367 **	1.065–2.551
	Wa West	0.765 $\pm$ 0.160	0.507–1.152

Notes: $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; OR = odds ratio, SE = Standard Error, confidence interval = CI, † = continuous, dependent variable (water insecurity).

4.3. Multiple Ordered Logistic Regression

The multivariate results are presented in Table 4, highlighting the factors that contribute to severe water insecurity among smallholder farmers in Ghana at the individual, household, and community levels. In the individual-level model, smallholder farmers who rated their preparedness as good had lower chances of experiencing severe water insecurity compared to those who rated their preparedness as poor (0.35 ± 0.099 , $p < 0.001$). This trend continued at the household level, where severe water insecurity significantly declined for smallholder farmers who rated their preparedness as good (0.037 ± 0.029 , $p < 0.001$). Other household-level factors also showed significant associations; each additional minute required for a round trip to fetch water was associated with a slight increase in the likelihood of experiencing severe water insecurity (1.0266 ± 0.006 , $p < 0.001$). Additionally, a rise in reported water-fetching injuries correlated with an increased risk of water insecurity (1.066 ± 0.065 , $p < 0.01$) compared to those without injuries. Not treating water substantially increased the associated risk of experiencing severe water insecurity (2.640 ± 1.101 , $p < 0.01$) compared to those who treated their water. At the community level, smallholder farmers who reported good preparedness had a lower risk of experiencing severe water insecurity (0.103 ± 0.105 , $p < 0.001$). Also, an increase in the round-trip water-fetching time (1.036 ± 0.007 , $p < 0.001$) or water injuries (1.054 ± 0.079 , $p < 0.001$) increased the likelihood of smallholder farmers experiencing severe water insecurity. Smallholder farmers who experienced water borrowing in the past months were more likely to face the risk of severe water insecurity (1.310 ± 0.182 , $p < 0.01$) compared to those who did not experience water borrowing. Smallholder farmers who reported not treating water (2.919 ± 1.459 , $p < 0.001$) were more likely to face severe water insecurity. Moreover, smallholder farmers who experienced adverse climatic stressors—including droughts (1.086 ± 0.126 , $p < 0.001$) and floods (1.196 ± 0.269 , $p < 0.01$)—were more likely to face severe water insecurity compared

to those who reported no such events. Conversely, smallholder farmers who received early warnings about climate events were more protective against and less likely at risk of water insecurity (0.218 ± 0.138 , $p < 0.001$) compared to those who did not receive warnings. Smallholder farmers who accessed climate knowledge support systems (0.228 ± 0.123 , $p < 0.001$) were less likely to be at risk of water insecurity compared to those without such systems. Finally, longer residency in the locality was associated with reduced severe water insecurity, particularly among smallholder farmers residing for 31–40 years (0.081 ± 0.080 , $p < 0.001$), 41–50 years (0.071 ± 0.077 , $p < 0.001$), 50–60 years (0.037 ± 0.044 , $p < 0.001$), and over 60 years (0.063 ± 0.054 , $p < 0.01$) compared to those who had lived in the area for 10 years or less. Geographically, smallholder farmers in Wa West were less likely (0.063 ± 0.054 , $p < 0.001$) to face severe water insecurity compared to those in Nadowli-Kaleo.

Table 4. Multiple ordered logistic regression predicting smallholder farmers' severe water insecurity experience in Ghana.

Predictors	Nested Ordered Logistic Regression					
	Individual-Level Model		Household-Level Model		Community-Level Model	
	OR $\pm$ SE	[95% CI]	OR $\pm$ SE	[95% CI]	OR $\pm$ SE	[95% CI]
Preparedness (ref: poor)						
Satisfactory	0.891 $\pm$ 0.162	0.624–1.273	0.629 $\pm$ 0.267	0.273–1.449	1.048 $\pm$ 0.574	0.358–3.067
Good	0.35 $\pm$ 0.099 ***	0.204–0.613	0.037 $\pm$ 0.029 ***	0.007–0.173	0.103 $\pm$ 0.105 **	0.013–0.760
Age †	0.991 $\pm$ 0.007	0.976–1.006	1.023 $\pm$ 0.017	0.989–1.058	1.043 $\pm$ 0.023	0.997–1.091
Education (ref: no formal education)						
Formal education	0.832 $\pm$ 0.181	0.542–1.276	1.949 $\pm$ 0.976	0.730–5.203	3.030 $\pm$ 1.906	0.883–10.399
Gender (ref: male)						
Female	0.993 $\pm$ 0.195	0.675–1.460	0.633 $\pm$ 0.266	0.277–1.444	0.605 $\pm$ 0.331	0.207–1.769
Marital status (ref: single)						
Married	1.023 $\pm$ 0.373	0.501–2.092	1.275 $\pm$ 1.201	0.201–8.081	1.610 $\pm$ 1.752	0.190–13.597
Divorced/widowed/separated	1.472 $\pm$ 0.616	0.648–3.344	1.701 $\pm$ 1.854	0.200–4.406	2.770 $\pm$ 3.691	0.203–7.749
Marital structure (ref: monogamy)						
Polygamy	0.939 $\pm$ 0.225	0.587–1.504	2.088 $\pm$ 1.197	0.678–6.427	2.940 $\pm$ 2.023	0.763–11.330
Time spent on round trip to fetch water (minutes) †			1.0266 $\pm$ 0.006 ***	1.014–1.038	1.036 $\pm$ 0.007 ***	1.021–1.052
Distance to water source (km) †			1.026 $\pm$ 0.017	0.992–1.061	0.990 $\pm$ 0.021	0.949–1.034
Number of water-fetching injuries (counts per month for the past year) †			1.066 $\pm$ 0.065 **	1.046–1.104	1.054 $\pm$ 0.079 ***	1.010–1.122
Water struggles due to availability (counts per month for the past year) †			1.024 $\pm$ 0.065	0.904–1.159	0.941 $\pm$ 0.073	0.807–1.096
Water borrowing in the past months (ref: no)						
Yes			1.998 $\pm$ 0.452	1.410–2.428	1.310 $\pm$ 0.182 **	1.098–1.979
Subjective water storage facility (ref: good)						
Poor			1.566 $\pm$ 0.720	0.635–3.859	2.165 $\pm$ 1.368	0.627–7.473
Water treatment (ref: yes)						
No			2.640 $\pm$ 1.101 ***	1.166–5.979	2.919 $\pm$ 1.459 ***	1.095–7.777
Household size (ref: 1–4)						
5–8			0.713 $\pm$ 0.374	0.255–1.994	2.091 $\pm$ 1.394	0.565–7.730
9+			0.409 $\pm$ 0.248	0.124–1.345	1.097 $\pm$ 0.810	0.258–4.668
Household wealth (ref: richest)						
Richer			1.358 $\pm$ 0.713	0.485–3.801	5.894 $\pm$ 3.884	1.619–21.449
Middle			1.186 $\pm$ 0.703	0.371–3.793	2.006 $\pm$ 1.466	0.478–8.407
Poorer			2.321 $\pm$ 1.802	0.506–10.632	1.676 $\pm$ 1.616	0.253–11.089
Poorest			0.849 $\pm$ 0.504	0.264–2.721	1.093 $\pm$ 0.800	0.260–4.594
Household decision making (ref: male head)						
Female head			1.543 $\pm$ 1.033	0.415–5.731	0.814 $\pm$ 0.646	0.172–3.856
Joint decision making			0.482 $\pm$ 0.279	0.154–1.502	0.406 $\pm$ 0.286	0.101–1.621
Climatic stressors experienced (ref: no event experience)						

Table 4. Cont.

Nested Ordered Logistic Regression			
Droughts		1.086 ± 0.126 ***	1.004–1.517
Floods		1.196 ± 0.269 **	1.013–2.880
Other climatic stressors experienced (storm surge/erratic rainfall/dry spells/pests/diseases)		1.288 ± 1.768 **	1.087–2.960
Received early warnings (ref: no)			
Yes		0.218 ± 0.138 ***	0.063–0.758
Community-level climate and disaster action plans (ref: no)			
Yes		0.498 ± 0.263	0.177–1.402
Climate knowledge support systems (ref: no)			
Yes		0.228 ± 0.123 ***	0.078–0.661
Years of residing in the locality (ref: 10 or less)			
11–20		0.179 ± 0.171	0.027–1.168
21–30		0.246 ± 0.236	0.037–1.619
31–40		0.081 ± 0.080 ***	0.011–0.571
41–50		0.071 ± 0.077 ***	0.008–0.602
51–60		0.037 ± 0.044 ***	0.003–0.378
61+		0.048 ± 0.069 **	0.002–0.797
Geographic location (ref: Nadowli-Kaleo)			
Wa East		1.837 ± 1.611	0.329–8.245
Wa West		0.063 ± 0.054 ***	0.011–0.342
Log-likelihood	−524.951	−119.237	−89.543
Pseudo R ²	0.017	0.237	0.427
Akaike Information Criterion (AIC)	1069.902	288.474	257.087
Bayesian Information Criterion (BIC)	1112.344	364.235	375.274

Notes: $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; OR = odds ratio, SE = Standard Error, † = continuous, confidence interval = CI, dependent variable (water insecurity).

5. Discussion

This study investigated the multidimensional drivers of water insecurity among smallholder farmers anchored on the Sustainable Livelihood Framework (SLF) lens, which emphasizes how the five forms of capital—human, social, physical, natural, and financial—shape rural livelihoods [25]. The findings from this study reveal how vulnerabilities and adaptive strategies are embedded within these livelihood assets.

Consistent with the hypothesis, smallholder farmers who reported good preparedness had a significantly lower likelihood of experiencing severe water insecurity. Preparedness, a key component of human capital, often reflects households' knowledge, skills, and behavioral capacities to anticipate and respond to shocks [25]. This aligns with findings from Ethiopia, where farmers with prior exposure to climate adaptation training reported better outcomes during water-related crises [53]. In the UWR, where seasonal rainfall variability is common, preparedness likely includes water harvesting, storage practices, or the use of water-saving technologies [19,22,34]. These adaptive capacities enhance resilience by reducing the dependence on unpredictable external water sources.

Another important finding is that increased time spent on round-trip water collection was strongly associated with severe water insecurity. This finding reflects deficits in physical capital, particularly in water infrastructure availability and proximity. Similar results have been documented in rural Kenya and Malawi, where long distances to water sources were linked to physical exhaustion, health challenges, and decreased time available for income-generating activities [54,55]. In Ghana's UWR, where communities are often dispersed and infrastructure is limited, the physical burden of water fetching not only

heightens insecurity but also exacerbates gender- and age-based vulnerabilities, as women and children predominantly shoulder this responsibility [56,57].

Furthermore, water-related injuries increased the likelihood of farmers experiencing severe water insecurity. Injuries, such as slips, falls, or musculoskeletal strain, diminish human capital by reducing household labor availability [58,59]. Studies have reported similar findings, where physical injuries during water collection led to increased medical expenses and reduced on-farm labor capacity [59]. In the UWR, where healthcare access may already be constrained, such injuries can have cascading effects on both health and livelihood productivity, reinforcing cycles of vulnerability [60,61].

Invariably, smallholder farmers who reported borrowing water in the past month were more likely to experience severe water insecurity. While water borrowing can serve as a short-term coping mechanism, it often reflects deeper vulnerabilities in natural and social capital from the SLF lens [25]. Households that rely on borrowed water typically lack consistent access to their reliable sources, indicating stress on natural capital such as local boreholes, wells, or rain-fed storage [62]. Moreover, while social capital can facilitate water sharing within communities, repeated borrowing may signal strained relationships or social exclusion, especially when borrowing becomes habitual rather than occasional [63]. Studies from Kenya and Ethiopia have shown that households engaged in frequent water borrowing often reside in marginalized areas with limited infrastructure and may face social tensions or stigma [64,65]. In Ghana's UWR, reliance on water borrowing could indicate physical scarcity and limited access to communal water governance mechanisms. Therefore, while borrowing water may provide temporary relief, it is ultimately a symptom of chronic water insecurity rather than a sustainable solution.

Moreover, households that did not treat their water were significantly more likely to report severe water insecurity. This behavior intersects with financial and human capital—some households may lack the resources to purchase treatment supplies (e.g., filters, chlorine) [66]. Some households may treat their water due to concerns about quality, while others may lack awareness of the benefits of water treatment. Comparable trends have been found in Ethiopia, where lower levels of education and income were linked to the reduced uptake of household water treatment methods [67]. Holvoet found that education and exposure to information about water treatment significantly increase the likelihood that households will treat their water [68]. In Ghana's UWR, where poverty rates are among the highest nationally, such constraints (e.g., limited access to education and healthcare, inadequate infrastructure, insufficient economic opportunities, and environmental challenges, such as erratic rainfall and soil degradation) likely contribute to untreated and unsafe water use, thereby increasing vulnerability [69].

Importantly, smallholder farmers exposed to adverse climatic stressors—including droughts and floods—were significantly more vulnerable to water insecurity [6,70]. These findings highlight the fragility of natural capital under climate stress [9]. In similar agroecological zones across the Sahel, recurrent droughts and erratic rainfall have been identified as major drivers of water scarcity and disruption of rural livelihoods [8]. In northern Ghana, where rain-fed agriculture dominates, climate extremes can lead to the drying of rivers and boreholes, soil erosion, and disruptions to traditional water-sharing arrangements, all of which exacerbate water insecurity [20,71].

Again, smallholder farmers who received early warnings about climate events were more likely to be protected from severe water insecurity. This underscores the importance of social capital and access to institutional support systems [25]. Early warning systems provide vital lead time for households to plan for water storage, adjust their agricultural calendars, or temporarily relocate livestock [46]. Studies elsewhere in SSA have highlighted how community-based early warning mechanisms enhance adaptive capacity and reduce

vulnerability to climate-related shocks [72,73]. In Ghana, expanding such systems through local radio, extension services, and mobile platforms could offer a cost-effective strategy for strengthening resilience [46].

The study also found that access to climate knowledge support systems, such as agricultural extension, meteorological information, or community training, was linked to a reduced risk of severe water insecurity. This reflects a strengthening of human and social capital, allowing farmers to make informed decisions and adopt sustainable water management practices [25,74]. A study in Rwanda found that farmers with access to climate advisory services were more likely to engage in adaptive behaviors such as rainwater harvesting and conservation agriculture [75]. Building locally relevant knowledge platforms in the UWR can bridge the information gap and empower communities.

Likewise, longer-term residency in the community was associated with lower levels of water insecurity. Farmers who had resided in the area for over 30 years were significantly less likely to report severe water insecurity compared to those who had stayed in the area for a shorter period. From the SLF perspective, long-term residency strengthens social capital by fostering stronger community networks, local knowledge of water sources, and established coping mechanisms [76,77]. Studies from Zimbabwe and Mozambique support this finding, showing that long-standing community members are more effectively integrated into communal water management and informal resource-sharing arrangements [78,79]. This insight is particularly important for policymakers aiming to support newly resettled or migrant populations who may lack these embedded social structures.

Geographic variations revealed that smallholder farmers in Wa West were less likely to face severe water insecurity than those in Nadowli-Kaleo. This may reflect differences in physical and natural capital across districts from the SLF lens [25]. Wa West may benefit from more robust water infrastructure, improved soil water retention, or increased institutional investments. Regional water access and infrastructure disparities have been documented in other parts of Ghana and West Africa [80,81]. Understanding each district's specific ecological and infrastructural conditions is crucial for targeting interventions and achieving equitable water security outcomes.

Despite this study's contribution, it has limitations that should be acknowledged. First, the cross-sectional design limits the ability to infer causality between the identified factors and water insecurity. While associations are evident, longitudinal data would be needed to confirm temporal relationships and capture changes over time. Second, the study relied primarily on self-reported data, which may be subject to recall or social desirability bias, especially on sensitive topics such as preparedness or water treatment behaviors. Additionally, although this study assessed multiple climate stressors independently, low response rates for specific events, such as storm surges, erratic rainfall, and dry spells, necessitated combining these stressors into a single category for statistical analysis. This approach, while necessary for robust analysis, may obscure nuanced differences in how communities experience and respond to these distinct stressors. Third, the analysis did not include detailed hydroclimatic or geospatial data on water availability and infrastructure, which could have provided more nuanced insights into the environmental and infrastructural drivers of water insecurity. Finally, although the study focused on northwestern Ghana, its findings may not be generalizable to other regions in Ghana or across sub-Saharan Africa, given the different ecological, cultural, and governance contexts. Future research could benefit from mixed-methods approaches and a broader geographic coverage to enhance the robustness and applicability of the findings.

6. Conclusions

This study contributes to the growing literature on rural water insecurity by identifying key drivers among smallholder farmers in northwestern Ghana through the Sustainable Livelihood Framework. The findings highlight that water insecurity is not merely a function of water availability but is intricately tied to multiple dimensions of livelihood capital, including human preparedness, physical access to infrastructure, natural resource quality, and social support networks. Farmers with better preparedness, access to early warning systems, climate knowledge support, and long-term residency were less likely to experience severe water insecurity. Conversely, those affected by adverse climatic events, long water collection times, untreated water use, water injuries, and water borrowing were at significantly higher risk. These insights underscore the multifaceted nature of water insecurity and the need for integrated responses that address both immediate needs and long-term structural vulnerabilities.

7. Policy Direction

The findings of this study offer several implications for policy and development interventions aimed at reducing water insecurity in rural Ghana and similar settings. First, strengthening human capital through education and preparedness programs, particularly on water management, treatment practices, and climate adaptation, is essential. Second, investments in physical infrastructure, such as boreholes, rainwater harvesting systems, and safe water storage facilities, should be prioritized in underserved communities to reduce the time burden and physical risks associated with water collection. Third, enhancing natural capital by protecting local water sources from contamination and improving watershed management will help ensure the quality and sustainability of water supplies. Fourth, strengthening social capital through community-based early warning systems, peer support groups, and inclusive water governance can foster collective resilience. Finally, policies should recognize and address spatial disparities in water access by targeting interventions in high-risk districts, such as Nadowli-Kaleo. A coordinated, multi-sectoral approach—linking water, health, agriculture, and climate services—will be critical to securing water for livelihoods and resilience in the face of escalating environmental and socio-economic pressures.

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References

1. He, C.; Zhang, L.; Zhang, X.; Eslamian, S. Water Security: Concept, Measurement, and Operationalization. In *Handbook of Engineering Hydrology, Volume 3: Environmental Hydrology and Water Management*; Eslamian, S., Ed.; Taylor and Francis, CRC Group: Boca Raton, FL, USA, 2014; pp. 545–554.
2. Jepson, W.E.; Wutich, A.; Collins, S.M.; Boateng, G.O.; Young, S.L. Progress in Household Water Insecurity Metrics: A Cross-Disciplinary Approach. *Wiley Interdiscip. Rev. Water* **2017**, *4*, e1214. [CrossRef]
3. Stoler, J.; Jepson, W.E.; Brewis, A.; Wutich, A. Frontiers of Household Water Insecurity Metrics: Severity, Adaptation and Resilience. *BMJ Glob. Health* **2023**, *8*, e011756. [CrossRef]
4. Kangmennaang, J.; Bisung, E.; Elliott, S.J. ‘We Are Drinking Diseases’: Perception of Water Insecurity and Emotional Distress in Urban Slums in Accra, Ghana. *Int. J. Environ. Res. Public Health* **2020**, *17*, 890. [CrossRef] [PubMed]
5. Nunbogu, A.M.; Elliott, S.J. Towards an Integrated Theoretical Framework for Understanding Water Insecurity and Gender-Based Violence in Low-and Middle-Income Countries (LMICs). *Health Place* **2021**, *71*, 102651. [CrossRef]
6. United Nations Educational Scientific and Cultural Organization [UNESCO]. *UN-Water United Nations World Water Development Report 2020: Water and Climate Change*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2020.
7. United Nations Children’s Fund [UNICEF]; World Health Organization [WHO]. Progress on Household Drinking Water, Sanitation and Hygiene 2000–2020: Five Years into the SDGs. Available online: <https://www.who.int/publications/i/item/9789240030848> (accessed on 22 May 2025).
8. Masson-Delmotte, V.; Zhai, P.; Pirani, A.; Connors, S.L.; Péan, C.; Berger, S.; Caud, N.; Chen, Y.; Goldfarb, L.; Gomis, M.I.; et al. (Eds.) Intergovernmental Panel on Climate Change [PCC] Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2021; pp. 3–32.
9. World Meteorological Organization [WMO]. *State of the Climate in Africa 2024*; WMO: Geneva, Switzerland, 2025.
10. Brewis, A.; Workman, C.; Wutich, A.; Jepson, W.; Young, S.; Adams, E.; Ahmed, J.F.; Alexander, M.; Balogun, M.; Boivin, M.; et al. Household Water Insecurity Is Strongly Associated with Food Insecurity: Evidence from 27 Sites in Low- and Middle-Income Countries. *Am. J. Hum. Biol.* **2020**, *32*, e23309. [CrossRef] [PubMed]
11. Stoler, J.; Pearson, A.L.; Staddon, C.; Wutich, A.; Mack, E.; Brewis, A.; Rosinger, A.Y.; Adams, E.; Ahmed, J.F.; Alexander, M.; et al. Cash Water Expenditures Are Associated with Household Water Insecurity, Food Insecurity, and Perceived Stress in Study Sites across 20 Low- and Middle-Income Countries. *Sci. Total Environ.* **2020**, *716*, 135881. [CrossRef]
12. Shah, S.H.; Harris, L.M.; Menghwani, V.; Stoler, J.; Brewis, A.; Miller, J.D.; Workman, C.L.; Adams, E.A.; Pearson, A.L.; Hagaman, A.; et al. Variations in Household Water Affordability and Water Insecurity: An Intersectional Perspective from 18 Low- and Middle-Income Countries. *Environ. Plan. F* **2023**, *2*, 369–398. [CrossRef]
13. Bethancourt, H.J.; Swanson, Z.S.; Nzunza, R.; Young, S.L.; Lomeiku, L.; Douglass, M.J.; Braun, D.R.; Ndiema, E.K.; Pontzer, H.; Rosinger, A.Y. The Co-Occurrence of Water Insecurity and Food Insecurity among Daasanach Pastoralists in Northern Kenya. *Public Health Nutr.* **2023**, *26*, 693–703. [CrossRef]
14. Nti, E.K.; Kranjac-Berisavljevic, G.; Doke, D.A. Water Security and Sustainability Issues in Ghana’s Pra River Basin: An Introduction—Projected Usefulness of Artificial Intelligence. *Technol. Sustain.* **2024**, *4*, 77–97. [CrossRef]
15. Yomo, M.; Mourad, K.A.; Gnazou, M.D.T. Examining Water Security in the Challenging Environment in Togo, West Africa. *Water* **2019**, *11*, 231. [CrossRef]
16. Anghileri, D.; Pastori, M.; Marcos-Garcia, P.; Umlauf, G.; Crestaz, E.; Seliger, R.; Iervolino, A.; Cordano, E.; Cattaneo, L.; Carmona-Moreno, C. Global Water Challenges in Sub-Saharan Africa and How to Strengthen Science-Policy Dialogues on Transboundary Governance and Cooperation. *J. Environ. Manag.* **2024**, *365*, 121417. [CrossRef] [PubMed]
17. Ghana Statistical Service [GSS]. *Ghana 2021 Population and Housing Census General Report*; GSS: Accra, Ghana, 2021; Volume 3A.
18. Community Water and Sanitation Agency [CWSA]. Water and Sanitation Activities in the Upper West Region. Available online: <https://www.cwsa.gov.gh/upper-west-region-3/water-and-sanitation/#:~:text=The%20region%20is%20drained%20by,dueto%20ground%20water%20supply> (accessed on 1 February 2024).
19. Baddianaah, I.; Dongzagla, A.; Salifu, S.N. Navigating Access to Safe Water by Rural Households in Sub-Saharan Africa: Insights from North-Western Ghana. *Sustain. Environ.* **2024**, *10*, 2303803. [CrossRef]
20. Alhassan, J.; Appiah, D.O.; Iddrisu, S.; Ofori, A.; Tetteh, J. Incidence of Water Scarcity: Understanding the Triggers and Implications for Women’s Non-Agricultural Livelihoods in Northern Ghana. *Cogent Soc. Sci.* **2024**, *10*, 2433691. [CrossRef]
21. Abanyie, S.K.; Amuah, E.E.Y.; Nang, D.B. Water Scarcity and Its Implications on Sanitation: A Perspective Study in an Emerging City in Northern Ghana. *Green Technol. Sustain.* **2025**, *3*, 100138. [CrossRef]
22. Pienaaah, C.K.A.; Saaka, S.A.; Mohammed, K.; Amoak, D.; Luginaah, I. The Role of Water and Energy in Food Security among Smallholder Farmers in Semi-Arid Ghana. *Afr. Geogr. Rev.* **2025**; in press. [CrossRef]
23. Kpieta, A.; Laari, P. Small-Scall Dams Water Quality and the Possible Health Risk to Water Users of the Upper West Region of Ghana. *Eur. Sci. J. May* **2014**, *10*, 249–270.

24. Osumanu, I.K.; Zumayelleh, E.A.; Kosoe, E.A. Sustainability of Community-Managed Small Town and Rural Water Systems in Northern Ghana: Lessons from Upper West Region. *Community Dev. J.* **2022**, *57*, 93–111. [\[CrossRef\]](#)
25. British Department for International Development [DFID]. *DFID's Sustainable Livelihoods Approach and Its Framework*; DFID: London, UK, 2000.
26. Reed, M.S.; Podesta, G.; Fazey, I.; Geeson, N.; Hessel, R.; Hubacek, K.; Letson, D.; Nainggolan, D.; Prell, C.; Rickenbach, M.G.; et al. Combining Analytical Frameworks to Assess Livelihood Vulnerability to Climate Change and Analyse Adaptation Options. *Ecol. Econ.* **2013**, *94*, 66–77. [\[CrossRef\]](#)
27. Serrat, O. *Knowledge Solutions: Tools, Methods, and Approaches to Drive Organizational Performance*; Springer: Singapore, 2017; ISBN 9789811009839.
28. World Bank How to Protect, Build, and Use Human Capital to Address Climate Change. 2023. Available online: <https://thedocs.worldbank.org/en/doc/cc99b238fa9a0f266579d49dc591b2d4-0140062023/original/HCP-Climate-Policy-Brief.pdf> (accessed on 17 March 2023).
29. Hitka, M.; Kucharčíková, A.; Štarchoň, P.; Balážová, Ž.; Lukáč, M.; Stacho, Z. Knowledge and Human Capital as Sustainable Competitive Advantage in Human Resource Management. *Sustainability* **2019**, *11*, 4985. [\[CrossRef\]](#)
30. Ali, S.; Ying, L.; Nazir, A.; Abdullah; Ishaq, M.; Shah, T.; Ye, X.; Ilyas, A.; Tariq, A. Rural Farmers Perception and Coping Strategies towards Climate Change and Their Determinants: Evidence from Khyber Pakhtunkhwa Province, Pakistan. *J. Clean. Prod.* **2021**, *291*, 125250. [\[CrossRef\]](#)
31. Hagos, F.; Musiyiwa, K.; Witthaus, L.M.; Mwadzingeni, L.; Mugandani, R.; Mafongoya, P.L. Perception of Climate Change and Coping Strategies among Smallholder Irrigators in Zimbabwe. *Front. Sustain. Food Syst.* **2023**, *7*, 1027846.
32. Nelson, S.; Drabarek, D.; Jenkins, A.; Negin, J.; Abimbola, S. How Community Participation in Water and Sanitation Interventions Impacts Human Health, WASH Infrastructure and Service Longevity in Low-Income and Middle-Income Countries: A Realist Review. *BMJ Open* **2021**, *11*, e053320. [\[CrossRef\]](#) [\[PubMed\]](#)
33. Kemp-Benedict, E.; Bharwani, S.; De La Rosa, E.; Krittassudthacheewa, C.; Matin, N. *Assessing Water-Related Poverty Using the Sustainable Livelihoods Framework*; Stockholm Environment Institute: Stockholm, Sweden, 2011.
34. Benebere, P.; Asante, F.; Odame Appiah, D. Hindrances to Adaptation to Water Insecurity Under Climate Variability in Peri-Urban Ghana. *Cogent Soc. Sci.* **2017**, *3*, 1394786. [\[CrossRef\]](#)
35. Pizzorni, M.; Innocenti, A.; Tollin, N. Droughts and Floods in a Changing Climate and Implications for Multi-Hazard Urban Planning: A Review. *City Environ. Interact.* **2024**, *24*, 100169. [\[CrossRef\]](#)
36. Ghana Statistical Service [GSS]. Ghana Statistical Service [GSS]. Multidimensional Poverty-Ghana. Accra, 2020. Available online: https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/Multidimensional%20Poverty%20Ghana_Report.pdf (accessed on 16 June 2023).
37. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Hydrology and Earth System Sciences Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1633–1644. [\[CrossRef\]](#)
38. Ministry of Food and Agriculture [MOFA]. Agriculture in Ghana: Facts and Figures (2019); Accra, Ghana, 2020. Available online: <https://mofa.gov.gh/site/images/pdf/2019%20AGRICULTURE%20FACT%20AND%20FIGURES.pdf> (accessed on 11 July 2024).
39. Atanga, R.A.; Tankpa, V. Climate Change, Flood Disaster Risk and Food Security Nexus in Northern Ghana. *Front. Sustain. Food Syst.* **2021**, *5*, 706721. [\[CrossRef\]](#)
40. Awuni, S.; Adarkwah, F.; Ofori, B.D.; Purwestri, R.C.; Huertas Bernal, D.C.; Hajek, M. Managing the Challenges of Climate Change Mitigation and Adaptation Strategies in Ghana. *Heliyon* **2023**, *9*, e15491. [\[CrossRef\]](#)
41. United Nations Environment Programme [UNEP]; United Nations Development Programme [UNDP]. *National Climate Change Adaptation Strategy*; UNEP: Nairobi, Kenya, 2012.
42. Ministry of Environment Science Technology and Innovation (MESTI). *Ghana: Updated Nationally Determined Contribution under the Paris Agreement (2020–2030)*; MESTI: Accra, Ghana, 2021.
43. Pienaaah, C.K.A.; Saaka, S.A.; Batung, E.; Mohammed, K.; Luginaah, I. Household Water Insecurity Experience in the Upper West Region of Ghana: Insights for Effective Water Resource Management. *PLoS Water* **2024**, *3*, e0000216. [\[CrossRef\]](#)
44. Young, S.L.; Boateng, G.O.; Jamaluddine, Z.; Miller, J.D.; Frongillo, E.A.; Neilands, T.B.; Collins, S.M.; Wutich, A.; Jepson, W.E.; Stoler, J. The Household Water InSecurity Experiences (HWISE) Scale: Development and Validation of a Household Water Insecurity Measure for Low-Income and Middle-Income Countries. *BMJ Glob. Health* **2019**, *4*, e001750. [\[CrossRef\]](#)
45. Brewis, A.; Roba, K.T.; Wutich, A.; Manning, M.; Yousuf, J. Household Water Insecurity and Psychological Distress in Eastern Ethiopia: Unfairness and Water Sharing as Undertheorized Factors. *SSM-Ment. Health* **2021**, *1*. [\[CrossRef\]](#)
46. World Meteorological Organization. The “Early Warnings for All” Initiative Is a Groundbreaking Effort to Ensure Everyone on Earth Is Protected from Hazardous Weather, Water, or Climate Events Through Life-Saving Early Warning Systems by the End of 2027. WMO. Available online: <https://public.wmo.int/en/earlywarningsforall> (accessed on 12 January 2025).

47. Jones, L.; Tanner, T. 'Subjective Resilience': Using Perceptions to Quantify Household Resilience to Climate Extremes and Disasters. *Reg. Environ. Change* **2017**, *17*, 229–243. [\[CrossRef\]](#)
48. Kangmenang, J.; Elliott, S.J. Linking Water (in)Security and Wellbeing in Low-and Middle-Income Countries. *Water Secur.* **2021**, *13*, 100089. [\[CrossRef\]](#)
49. Young, S.L.; Bethancourt, H.J.; Ritter, Z.R.; Frongillo, E.A. The Individual Water Insecurity Experiences (IWISE) Scale: Reliability, Equivalence and Validity of an Individual-Level Measure of Water Security. *BMJ Glob. Health* **2021**, *6*, e006460. [\[CrossRef\]](#)
50. Dinko, D.H.; Bahati, I. A Review of the Impact of Climate Change on Water Security and Livelihoods in Semiarid Africa: Cases From Kenya, Malawi, and Ghana. *J. Clim. Resil. Justice* **2023**, *1*, 107–118. [\[CrossRef\]](#)
51. Pienaaah, C.K.A.; Yoshida, Y.; Saaka, S.A.; Ategeeng, F.N.; Luginaah, I. Determinants of Diarrhea Prevalence among Children under 5 Years in Semi-Arid Ghana. *J. Water Sanit. Hyg. Dev.* **2024**, *14*, 583–594. [\[CrossRef\]](#)
52. Hedeker, D.; Siddiqui, O.; Hu, F.B. Random-Effects Regression Analysis of Correlated Grouped-Time Survival Data. *Stat Methods Med. Res.* **2000**, *9*, 161–179. [\[CrossRef\]](#)
53. Belay, A.; Oludhe, C.; Mirzabaev, A.; Recha, J.W.; Berhane, Z.; Osano, P.M.; Demissie, T.; Olaka, L.A.; Solomon, D. Knowledge of Climate Change and Adaptation by Smallholder Farmers: Evidence from Southern Ethiopia. *Heliyon* **2022**, *8*, e12089. [\[CrossRef\]](#)
54. Adams, E.A.; Byrns, S.; Kumwenda, S.; Quilliam, R.; Mkandawire, T.; Price, H. Water Journeys: Household Water Insecurity, Health Risks, and Embodiment in Slums and Informal Settlements. *Soc. Sci. Med.* **2022**, *313*, 115394. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Cook, J.; Kabubo-Mariara, J.; Kimuyu, P. The Short-Run Impacts of Reducing Water Collection Times on Time Use, Well-Being, and Education in Rural Kenya. *Econ. Dev. Cult. Change* **2023**, *73*, 273–306. [\[CrossRef\]](#)
56. Akanzum, J.; Pienaaah, C.K.A. Review of the Effects of Adequate Sanitary Facilities on the Participation and Performance of the Schoolgirl Child in Ghana. *ISABB J. Health Environ. Sci.* **2023**, *8*, 1–14. [\[CrossRef\]](#)
57. Apatinga, G.A.; Schuster-Wallace, C.; Dickson-Anderson, S. Exploring the Experiences of the Overburden of Water Collection Responsibility of Rural Women in Ghana. *J. Water Health* **2024**, *22*, 2015–2039. [\[CrossRef\]](#) [\[PubMed\]](#)
58. Otufale, G.A.; Coster, A.S. Impact of Water Scarcity and Drudgery of Water Collection on Women' Health in Ogun of Nigeria. *J. Hum. Ecol.* **2012**, *39*, 1–9. [\[CrossRef\]](#)
59. Venkataramanan, V.; Geere, J.A.L.; Thomae, B.; Stoler, J.; Hunter, P.R.; Young, S.L. In Pursuit of a 'Safe' Water: The Burden of Personal Injury from Water Fetching in 21 Low-Income and Middle-Income Countries. *BMJ Glob. Health* **2020**, *5*, e003328. [\[CrossRef\]](#)
60. Bagrmwin, L.; Ferrell, B.; Ziem, B.; Azie, R.A.E.; Samba, E.I.; Kuunifaa, E.; Kaburu, R.K.; Kobekyaa, F.; Dun-Dery, F.; Nukpezah, R.N. Health Resource Gaps in Primary Health Care Facilities: Community Members' Perspectives in the Era of Universal Health Coverage in Lawra Municipality, Ghana. *Adv. Public Health* **2023**, *2023*, 6650854. [\[CrossRef\]](#)
61. Dassah, E.; Aldersey, H.M.; McColl, M.A.; Davison, C. 'When I Don't Have Money to Buy the Drugs, I Just Manage.'—Exploring the Lived Experience of Persons with Physical Disabilities in Accessing Primary Health Care Services in Rural Ghana. *Soc. Sci. Med.* **2018**, *214*, 83–90. [\[CrossRef\]](#)
62. Wutich, A.; Budds, J.; Jepson, W.; Harris, L.M.; Adams, E.; Brewis, A.; Cronk, L.; Demyers, C.; Maes, K.; Marley, T.; et al. Household Water Sharing: A Review of Water Gifts, Exchanges, and Transfers across Cultures. *Wiley Interdiscip. Rev. Water* **2018**, *5*, e1309. [\[CrossRef\]](#)
63. Ahmed, F.; Shahid, M.; Cao, Y.; Qureshi, M.G.; Zia, S.; Fatima, S.; Guo, J. A Qualitative Exploration in Causes of Water Insecurity Experiences, and Gender and Nutritional Consequences in South-Punjab, Pakistan. *Int. J. Environ. Res. Public Health* **2021**, *18*, 12534. [\[CrossRef\]](#)
64. Bukachi, S.A.; Omia, D.O.; Musyoka, M.M.; Wambua, F.M.; Peter, M.N.; Korzenevica, M. Exploring Water Access in Rural Kenya: Narratives of Social Capital, Gender Inequalities and Household Water Security in Kitui County. *Water Int.* **2021**, *46*, 677–696. [\[CrossRef\]](#)
65. Ford, L.B.; Bethancourt, H.J.; Swanson, Z.S.; Nzunza, R.; Wutich, A.; Brewis, A.; Young, S.; Almeida, D.M.; Douglass, M.; Ndiema, E.K.; et al. Water Insecurity, Water Borrowing and Psychosocial Stress among Daasanach Pastoralists in Northern Kenya. *Water Int.* **2023**, *48*, 63–86. [\[CrossRef\]](#)
66. Atalay, Y.A.; Gebeyehu, N.A.; Gelaw, K.A. Household Water Treatment Practice and Associated Factors in Sub-Saharan Africa: A Systematic Review and Meta-Analysis. *Environ. Health Insights* **2024**, *18*, 1–12. [\[CrossRef\]](#)
67. Desye, B.; Tesfaye, A.H.; Berihun, G.; Sisay, T.; Daba, C.; Berhanu, L. Household Water Treatment Practice and Associated Factors in Ethiopia: A Systematic Review and Meta-Analysis. *PLoS ONE* **2023**, *18*, e0285794. [\[CrossRef\]](#) [\[PubMed\]](#)
68. Holvoet, N.; Tiholaz, D. Enabling Household Water Treatment in Rural Tanzania: Change Minds to Save Lives. Master's Dissertation, Institute of Development Policy, University of Antwerp, Antwerp, Belgium, 2020.
69. Oppong, F.B.; Boateng, D.; Senkyire, E.K.; Logo, D.D. Demographic Disparities in Unimproved Drinking Water and Sanitation in Ghana: A Nationally Representative Cross-Sectional Study. *BMJ Open* **2022**, *12*, e060595. [\[CrossRef\]](#)
70. Aguilar, F.X.; Hendrawan, D.; Cai, Z.; Roshetko, J.M.; Stallmann, J. Smallholder Farmer Resilience to Water Scarcity. *Environ. Dev. Sustain.* **2022**, *24*, 2543–2576. [\[CrossRef\]](#)

71. Pienaaah, C.K.A. Pathways to Farmer-Pastoralist-Conservationist Conflict Resolution for Sustainable Natural Resource Management along the Black Volta River Corridor in Northern Ghana. *Environ. Dev. Sustain.* **2025**. [[CrossRef](#)]
72. Kilungo, A.; Chukwuonye, G.N.; Okpanachi, V.; Hussein, M. Preparedness of Sub-Saharan African Countries to Address Climate Change and Health Impact: A Scoping Review. *medRxiv* **2024**. [[CrossRef](#)]
73. Liu, X. Climate Change and Sustainable Development in Africa: Challenges and How to Respond through Early Warning Systems. *Chin. J. Urban Environ. Stud.* **2025**, *13*, 2550005. [[CrossRef](#)]
74. Murgatroyd, A.; Charles, K.J.; Chautard, A.; Dyer, E.; Grasham, C.; Hope, R.; Hoque, S.F.; Korzenevica, M.; Alvarez-Sala, J.; Dadson, S.; et al. *Water Security for Climate Resilience Report*; University of Oxford: Oxford, UK, 2016.
75. Birachi, E.; Kagabo, D.M.; Hansen, J.; Mutua, M.; Mbugua, M.; Chiputwa, B.; Rose, A.; Solomon, D. *Rwanda Climate Services for Agriculture: Evaluation of Farmers' Awareness, Use and Impacts*; Working Paper No. 304 CGIAR Research Program on Climate Change, Agriculture and Food Security; 2020.
76. Chai, Y.; Zeng, Y. Social Capital, Institutional Change, and Adaptive Governance of the 50-Year-Old Wang Hilltop Pond Irrigation System in Guangdong, China. *Int. J. Commons* **2018**, *12*, 191–216. [[CrossRef](#)]
77. Narain, V. Building the Resilience of Periurban Communities to the Impacts of Climate Change and Urbanization. *Int. J. Disaster Resil. Built Environ.* **2021**, *12*, 115–125. [[CrossRef](#)]
78. Shoko, E.; Naidu, M. Peace-Based Informal Practices around Shared Communal Water Resources in Tyrone Village of Mhondoro-Ngezi, Zimbabwe. *Int. J. Afr. Renaiss. Stud.* **2018**, *13*, 77–91. [[CrossRef](#)]
79. Shiras, T.; Cumming, O.; Brown, J.; Muneme, B.; Nala, R.; Dreibelbis, R. Shared Sanitation Management and the Role of Social Capital: Findings from an Urban Sanitation Intervention in Maputo, Mozambique. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2222. [[CrossRef](#)] [[PubMed](#)]
80. Dongzagla, A.; Dordaa, F.; Agbenyo, F. Spatial Inequality in Safely Managed Water Access in Ghana. *J. Water Sanit. Hyg. Dev.* **2022**, *12*, 869–882. [[CrossRef](#)]
81. Corral, P.; El-Horr, J.; Goldemberg, D.; Segovia, S.; Zhao, H. *Bridging the Divide: Insights into Regional Poverty and Inclusion in Ghana 1 Executive Summary*; The World Bank: Washington, DC, USA, 2024.

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