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Spatial and multivariate assessment of access to water for sustainable agriculture intensification in semi-arid Ghana

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Abstract

Climate change, population growth, rapid urbanization, shifting dietary patterns, and economic development pose significant challenges to food security, particularly in the Global South. Addressing these challenges involves efforts aimed at sustainable agricultural intensification (SAI), especially for smallholder farmers in marginalized regions. However, knowledge gaps persist regarding smallholder farmers' access to water for SAI, particularly in arid and semi-arid agroecological zones. This study investigates smallholder farmers' access to water for SAI in the Guinea and Sudan Savannah Agroecological Zones (SSAZ) of Ghana. Data were collected from 698 smallholder farmers across 25 communities using a structured questionnaire and geospatial techniques. The analysis employed cost distance analysis, factor analysis, and multinomial-ordered logistic regression. Findings indicate that the average distance travelled to access water from a dam or a river was 11 km and 9 km, respectively. Most respondents reported low to moderate water access for SAI. Key factors influencing water access included soil type, vegetation, and the distances to dams and rivers. To improve water access, it is recommended that smallholder farmers be educated on effective soil and water conservation techniques. Additionally, both government and non-governmental organizations should focus on building community-level dams to increase water availability for sustainable agricultural intensification.

Introduction

Globally, evidence suggests that climate change, rising global population, rapid urbanisation (over 50% of the world now lives in urban areas), water scarcity, changing diets and economic growth seriously affect food security, especially in the developing south. One of the major interventions rolled out to curb issues of food insecurity is promoting sustainable agriculture

accessible and can be freely used under the terms provided in the repository.

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intensification (SAI). Sustainable agriculture intensification refers to the process of increasing agricultural production in a way that is environmentally, socially, and economically sustainable [1, 2]. This includes improved access and efficient use of water, the adoption of drought-resistant crop varieties, and the implementation of water-saving technologies among smallholder farmers because they produce about 30–40% of the global food [3].

Access to water for sustainable agriculture intensification by smallholder farmers could curb the global challenge of food insecurity caused by climate change and other factors. According to Williams et al. [4], access to water for agricultural activities is one of the major problems faced by smallholder farmers in sub-Saharan Africa. Several studies suggest that access to water is a critical factor in the sustainability and intensification of agriculture, particularly for smallholder farmers who often face challenges in securing sufficient water for their crops. However, Fujs and Kashiwase [5] opine that agriculture is the largest consumer of water globally, accounting for approximately 70% of total freshwater withdrawals, this proportion differs across space and time. Access to water in the arid and semi-arid zones for agriculture is a major problem because such areas have limited availability of water. This is exacerbated by the effect of climate change and other factors resulting in food insecurity, especially among smallholder farmers defeating the fight against poverty and hunger.

In Ghana, especially in the semi-arid areas, smallholder farmers make up a significant portion of the agricultural sector and play a vital role in the country's food security and economic development. However, these farmers often face a range of barriers to water access, including inadequate infrastructure, limited financial resources, and climate change-related challenges. There are several factors that contribute to the lack of water access for smallholder farmers in Ghana, including poor infrastructure, limited financial resources, and the lack of appropriate technologies. Additionally, climate change is exacerbating the problem, with increasing temperatures and changes in rainfall patterns leading to more frequent droughts and water shortages. However, water access for irrigation is often a major challenge for these farmers, leading to low crop yields and reduced income. Apart from the environmental factors, background characteristics such as sex, age, level of education, marital status and income of farmers are found to be significant predictors of their access to water for agriculture.

In addition, the United Nations' Intergovernmental Panel on Climate Change (IPCC) predicts an increase in water stress in Africa as a result of future climate variabilities and changes [6]. Such predictions place much pressure on smallholder farmers' ability to intensify agriculture [7]. Studies by Asamoah [8] and Atampugre et al. [9] have shown that limited water access affects farmers' intensification and productivity in the semi-arid areas of Ghana. Other studies have assessed water access for agricultural purposes from different perspectives but there is little evidence on the use of the revised Penchansky and Thomas access model. Penchansky and Thomas' access model offers a holistic measure of water access from the smallholder farmers' perspective. Thus, this study aims to assess water access for SAI among smallholder farmers in semi-arid Ghana, examining current conditions and identifying key predictors of water access. The findings offer valuable insights for policy and practice, potentially guiding efforts to improve water access and support sustainable agricultural intensification in Ghana. Moreover, this research has broader implications for understanding the complex relationship between water access and agriculture in developing countries, and how it is affecting food security, economic development, and environmental sustainability.

Theoretical perspective of access to water

Though the concept of access is complex [10], some scholars have provided theories and models to help better explain it. One of the prominent ones is the Penchansky and Thomas access model, which was propounded in 1981 [11]. They proposed this model because they realised the importance of access to health policy and services. However, there was no precise definition for access, let alone even think of a holistic means of measuring it. Some scholars synonymously use accessibility and availability to define access [10]. Therefore, Penchansky and Thomas [12] helped to deconstruct such a perspective by defining access as the fit between characteristics and expectations of resources and consumers [11, 13]. On that basis, Penchansky and Thomas proposed a taxonomic definition of access [11] encompassing all factors that influence the level of use, which disaggregates the broad and ambiguous concept of access. According to them, access can be defined as the degree of fit between a client and the system. This was based on the assumption of guaranteed availability and supply of resources. This model has been used mainly in access to health facilities [10, 11, 14] but a few are into access to water [15, 16] and food [17, 18].

The taxonomic definition of access led to the development of dimensions of access, which are availability, accessibility, accommodation, affordability and acceptability. These dimensions measure resource access based on people's satisfaction [11]. The dimensions are not easily separated since the accessibility of a resource may be closely tied to availability [11]. For instance, availability affects accommodation and acceptability through a discriminant validity result that showed that the dimensions were independent. Also, [10] confirms that these dimensions are independent yet interconnected and each is important to assess access achievement. However, she argues that there is one missing dimension: awareness. She, therefore, proposed that awareness should be added to the original five (5) dimensions making it six (6) dimensions (see Table 1 for a detailed definition of the dimensions). To contribute to the debate on the access model, the accessibility dimension sounds more synonymous with the broad concept of access; therefore, it has been revised in this study to *proximity* (Table 1) since the explanation focuses on the distance between a resource and the consumer.

In applying the access model, a major challenge to researchers is recognising the interdependence between the different dimensions of access, making it difficult to measure these dimensions [13]. Also, this model can be used when using primary data [19]. However, the access model is effective in assessing resource utilisation or policy utilisation on specific populations [16, 19].

In measuring access to water for sustainable agriculture intensification, the modified access model of [11, 12] by [10] was deemed best for this study since awareness was incorporated

Table 1. The dimensions of access.

Dimension of access	Definition	Dimension components
Proximity	Location	This refers to the location between a resource and the consumer. This dimension assesses the reasonable proximity of a resource to the consumer in terms of time and distance.
Availability	Supply and demand	This refers to the supply of resources such as water. This dimension examines the sufficiency of a resource to meet the demands of consumers and communities served.
Acceptability	Consumer perception	This refers to consumers' attitudes about a resource. This examines the acceptable response to a consumer's attitude regarding the resource and characteristics of social or cultural concerns.
Affordability	Financial and incidental costs	This refers to consumers' ability to pay for the resources needed. This dimension examines the direct costs for consumers.
Accommodation	Organisation	This refers to consumers' acceptance of using a resource. This dimension explores consumers' willingness to use a resource.
Awareness	Communication and information	This refers to the knowledge or information consumers have about a resource. This dimension explores the awareness of consumers through effective communication and information strategies.

Source: Penchansky and Thomas [11] and Saurman [10]

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into the previous dimensions (accessibility, availability, acceptability, affordability and accommodation) in measuring consumers' perspective (satisfaction) of access. Farmers can be considered as consumers in this study because they utilise water for their crops. Again, the adoption of this model is based on the premise that it views access from a broader perspective by going beyond just availability and proximity but including dimensions such as acceptability, accommodation and affordability. To the best of our knowledge, little has been identified about using the entirety of the model to assess access to water for agricultural activities. The adoption of this model situates this study in a theoretical perspective that would help understand and improve access to water for sustainable agriculture intensification.

Study area

The study was conducted in the Bolgatanga Municipality and Bongo District, located in the Upper East Region (UER) (Fig 1), which are portions of the semi-arid zones of Guinea and Sunda Agroecological Zones of Ghana. The Bolgatanga Municipality is located in the centre of the UER and covers a total area of 729 $km^{2,}$ whereas Bongo District shares boundaries with Bolgatanga to the south, covering a total area of 460 km^2. The capitals of both areas are Bolgatanga and Bongo, respectively. Merging these two areas, to the North of Bongo is Burkina Faso, Kassena-Nankana is to the West, South-East of Bolgatanga Municipality is the Bolgatanga East District and Talensi District and Nabdam District to the East (Fig 1).

According to the Ghana Statistical Service [20, 21], the two districts can be found within the Guinea Savannah Ecological Zone which has a prolonged dry season. The average annual rainfall is approximately between 700 and 1010 mm, with a peak occurring in late August or

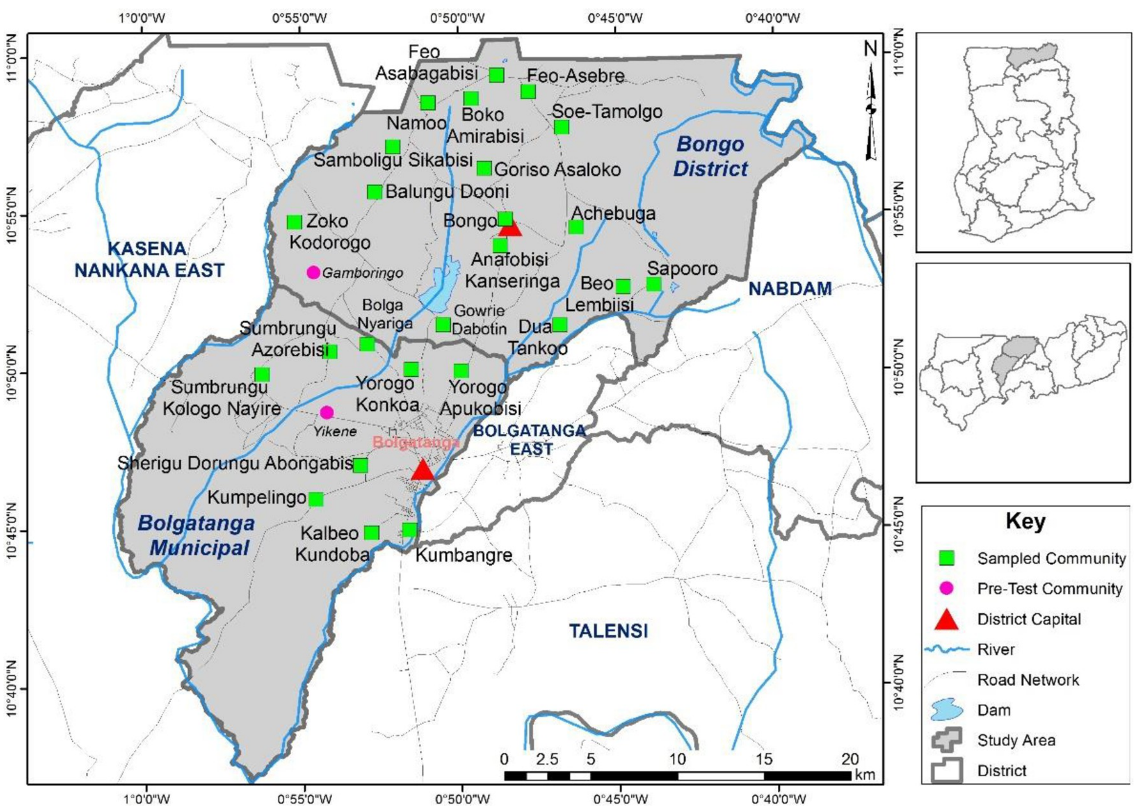

Fig 1. A map of the study area.

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early September [21, 22]. On average, temperatures range from 14 degrees Celsius at night to more than 35 degrees Celsius during the day [21]. The average evaporation is 168 cm per annum [20]. The two districts are characterised by 1% to 5% slopes (steepness). The dominant soil types in the districts are lixisol, leptosol, luvisol, gleysol, and fluvisol [23]. The two districts have similar environmental conditions and share the Vea Dam which serves as the main source of water for domestic and agricultural activities. In the dry season, rivers and streams dry up, the vegetation withers and farming activities halt.

Bolgatanga is more urbanised than Bongo because Bolgatanga is the administrative capital of the UER [21]. In addition, about 55.4% of households in Bolgatanga are residents of urban areas [21], while only 7.5% of households in Bongo live in urban areas [20]. The composition of males and females is about 48% and 52%, respectively [20, 21]. The study area is characterised by a youthful population of about 42%. The average household size is 5.5, composed of children, household heads, spouses and grandparents. In terms of marital status, about 45% of the population is married, while about 56% of the population is literate. Over 70% of the population is economically active, with 37% in Bolgatanga Municipality and 72% in Bongo District engaged in skilled agriculture. Most households are engaged in agricultural activities, especially crop farming and livestock rearing [20, 21].

Smallholder farmers have been reported to contribute substantially to promoting food security; however, they are worst hit by environmental changes (climate and landscape changes) and unequal access to resources such as water [24]. The Bongo District and Bolgatanga Municipality were selected because they are dominated by smallholder farmers, 95.7% for Bongo District and 60% for Bolgatanga Municipality [20, 21] cultivating crops such as rice, millet, sorghum, onion, groundnuts, green vegetables and tomatoes [25]. These smallholder farmers face similar challenges, such as limited water access, as FAO et al. [24] stated.

Materials and methods

Study design and sampling

This study employed the cross-sectional design to assess smallholder farmers' perspectives on SAI. The cross-sectional study design involves collecting data from a sample of individuals at a specific time. Also, the cross-sectional study design is useful for exploring the relationship between variables. The study's target population was household heads who were smallholder farmers. Using the Survey Monkey sample size calculator, 391 and 307 smallholder farmers were sampled for Bongo District and Bolgatanga Municipality, respectively. Based on a multistage sampling procedure, a simple random approach was used to select 9 and 16 communities from Bongo District and Bolgatanga Municipality, respectively. The next multistage sampling level was a systematic approach to select smallholder farmers.

Data collection and analysis

This study utilised both primary and secondary data. The primary data was gathered through the use of a questionnaire. The questionnaire had three sections concerned with access to water. The first section focused on the demographic characteristics such as sex, age and monthly income of the respondents. Also, the second section aimed at the respondents' farming characteristics, such as farming experience, farm size and land tenure. The third was based on ten questions focused on water access. This had binary questions, a Likert scale and open-ended questions. Prior to the data collection (survey), five field assistants were trained in two days on the kind of data to be gathered from the smallholder farmers. The recruitment period for this study started from 28th February 2021 to 19th March 2021. Using a survey coupled with a computer-assisted personal interview (KoBo Toolbox), a 100% response rate was achieved. GPS coordinates of smallholder farmsteads were captured for the spatial analysis on distance to water sources.

For the secondary data, the study used GIS and remote sensing tools and techniques to estimate ecological variables such as soil type, slope, normalised difference vegetation (NDVI), land surface temperature (LST) and land cover classification to assess their effect on access to water for agriculture activities. Data such as slope, normalised difference vegetation (NDVI), land surface temperature (LST) and land cover classification had to be pre-processed using ASTER Digital Elevation Model (DEM) and 2019 Multispectral Landsat data for both study areas. Using ASTER DEM data, the slope data was estimated in ArcGIS Pro version 2.8 using the extract slope tool. The NDVI was estimated using the 2019 Multispectral Landsat data obtained from the United States Geological Survey (USGS) website. Using ENVI 5.3, the land surface temperature data was estimated from the thermal bands in the 2019 Multispectral Landsat data. Further, the Multispectral Landsat data was classified using the supervised classification algorithm in ArcGIS Pro version 2.8. The supervised classification had seven land cover classes (barren, water, developed, forest, shrubland, cultivated and wetland) informed by the Anderson Classification Scheme. The soil type was extracted from the soil data obtained from the Council for Scientific and Industrial Research—Asokwa, Ghana.

In the preparation of the data for the spatial analysis, the GPS coordinates of the farmsteads were overlaid on the soil type, slope, NDVI and LST to extract the various datasets. The extraction of the land cover types began with running a kilometer buffer around each GPS coordinate. The buffer was used to extract the land cover types which were later estimated in proportions per GPS coordinates. The purpose of this estimation was that the type of land cover around a farmstead influences its access to water. These estimated datasets were later merged with the survey data for the various analyses.

The spatial analysis began with the cost distance analysis to examine water access to dams and rivers from respondents' farmsteads. This analysis was carried out using the DEM, mapped-out dams, and delineated rivers in ArcGIS Pro version 2.8. The cost distance analysis of dams and rivers for each district was run separately and used to generate maps. Also, the coordinates of the respondents were overlaid on the cost distance results to extract distance values covered by respondents to access those water sources. These distance values were exported and analysed using IBM SPSS version 23. The basic statistical analyses conducted were mean, standard deviation, maximum, and minimum distance for each district per water source. T-test analysis was conducted to test for statistical differences in the distance travelled to access the water sources between the two districts. The purpose was to give a true picture of the distance travelled by respondents to access water from a dam or river.

The non-spatial analysis began with frequency distribution and multiple response analysis on water sources used by respondents for agricultural activities, especially crop farming. The percentage of agreement was conducted to obtain a general view of respondents to the six items used for measuring water access. The five-point Likert scale of the six items was recoded into 0 where strongly disagree, disagree and neutral and 1 where agree and strongly agree. A summation across all six items was estimated and categorised as 0 = no access, 1–5 = partial access and 6 = complete access. This analysis gave equal weights to the item, which may not give a true reflection. This led to conducting an Exploratory Factor Analysis (EFA) using the principal component extraction method. Before the factor analysis, the internal consistency or reliability of the data was examined using Cronbach's alpha tool. The Cronbach's alpha value was 0.85, higher than the recommended 0.7 [26]. This also implied that the data was suitable for the EFA analysis. An Exploratory Factor Analysis (EFA) was conducted to test if the items were unidimensional. The EFA analysis showed that the items measured a single dimension, thus unidimensional. This meant the items measured the exact component of water access. An index was created from the factor scores where the values ranged between 0 and 1. With reference to [27], the index was categorised based on terciles to represent low, moderate and high water access. All these analyses were conducted using the IBM SPSS version 23.

The study used multinomial-ordered logistic regression to examine the predictors of smallholder farmers' access to water for sustainable agriculture intensification using demographic and farming characteristics and ecological indicators. The dependent variable was water access (low, moderate and high), whereas the independent variables were demographic and farming characteristics and ecological indicators. The multivariate analysis was conducted using a multinomial-ordered logistic regression tool in Stata version 16. The multivariate analysis was conducted using a stepwise approach to only retain statistically significant variables.

The equation of the multinomial-ordered logistic regression is as follows:

$$logit(P(Y \leq j)) = \beta 0, j + \beta 1\ X1 + \beta 2\ X2 + \ldots + \beta p\ Xp$$

Where:

Y = the ordered categorical outcome variable.

j = the current category, with j = 1, 2,. . ., k-1, where k is the total number of categories.

$P(Y \leq j)$ = the probability that Y is less than or equal to j.

β0, β1, β2,. . ., βp are the coefficients associated with the predictor variables X1, X2,. . ., Xp for the j-th category.

logit() = the log-odds function.

Ethics statement

Ethical clearance was obtained from the Institutional Review Board (IRB) of the University of Cape Coast, reference number **UCCIRB/CHLS/2020/45**. The ethical review process was conducted to rigorously evaluate and ensure that the proposed fieldwork adhered to ethical standards and guidelines. The review aimed to determine if the fieldwork could potentially have any harmful implications for both human participants and the environment. The IRB assessed various aspects of the research proposal, including:

- **Potential Risks to Human Participants:** Evaluating the likelihood of physical, psychological, or emotional harm to individuals involved in the study.
- **Environmental Impact:** Assessing the potential for the fieldwork to negatively affect the surrounding environment, including flora, fauna, and ecosystems.
- **Informed Consent:** Ensuring that participants would be fully informed about the nature of the research, their role in the study, potential risks, and their rights, including the right to withdraw at any time without penalty.
- **Confidentiality:** Reviewing measures to protect the privacy and confidentiality of participants' data.
- **Ethical Conduct:** Ensuring that the research would be conducted with integrity, transparency, and respect for all participants and stakeholders.

The clearance granted by the IRB signifies that the research proposal met all ethical requirements, thereby allowing the fieldwork to proceed under ethically sound conditions. In the course of the data collection, respondents were informed about the purpose of the study and their consents were obtained through signing or thumbprinting. Thus, all respondents for this study consented willingly to participate in this study.

Results

Socio-demographic and farming characteristics of respondents

Descriptive analysis (Table 2) of the socio-demographic data revealed that almost two-thirds (64.45%) of the respondents in the Bongo District and seven in ten (70.68%) in the Bolgatanga Municipality were males. In addition, most of the respondents (85.4%) were married, with

Table 2. Demographic characteristics of respondents.

Variable	Bongo (N = 391)		Bolgatanga (N = 307)		Total (N = 698)		X^2 (p-value)
	Freq.	%	Freq.	%	Freq.	%	
Sex							
Female	139	35.55	90	29.32	229	32.81	3.032 (0.082)
Male	252	64.45	217	70.68	469	67.19	
Age							
18–27	29	7.42	22	7.17	51	7.31	5. 178 (0.270)
28–37	65	16.62	67	21.82	132	18.91	
38–47	124	31.71	92	29.97	216	30.95	
48–57	91	23.27	77	25.08	168	24.07	
58+	82	20.97	49	15.96	131	18.77	
Household size							
1–3	45	11.51	27	8.79	72	10.32	2.788 (0.426)
4–6	188	48.08	162	52.77	350	50.14	
7–9	109	27.88	76	24.76	185	26.50	
10+	49	12.53	42	13.68	91	13.04	
Level of education							
No formal edu.	217	55.50	167	54.40	384	55.01	0.771 (0.942)
Basic school	87	22.25	66	21.50	153	21.92	
JHS/JSS	40	10.23	35	11.40	75	10.74	
SHS/Voc	32	8.18	24	7.82	56	8.02	
Tertiary	15	3.84	15	4.89	30	4.30	
Monthly income							
GHC 0–200	197	50.38	127	41.37	324	46.42	10.849 (0.054)
GHC 201–400	112	28.64	101	32.90	213	30.52	
GHC 401–600	49	12.53	44	14.33	93	13.32	
GHC 601–800	10	2.56	19	6.19	29	4.15	
GHC 801–1000	12	3.07	6	1.95	18	2.58	
GHC 1001+	11	2.81	10	3.26	21	3.01	
Marital Status							
Never married (Single)	31	7.93	17	5.54	48	6.88	7.336 (0.197)
Married	329	84.14	267	86.97	596	85.39	
Widowed	13	3.32	17	5.54	30	4.30	
Divorced	9	2.30	3	0.98	12	1.72	
Separated	8	2.05	3	0.98	11	1.58	
Co-Habitation	1	0.26	0	0.00	1	0.14	
Ethnicity							
Dagaaba	1	0.26	0	0.00	1	0.14	4.118 (0.390)
Gruni	389	99.49	305	99.35	694	99.43	
Kasena	0	0.00	1	0.33	1	0.14	
Kusaal	0	0.00	1	0.33	1	0.14	
Nab	1	0.26	0	0.00	1	0.14	

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Bolgatanga Municipality recording a higher percentage (86.97%) than the Bongo District (84.14%). In addition, most of the respondents belonged to the Gruni (99.4%) ethnic group in both districts. Again, most respondents were between the ages of 38 and 47 years (30.9%), while the least was found between 18 and 27 years (7.3%) in both districts. Almost half (46.4%) of the respondents earned between GHC 0–200, whereas only 3% earned GHC 1001+ per month. The income distribution within the two districts takes the pyramid structure where there is a broad base of those who earn less compared to those at the top.

Also, most respondents had a household size of 4–6 (50.1%), with very little variation between Bongo District and Bolgatanga Municipality, 48% and 50%, respectively. The lowest household sizes in both districts were between 1–3. Finally, it was found that more than half (55%) of the respondents had no formal education, while about 4.3% of the respondents had tertiary education. Specifically, it was found that a little above half of the respondents in both Bongo District and Bolgatanga Municipality had no formal education. Similarly, both districts recorded their lowest percentage of educational status being tertiary. The difference observed was that the Bolgatanga Municipality (4.30%) had a relatively higher percentage of respondents with tertiary education compared to the Bongo District (3.84%).

Sources of water for SAI

The results in Table 3 reveal that most smallholder farmers rely solely on rainfall for their SAI-related water needs in both districts. However, there is a notable minority who utilize additional water sources. Specifically, in Bolgatanga, 21% of smallholders reported using other water sources, such as small dams, streams, and boreholes. In Bongo, this figure is lower, with only 6.4% of smallholders using these alternative sources.

This situation could be attributed to several factors. Limited availability of water sources is a significant barrier, as there may not be enough small dams, streams, or boreholes accessible to all farmers. Additionally, biophysical barriers, such as the geographical distribution of water resources and the variability in water table, may further restrict access to these alternative water sources. Consequently, the reliance on rainfall remains predominant among smallholder farmers in both districts, highlighting the challenges they face in securing consistent and reliable water supplies for sustainable agricultural intensification activities.

Despite the relatively low number of smallholder farmers utilizing additional water sources for SAI in both districts, the chi-square test ($X^2 = 33.443$, p-value = 0.000) revealed a statistically significant difference in water access during the dry season between Bolgatanga Municipality and Bongo District. To further understand this difference, an analysis was conducted on the types of water sources used by the 90 smallholder farmers who use additional water sources for their agricultural activities. The results showed that the majority of these farmers in both districts rely on surface water. Groundwater sources, such as boreholes and wells, were identified as the second most commonly used sources. Moreover, the analysis highlighted a

Table 3. Utilisation of water sources aside from rainwater.

District		Frequency	Percent	X^2 (p-value)
Bolgatanga	No	242	78.80	
	Yes	65	21.20	
	Total	307	100.00	33.443 (<0.001)
Bongo	No	366	93.60	
	Yes	25	6.40	
	Total	391	100.0	

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noteworthy disparity between the two districts: a higher proportion of smallholder farmers in the Bongo District (28.6%) use groundwater compared to those in Bolgatanga Municipality (23.9%). Specifically, 4.7% more farmers in Bongo District rely on groundwater for their agricultural needs. This distinction underscores the varying levels of access to different types of water resources between the two districts, particularly during the dry season.

Proximity analysis of access to water for SAI

The proximity analysis, specifically cost distance analysis in ArcGIS Pro version 2.8, was used to assess smallholder farmers' access to surface water for SAI. By incorporating factors like topography, the analysis provides a more realistic representation of the challenges faced by farmers in accessing water resources. The Jenks natural breaks classification method was deemed appropriate for categorizing the results as it effectively highlights the inherent groupings within the data. This enables a clear visualization of the spatial distribution of access to water, facilitating the identification of areas with better and poorer access.

Results from the cost distance analysis as presented in Fig 2 revealed that the average distance from the farmstead to access dam water in Bongo District and Bolgatanga Municipality was 18.6–28.1km and 22.3–35.7km, respectively. The results show that smallholder farmers in Bongo District have a relatively shorter distance to access dam water for farming than those in Bolgatanga Municipality. Narrowing down to Bongo District, the shortest distance from the farmstead to access dam water was 0–10.1km, whereas the farthest distance to be covered was 40–61.4km. Regarding Bolgatanga Municipality, the results revealed that the shortest distance

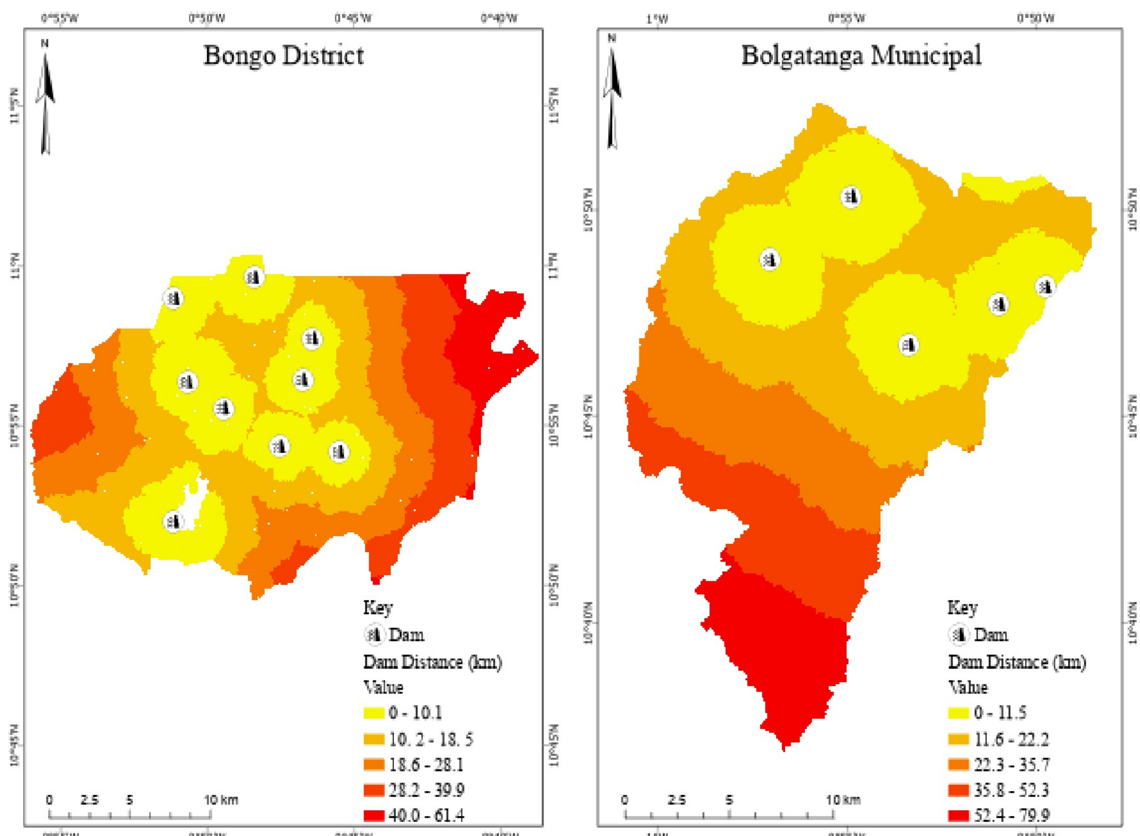

Fig 2. Cost distance analysis of dams.

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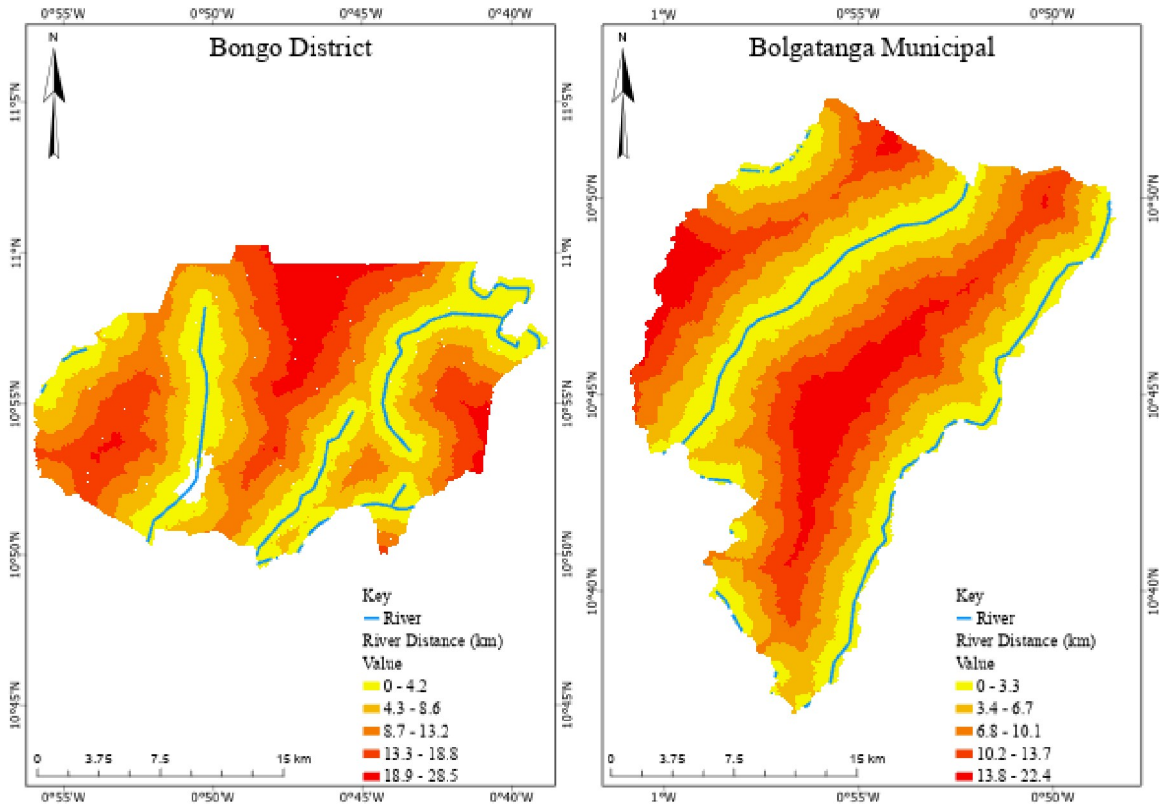

Fig 3. Cost distance analysis of river.

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to be covered by smallholder farmers was 0–11.5km, while the farthest distance to be covered was 52.5–79.9km. The estimated cost distance analysis implies that the closer dams are to smallholder farmers, the shorter the travel distance to access water for agricultural activities. The results indicate a significant disparity in access to dam water between Bongo District and Bolgatanga Municipality, with farmers in the former enjoying relatively shorter distances to water sources. The analysis also highlights intra-district variations, with some farmers in both districts facing considerably longer travel distances.

In addition to using dams, some smallholder farmers rely on rivers as their primary water source for agricultural activities. To evaluate the distances these farmers, travel to access river water, a cost distance analysis was performed. The results, illustrated in Fig 3, indicate that smallholder farmers in Bongo District travel an average distance of 8.7 to 13.2 kilometers to access river water, whereas those in Bolgatanga Municipality travel slightly shorter distances, averaging between 6.8 and 10.1 kilometers. Further examination of the data reveals that the shortest distance travelled by farmers to access river water in Bongo District ranges from 0 to 4.2 kilometers, while in Bolgatanga Municipality, this distance is slightly shorter, ranging from 0 to 3.3 kilometers. On the other hand, the farthest distances recorded for accessing river water are significantly longer, with Bongo District farmers travelling between 18.9 and 28.5 kilometers, compared to 13.8 to 22.4 kilometers in Bolgatanga Municipality. These findings suggest that smallholder farmers in Bolgatanga Municipality generally have better access to river water compared to those in Bongo District, as they travel shorter distances on average. This disparity in access to river water can have important implications for agricultural productivity and sustainability.

Table 4. Descriptive statistics of distance travelled by farmers to access dams and rivers.

Distance (km)	Bolgatanga Municipality		Bongo District	
	Dam	River	Dam	River
No.	307	307	391	391
Mean	9.39	7.68	12.64	10.01
Median	9.31	8.53	8.85	11.62
Std. Deviation	4.42	4.05	8.13	4.33
Minimum	0.12	0.92	1.70	0.83
Maximum	23.55	14.95	33.36	24.64

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The cost distance analysis in Fig 3 estimates distances to facilities throughout the study area without focusing on the settled areas. The above analysis estimated the proximity to the mapped-out water sources (dams and rivers) throughout the study areas. However, it does not give the exact distance the smallholder farmers travel from their farmstead to access water for agricultural activities. Therefore, the respondents' farmstead coordinates were used to obtain the estimated distances to both dams and rivers. The estimated distance values were extracted to the coordinates of the smallholder farmers and the basic statistics was computed in ArcGIS Pro version 2.8. The basic statistics computed covered the mean, median, standard deviation, minimum, and maximum distance (See Table 4).

The average distance travelled by respondents to access river water in both districts was shorter compared to accessing dam water. In Bolgatanga Municipality, the average distance to rivers was 7.68 km, while the distance to dams it was 9.39 km. In Bongo District, the average distance to rivers was 10.01 km, while the distance to dams it was 12.64 km. There was considerable variation in the distances travelled by respondents, as indicated by the standard deviation values. The standard deviation for distances to dams was higher in Bongo District (8.13 km) compared to Bolgatanga Municipality (4.42 km). For rivers, the standard deviation was also higher in Bongo District (4.33 km) compared to Bolgatanga Municipality (4.05 km). The shortest distance to access dam water in Bolgatanga Municipality was 0.12 km, whereas in Bongo District it was 1.7 km. The farthest distances were 23.55 km in Bolgatanga Municipality and 33.36 km in Bongo District. For river water, the shortest distance in Bolgatanga Municipality was 0.92 km, compared to 0.83 km in Bongo District. The farthest distances were 14.95 km in Bolgatanga Municipality and 24.64 km in Bongo District. For both dam and river water access, the t-test results indicate statistically significant differences in distances travelled between the two districts (i.e., for dam water: $t = -6.267$; p-value = 0.000 and for river water: $t = -7.224$; p-value = 0.000). The geographic distribution of respondents influences the variation in travel distances. Areas with better water access infrastructure show shorter average distances. These significant differences underscore the need for targeted interventions to address the disparities in water access between the districts.

Application of the Penchansky and Thomas model of access to water for SAI

Penchansky and Thomas' access model offers a holistic measure of the concept of access. This model was adopted for this study to obtain a true measure of access to water for SAI. From Table 5, most of the respondents in Bolgatanga Municipality disagreed with the indicators or items used to measure water access. In detail, the item "The water sources are highly affordable" (47.23%) was highly disagreed with. However, about 30% of the respondents agreed to receive effective communication on using water resources for farming. Similar results were

Table 5. Descriptive statistics of the indicators of water access.

Item	SD		D		N		A		SA	
	N	%	N	%	N	%	N	%	N	%
Bolgatanga Municipality										
There is enough water for farming	62	20.20	136	44.30	53	17.26	48	15.64	8	2.61
The distance to water for farming is short	58	18.89	142	46.25	58	18.89	43	14.01	6	1.95
I like the water resource used for farming	52	16.94	134	43.65	62	20.20	51	16.61	8	2.61
The water sources are highly affordable	54	17.59	145	47.23	67	21.82	33	10.75	8	2.61
I am willing to use the available water for farming	35	11.40	98	31.92	76	24.76	92	29.97	6	1.95
There is effective communication on the use of water resources for farming	34	11.07	156	50.81	84	27.36	27	8.79	6	1.95
Bongo District										
There is enough water for farming	130	33.25	148	37.85	78	19.95	23	5.88	12	3.07
The distance to water for farming is short	134	34.27	161	41.18	67	17.14	13	3.32	16	4.09
I like the water resource used for farming	103	26.34	160	40.92	94	24.04	22	5.63	12	3.07
The water sources are highly affordable	110	28.13	164	41.94	85	21.74	19	4.86	13	3.32
I am willing to use the available water for farming	75	19.18	102	26.09	108	27.62	85	21.74	21	5.37
There is effective communication on the use of water resources for farming	79	20.20	170	43.48	111	28.39	21	5.37	10	2.56

Scale: Strongly disagree (SD); Disagree (D); Neutral (N); Agree (A); Strongly agree (SA)

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observed in Bongo District, where most respondents disagreed with the items used in measuring water access. For instance, the item "The water sources are highly affordable" (41.94%) had the highest percentage of disagreement. Also, it was found that about 22% of the respondents agreed to be willing to use the available water farming. Between the two districts, it was observed that many of the Bongo District respondents strongly disagreed with the items compared to those in Bolgatanga Municipality. Focusing on the objective of this chapter, the data was further transformed to observe the pattern of limited access to water for smallholder farmers.

The study further used exploratory factor analysis (EFA) to examine the dimensions' convergence and/or divergence for measuring water access for SAI (Table 6). The exploratory factor analysis (EFA) results provide a comprehensive understanding of the dimensions influencing smallholder farmers' access to water for sustainable agricultural intensification (SAI). The use of EFA to examine the convergence and/or divergence of these dimensions offers significant insights into water access measurement and its implications. The Cronbach's alpha value of 0.85 indicates high internal consistency among the dimensions used to measure water access, suggesting that the indicators are reliable and accurately reflect the construct

Table 6. Factor analysis of smallholder farmers' perspective on water access for SAI.

Factors	EFA loadings	%	Eigenvalue	α
Water Access		**58.70**	**3.52**	**0.85**
I like the water resources (WA3)	0.85			
Enough water (WA1)	0.8			
Affordable water (WA4)	0.79			
Short distance (WA2)	0.75			
Effective communication (WA6)	0.75			
Willingness to use (WA5)	0.65			

KMO = 0.89, Bartlett's Test of Sphericity = 1651.62, df = 15, p-value = 0.000, α = Cronbach's alpha, % = percentage of variance explained

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Table 7. Descriptive statistics of water access terciles for SAI.

Category	Bolgatanga Municipality		Bongo District		X^2 (p-value)
	Freq	%	Freq	%	
Low access	54	17.6	178	45.5	
Moderate access	129	42.0	104	26.6	60.694 (<0.001)
High access	124	40.4	109	27.9	
Total	307	100	391	100	

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being measured. The Kaiser-Meyer-Olkin (KMO) value of 0.89 and the statistically significant Bartlett's Test of Sphericity (X2 = 1651.62, df = 15, p-value = <0.001) confirm the adequacy of the data for factor analysis (Table 6). This high KMO value and significant Bartlett's test indicate that the sample size is sufficient, and the variables are correlated enough for EFA. The factor loadings ranged from 0.65 to 0.85, indicating that all indicators had good loadings and contributed significantly to the measurement of water access. The extracted component explained 58.70% of the variance, showing that a substantial proportion of the variability in water access is captured by these factors. Using the index created from the factor scores, water access was categorized into low, moderate, and high access based on terciles.

The categorization revealed significant disparities in water access between Bolgatanga Municipality and Bongo District, with Bolgatanga having higher proportions of moderate and high access compared to Bongo (Table 7). The results in Table 7 show that most of the smallholder farmers in Bolgatanga Municipality had moderate (42%) and high (40.4%) access to water while in Bongo District, most of the smallholder farmers had low (45.5%) and moderate (26.6%) access to water. A chi-square test (X^2 = 60.694, p-value = 0.000) shows a statistically significant difference in water access between Bolgatanga Municipality and Bongo District respondents at a 99% confidence level.

Predictors of smallholder farmers' access to water for SAI

To determine the predictors of smallholder farmers' access to water, the multinomial ordered logistic regression was adopted since the dependent variable (water access) was categorised into three levels and in an ordered form. This dependent variable was then regressed against socio-demographic variables such as sex, age, educational level, land tenure and income, farming characteristics such as the number of farmlands, farm size and farming experience and ecological indicators such as cost distance to river and dam, the proportion of landscape classes and Normalised Difference Vegetation Index (NDVI). Prior to the regression analysis, a collinearity test was conducted using a pairwise correlation analysis among the independent variables. The results showed that none of the independent variables correlated to a coefficient greater than 0.7, which was lower than the recommended <0.8 [28, 29].

The study adopted the stepwise approach in identifying the statistically significant predictors of smallholder farmers' access to water for agricultural activities across both districts. The regression parameters for Bolgatanga Municipality suggest that the results explained about 55% of the data with 72.84 Wald chi-square and was statistically significant (Table 8). Similarly, the regression parameters for Bongo Districts indicate that the analysis explained about 51% of the data with 203.55 Wald chi-square and was statistically significant (Table 8).

Table 8 presents the ordered multinomial logistic regression analysis of water access among smallholder farmers in both Bolgatanga Municipality and Bongo District. It was found that the monthly income of respondents in the Bongo District significantly predicts their water access. Specifically, respondents who earned GHC 401–600 [OR = 3.678, CI = 1.328, 10.189] were

Table 8. Multinomial ordered logistic regression on smallholder farmers' access to water.

Independent variable	Bolgatanga Municipality	Bongo District
	OR [95% CI]	OR [95% CI]
Monthly Income (Ref. Bongo GHC 0–200)		
GHC 201–400	1.110 [0.570, 2.160]	1.149 [0.606, 2.180]
GHC 401–600	0.759 [0.343, 1.681]	3.678* [1.328, 10.189]
GHC 601+	1.137 [0.309, 4.185]	1.531 [0.494, 4.745]
Educational Level (Ref. No formal education)		
Basic	0.613 [0.293, 1.280]	0.395* [0.190, 0.824]
JHS	0.435 [0.159, 1.189]	0.439 [0.170, 1.135]
SHS/Voc.	0.448 [0.158, 1.271]	1.065 [0.389, 2.919]
Tertiary	0.228* [0.056, 0.993]	1.665 [0.312, 8.897]
Soil type (Ref. Lixisols)		
Fluvisols	2.774 [0.098, 78.383]	2.132 [0.677, 6.718]
Leptosols	0.021** [0.048, 0.806]	0.005** [0.002, 0.019]
Slope (Ref. Gentle)		
Moderate	2.106 [0.8.33, 5.322]	0.238** [0.115, 0.493]
Steep	0.196* [0.052, 0.996]	0.201** [0.066, 0.614]
NDVI (Ref. No vegetation)		
Sparse vegetation	0.145** [0.037, 0.570]	0.189** [0.059, 0.605]
Dense vegetation	0.190* [0.038 0.953]	1.359 [0.294, 6.280]
Cost distance to Dam (Ref. Near)		
Far	0.120** [0.042, 0.345]	1.655 [0.626, 4.376]
Farthest	0.018** [0.003, 0.112]	0.598 [0.196, 1.822]
Cost distance to River (Ref. Near)		
Far	0.154** [0.047, 0.511]	3.625** [1.394, 9.424]
Farthest	0.108** [0.025, 0.474]	0.436 [0.112, 1.697]
Land surface temperature (Ref. Low)		
Moderate	189.864** [27.752, 1298.930]	23.713** [4.532, 124.073]
High	98.068** [15.232, 631.370]	18.457** [2.952, 115.381]
Cultivated (Ref. Low)		
Moderate	4.627** [1.531, 14.990]	1.135 [0.414, 3.110]
High	2.870* [1.146, 7.190]	2.020 [0.854, 4.780]
Forest (Ref. Low)		
Moderate	0.071** [0.022, 0.229]	0.123** [0.0409, 0.368]
High	0.911 [0.355, 2.339]	1.172 [0.365, 3.780]
Water (Ref. Low)		
Moderate	0.954 [0.359, 2.536]	3.449** [1.365, 8.713]
High	4.781* [1.397, 16.359]	2.855* [1.181, 6.899]
Wetland (Ref. Low)		
Moderate	12.349** [3.433, 44.426]	3.064* [1.286, 7.301]
High	22.341** [4.871, 102.486]	2.183 [0.660, 7.225]
Cut (Low)	-4.166 [-7.802, -0.530]	-1.044 [-3.721, 1.633]
Cut (Moderate)	0.988 [-2.323, 4.299]	2.051 [-0.613, 4.715]
N	307	391
Wald chi^2	75.33	211.85
Prob > chi^2	0.000	0.000

(*Continued*)

Table 8. (Continued)

Independent variable	Bolgatanga Municipality	Bongo District
	OR [95% CI]	OR [95% CI]
R^2	0.555	0.515

** = p<0.001

* = p<0.05, OR = Odds Ration, CI = Confidence Interval

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more likely to have high water access for agricultural purposes than those who earned GHC 0–200. However, monthly income was not a statistically significant predictor of water access in the Bolgatanga Municipality and this could be due to the relatively shorter distance to access water.

Smallholder farmers' educational level significantly predicted water access in the Bongo District. The results revealed that respondents with basic education [OR = 0.395, CI = 0.190, 0.824] had less likelihood of having high access to water than those without formal education. Although the higher levels of education were not statistically significant, it was found that respondents with higher education had more likelihood of having higher water access compared to those with no formal education.

In terms of soil type, it was found that respondents in both districts whose farms had leptosols had less likelihood of having high water access compared to those whose farms had lixisols. In addition, the results in Table 8 show that respondents who farmed on moderate [OR = 0.238, CI = 0.115, 0.493] and steep [OR = 0.201, CI = 0.002, 0.019] slopes had less likelihood of having high water access compared to those on gentle slopes [OR = 0.196, CI = 0.052, 0.996] in Bongo District. Similarly, respondents who farm on steep slopes in Bolgatanga Municipality were less likely to have high water access than those on gentle slopes. With regards to vegetation, the results in Table 8 showed that respondents whose farms are in sparse vegetation [OR = 0.145, CI = 0.037, 0.570] and dense vegetation [OR = 0.190, CI = 0.038, 0.953] have less likelihood of having high access to water compared to those in areas with no vegetation in Bolgatanga Municipality. Similarly, respondents in Bongo Districts whose farms were in sparsely vegetated areas [OR = 0.189, CI = 0.059, 0.605] were less likely to have high water access than those in areas with no vegetation.

Considering the cost distance to a dam, the results show that respondents in Bolgatanga Municipality whose farms were far [OR = 0.120, CI = 0.042, 0.345] and farthest [OR = 0.018, CI = 0.003, 0.112] from a dam have less likelihood to have high water access compared to those who are near a dam. Also, it was found that respondents in Bolgatanga Municipality whose farms were far [OR = 0.154, CI = 0.047, 0.511] and farthest [OR = 0.108, CI = 0.025, 0.474] from a river had less likelihood of having high water access compared to those who are near a river. In Bongo District, it was found that respondents whose farms were far [OR = 3.625, CI = 1.394, 9.424] from a river had high water access compared to those who were near a river. In addition, it was found that respondents in areas with moderate and high land surface temperature have more likelihood of having high water access compared to those in areas with low land surface temperature in both districts.

With regards to the proportion of landscape class, it was found that respondents in areas with moderate [OR = 4.627, CI = 1.531, 14.990] and high [OR = 2.870, CI = 1.146, 7.190] proportions of cultivated lands have more likelihood to have high water access compared to those in areas with a low proportion of cultivated lands in Bolgatanga Municipality. Also, respondents in areas with a moderate proportion of forest in both districts have less likelihood of high water access than those with low forest proportions. Furthermore, respondents in Bongo

District with moderate [OR = 3.449, CI = 1.365, 8.713] and high [OR = 2.855, CI = 1.181, 6.899] proportions of water body have more likelihood to have high water access compared to those in areas with a low proportion of water body. Similar to Bolgatanga Municipality, it was found that areas with high [OR = 4.781, CI = 1.397, 16.359] proportions of water bodies are more likely to have high water access than those with a low proportion of water bodies.

Finally, it was found that respondents in areas with moderate [OR = 12.349, CI = 3.433, 44.426] and high [OR = 22.341, CI = 4.871, 102.486] proportions of wetlands have more likelihood of having high water access compared to those in areas with a low proportion of wetlands in Bolgatanga Municipality. Similarly, respondents in areas with moderate [OR = 3.064, CI = 1.286, 7.301] proportions of wetlands are more likely to have high water access compared to those with a low proportion of wetlands in Bongo District.

Discussion

The study sought to examine smallholder farmers' access to water for SAI in the Guinea and Sudan Savannah Agroecological Zones (SSAZ) of Ghana. The implications of the results from the study are numerous. Shorter distances to water sources enhance agricultural productivity by reducing the time and effort required for water collection considering that proximity to water sources significantly improves crop yields and farming efficiency [30]. The longer the travel distances, the higher the strain on available resources, which tends to reduce the time available for other farming activities [31]. The disparity in distances travelled suggests a need for improved water infrastructure, particularly in Bongo District. Building strategic water infrastructure like more dams and enhancing river access points can reduce travel distances and support smallholder farmers [32]. Integrating spatial analysis tools, such as the cost distance analysis used in this study, helps identify critical areas needing infrastructure development for SAI [33]. Access to water sources is closely linked to socioeconomic conditions [34]. That is, improved water access can lead to enhanced agricultural productivity, better food security, and improved livelihoods for smallholder farmers. The cost distance analysis reveals important insights into the distance smallholder farmers travel to access water sources for SAI activities. The findings highlight disparities between Bolgatanga Municipality and Bongo District, with significant implications for agricultural productivity, infrastructure development, and spatial planning. Addressing these disparities through targeted policies and improved water infrastructure can support sustainable agricultural intensification and enhance the livelihoods of smallholder farmers.

The exploratory factor analysis of water access for SAI provides additional valuable insights into the dimensions influencing smallholder farmers' access to water. The high internal consistency and suitability of the data for factor analysis validate the reliability of the indicators used. Considering access to water in equal weights may not offer the true measurement; therefore, applying weights offers robust results. The findings highlight significant disparities in water access between Bolgatanga Municipality and Bongo District, underscoring the need for targeted infrastructure development and resource allocation. Policymakers may need to consider the specific needs of different regions when allocating resources for improvement in water access. The use of weighted measures, as indicated by the factor scores, provides a more accurate assessment of water access and can guide more effective interventions [35]. Improved water access, particularly in areas with low and moderate access, can enhance farming practices and increase agricultural productivity considering that reliable water access is crucial for improving crop yields and ensuring food security among smallholder farmers. Farmers with better access to water are more likely to adopt sustainable agricultural practices, as they have the necessary resources to implement and maintain these practices. This is relevant because

Rockström et al. [36] have already highlighted the link between water access and the adoption of sustainable land and water management practices.

Semi-arid areas in Ghana have a single rainfall period in a year and this affects access to water for SAI. Evidence from the results of this study showed that most of the smallholder farmers do not farm during the dry season due to limited access to water. A few admitted to using other sources of water such as surface water (dam and river) during the dry season. Considering that surface water (rivers and dams) is the most used water source in the dry season, it is worth mentioning that the major rivers within the study area are the White and Red Volta and Sissili [21] while the major dam used for SAI is the Vea Dam. As surface water was the most dominant water source used by smallholder farmers, this corroborates with the findings by the Ghana Statistical Service report [20, 21], where rivers (streams) and dams were the main water sources for domestic and agricultural activities in the Upper East Region. On the importance of the dams during the dry season, government initiatives such as One Village One Dam (1V1D) and NGO assistance have supported the construction of community dams to serve agricultural and domestic activities such as washing, bathing, and cooking. The One Village One Dam (1V1D) policy is a government initiative to construct one dam in every community, especially in northern Ghana. However, during the field visits, the water level in some of the dams was very low while some of the dams had dried up during the long dry season (Fig 4). It was not just the dams that get dried up during the dry season but some of the rivers and their tributaries also get dried up. Similarly, it was observed (Fig 4) that while the rivers and their tributaries were dried up, some farmers dug the riverbed and used a water pump to transport the water to their farmlands. This finding supports the study by Asamoah [8], who found that beds of dried-up rivers are dug to get water for irrigation.

In considering smallholder farmers' travel distance to access water from dams and rivers for SAI, it was found to be relatively far. The findings of Atampugre et al. [9] and Evans et al. [37] show that the distance from farmlands to water sources found in this study is relatively far. According to Atampugre et al. [9], farms between 0-500m away from water sources are more likely to access water for agriculture easily. In addition, Evans et al. [37] stated that some farmers have invested in buying motor pumps to access water for agricultural activities. This is evident in Fig 2. However, the distance from the farmlands to the water source hinders access to water for farming.

To gain in-depth knowledge of factors that determine smallholder farmers' access to water for SAI, the binary logistic regression revealed several factors. For instance, it was found that the income of smallholder farmers determines their access to water for SAI. Thus, the more you earn, the higher your chances of getting access to water for SAI, particularly in the Bongo District. This finding confirms the studies by Ashoori et al. [38] and Mwangi and Kariuki [39], where income levels of smallholder farmers influenced their water access. Also, it was found that educational level determines smallholder farmers' access to water for SAI. The findings of this study validate studies by Ashoori et al. [38] and Giannoccaro et al. [40], where educational levels influence smallholder farmers' water access. However, it was found that those with a relatively higher educational level had lower chances of getting access to water compared to those with no formal education. This happens to be the reverse of the general knowledge where people with higher levels of education turn to have easy access to resources such as water. On the other hand, this could be due to the lower number of smallholder farmers who have a higher educational level.

Furthermore, some environmental factors were found to determine smallholder farmers' access to water. For example, smallholder farmers whose farms had Leptosols soil were found to have lower chances of having water access for SAI in both districts. In addition, smallholder farmers whose farms were on moderate and steep slopes had lower chances of water access in

Fig 4. A dried-up river and its bed dug to extract water.

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both districts. These findings support the study by Nahayo et al. [41], where agroecological factors such as soil type and topography influence water access. Moreover, it was found that land surface temperature determines smallholder farmers' access to water for SAI. This confirms the study by Cofie and Amede [42], where variability in climatic elements such as land surface temperature influences water access. Finally, it was found that smallholder farmers who had a higher access to water resources within a kilometre buffer had a higher chance of getting access to water in both districts. This corroborates the study by Rosegrant, Ringler and Zhu [43], where the presence of water bodies or infrastructure such as dams influences smallholder farmers' access to water.

The observed disparities in access to river water between Bongo District and Bolgatanga Municipality highlight the uneven distribution of water resources. The proximity analysis underscores the importance of dam location relative to farmsteads. Shorter distances to dams result in reduced travel times and lower transportation costs for farmers, which can enhance their ability to engage in SAI by ensuring more reliable and timely access to water. This finding aligns with existing literature that highlights the critical role of proximity to water sources in improving sustainable agriculture intensification [32, 33, 44]. The findings underscore the importance of spatial planning and infrastructure development for improving water access in the study area. Prioritizing the construction of dams and water harvesting structures in areas with longer travel distances could significantly enhance agricultural productivity and livelihoods. Additionally, the results emphasize the need for targeted interventions to support farmers in areas with limited water access. This could include promoting water-saving technologies, providing capacity building on efficient water management, and exploring alternative water sources. There is also an urgent need for targeted policies and interventions to improve water access for smallholder farmers through enhancing water infrastructure, such as constructing new dams, boreholes, and improving river access points to reduce travel distances and support sustainable agricultural intensification. Additionally, integrating spatial analysis tools in agricultural planning can help identify areas with critical water access issues and prioritize resource allocation effectively.

Conclusion

The results of this study underscore the significant impact that proximity to water sources has on sustainable agriculture intensification (SAI) among smallholder farmers in the Bolgatanga Municipality and Bongo District. The findings reveal that shorter distances to water sources, such as rivers and dams, enhance farming efficiency by reducing the time and effort required for water collection. This, in turn, can lead to improved crop yields and better overall farming practices. Conversely, longer travel distances strain available resources and reduce the time farmers can devote to other essential farming activities. The disparities in water access between Bolgatanga Municipality and Bongo District highlight the urgent need for targeted infrastructure development, particularly in the Bongo District. Strategic investments in building new dams and enhancing access points to rivers can significantly reduce travel distances, thereby supporting smallholder farmers more effectively. The use of spatial analysis tools, such as cost distance analysis, proves invaluable in identifying critical areas needing infrastructure improvements for sustainable agricultural intensification.

Access to reliable water sources is critical for the adoption of sustainable agricultural practices, especially in areas with low and moderate access. Reliable water access enables farmers to implement and maintain sustainable farming methods, ultimately leading to better crop yields and food security. In the semi-arid regions of Ghana, limited access to water during the dry season further hampers farming activities. The study's findings confirm that surface water sources like rivers and dams are vital for irrigation during dry periods, with initiatives like One Village One Dam playing a crucial role despite challenges such as low water levels. The study also identifies several socioeconomic and environmental factors influencing water access, including income, educational level, soil type, topography, and land surface temperature. These findings highlight the need for comprehensive policies and targeted interventions that address these diverse factors to improve water access for smallholder farmers. By integrating spatial analysis tools in agricultural planning and prioritizing resource allocation, policymakers can significantly enhance water access, support sustainable agricultural intensification, and improve the livelihoods of smallholder farmers in the Bolgatanga Municipality and Bongo District.

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