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Barriers and Challenges in the Implementation of Decentralized Solar Water Disinfection Treatment Systems—A Case of Ghana

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Abstract: Decentralized solar water disinfection systems (DSODIS) in continuous flow systems are alternatives for large-scale improved water access in rural contexts. However, DSODIS in rural Ghana are limited. An exploratory sequential mixed-methods design was used to explore the enablers of and barriers to, as well as reported barrier perceptions to, the effective implementation of DSODIS in the Sawla-Tuna-Kalba (STK) District of Ghana. The qualitative data (26 respondents) were analyzed thematically, and the quantitative data (1155 household heads) were subjected to Poisson regression analyses. Enablers were categorized into themes such as willingness to pay for DSODIS, household and community participation, and willingness to use water from DSODIS. Similarly, the barriers include environmental barriers, technological barriers, economic barriers, and political and legal barriers. Household characteristics such as main water source and income, age group, education, marital status, household size, being born in the community, and years living in the community are statistically associated with reported barrier perceptions. Households with unimproved water sources and high income (IRR = 1.432, $p = 0.000$) and improved water sources and high income (IRR = 1.295, $p = 0.000$) are 43% and 30% more likely, respectively, to report more barrier perceptions compared with households with unimproved water sources and low income. Females (IRR = 1.070, $p = 0.032$) are marginally more likely to report more barrier perceptions compared with males. The model output also indicates that household heads with higher educational attainment (IRR = 1.152, $p = 0.001$) are 15% more likely to report more barrier perceptions compared with those with no formal education. These findings provide valuable information for policymakers and stakeholders aiming to provide quality water in rural Ghana where centralized systems cannot be installed.

Keywords: barrier perceptions; enablers; decentralized systems; Poisson regression; improved water; Ghana



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1. Introduction

Access to clean and readily available safe water for household use is one of the growing challenges for many in some parts of developing countries [1]. It is estimated that eight out of ten rural people consume water from biologically contaminated and unimproved sources [2,3]. Sustainable approaches to quality water access involve wider community recognition of policy, practice, and technology modifications that, in turn,

require community engagement [2]. A major concern for providing safe and available water is identifying community-based indigenous knowledge and the experience of enablers of and barriers to safe water management and the implementation of simple technologies. Treatment of unimproved water before use serves as a form of primary prevention and control of diarrhea and other related waterborne diseases [4–6].

Access to quality water in rural Ghana is championed by the service entity Community Water and Sanitation Agency (CWSA). The CWSA is a government-owned utility agency established by an Act of Parliament (Act 564) in 1998, mandated to provide sustainable safe drinking water and sanitation services in rural communities and small towns in Ghana [7]. Since the establishment of the CWSA, existing data show that water infrastructure such as boreholes fitted with hand pumps and hand-dug wells, piped schemes, and mechanized systems are being improved [8,9]. However, this does not entirely meet the growing population's increasing need for improved water; hence, the pressure on existing water resources continues to increase [10].

With the increasing demand to extend coverage to other areas due to pressure on the country's current existing water resources, the water supply in the future remains uncertain [9,10]. Surface water remains the primary source to meet the domestic and agricultural needs of communities in rural Ghana, particularly the Savannah Region of Ghana. Solar water disinfection systems therefore remain viable options to improve water access in rural areas where centralized water systems cannot be installed [11–13]. Conventional solar water disinfection systems in continuous flow systems serve as an alternative for large-scale improved water access in rural contexts [14]. Decentralized solar water disinfection systems (DSODIS) are water disinfection systems for improving water quality. The scalability of DSODIS as an intervention for rural communities lacking access to clean water access is limited in Ghana. DSODIS can be of critical importance in addressing improved water access in rural communities because of their ability to provide water to individual homes, small groups of houses, and large-scale housing developments in a simple and economically feasible way [12–15]. Although DSODIS may improve clean water access, there are no available data to support the enablers of and barriers to their implementation in Ghana.

The implementation of DSODIS and other water infrastructure already adopted across the country will contribute to the achievement of Ghana's commitment to provide potable water to all indigenes, as well as meeting the sixth Sustainable Development Goal (SDG6), "availability and sustainable management of water and sanitation for all". Different enablers and barriers may variably influence the effective implementation of DSODIS in rural Ghana. Nonetheless, studies to determine perceived enablers of and barriers to DSODIS implementation in rural Ghana at the household level are nascent. Additionally, knowledge of how the combined effects of household water source and income influence reported barriers to DSODIS implementation is limited. The present study therefore employs an exploratory sequential mixed-methods design—qualitative → quantitative (QUAL→QUAN)—to understand households' perceptions of the enablers of and barriers to the effective implementation of DSODIS in the Sawla-Tuna-Kalba (STK) District of Ghana. Also, the interactive effects of household water source and income on the number of reported perceived barriers to the implementation of DSODIS in the STK District were explored. Furthermore, this study evaluated how the relationship between household water source and income with respect to reported barrier perceptions and DSODIS implementation is attenuated when theoretically relevant factors (compositional and contextual) are controlled for.

Promoting enablers and mitigating barriers will be necessary for the implementation of DSODIS in rural parts of Ghana for the achievement of quality water access for

all. The findings from this study will provide valuable information to policymakers and stakeholders aiming to provide quality water in rural Ghana.

2. Materials and Methods

2.1. Data Source

This study uses household survey data from the STK District of the Savannah Region of Ghana. The STK District is described by Afitiri and Afrifa [12]. Two distinct data types were collected, i.e., qualitative and quantitative data. With respect to the qualitative data, 26 household heads were included in the study based on the following criteria: that they had been residents of the STK District for the past 10 years, used unimproved water sources (either as a primary or secondary water source), had local representativeness, and could fully express their thoughts. The participants for the quantitative data collection were household heads present during the survey period in the included communities. A community was included when it was located in the STK District, was rural and had a household population of less than 500, and used an unimproved water source as either a primary or secondary water source. The definition of an unimproved water source, in the context of this study, refers to water sources that are not protected from outside contamination, especially fecal matter [12]. Such water sources include unprotected wells, unprotected springs, rivers, dams, and lakes. Improved water sources, on the other hand, refers to water sources that are protected from outside contamination, especially fecal matter. These water sources include household connections, standpipes, boreholes, protected dug wells, and protected springs.

2.2. Data Collection and Sampling Procedure

The qualitative research adopted a phenomenological approach to explore respondents' experiences with respect to the enablers of and barriers to effective implementation of DSODIS in the STK District and their communities of residence by using structured interview guides with probing questions. The qualitative survey instrument consisted of 13 items (Supplementary Material S1). A purposive sampling technique was utilized to select the 26 household heads as study respondents based on their experiences of water treatment and infrastructure, their local representativeness, and their ability to fully express their thoughts. The participants' responses were audio recorded. A DSODIS, in the context of this study, refers to a water system that relies on solar energy (UVA range: 315–400 nm) and photocatalysts to disinfect water to meet the Ghana Water Company's drinking water requirements and uses sunlight as its source of energy.

The quantitative data collection process was as described in Afitiri and Afrifa [12]. The quantitative survey instrument contained 65 items (Supporting Material S2). All household heads present during the survey period were recruited into the study as participants. A total of 27 communities were included in the quantitative survey, and 1155 households were interviewed. Data collection lasted from April 2024 to July 2024.

2.3. Measures

A structured interview guide with probing questions was used as the data collection tool for the qualitative study. The interview guide explored the respondents' opinions on the concepts of clean water, sources of water contamination, awareness of DSODISs, and barriers of and enablers to effective implementation of DSODIS in the STK District. The reported barriers in the qualitative study were further quantified for the household heads in the 27 included communities to respond as to whether they were perceived barriers to DSODIS implementation (referred to hereafter as reported barrier perceptions).

A quantitative data collection instrument (questionnaire) was designed for the cross-sectional study, consisting of five measurement dimensions: background information (including socio-demographic variables), water quality, water practice, water treatment system, and barriers to the implementation of DSODIS. The barriers component of the questionnaire consisted of eight identified barriers, where the respondents were required to answer whether they were barriers in their opinion. These barriers were derived from the responses of the qualitative study, the literature review, and practical experience. Cronbach's alpha (α) was used to measure the internal consistency and reliability of the quantitative data on the barriers to DSODIS, and a value of $\alpha = 0.790$ was obtained. This means that the items measuring barriers to DSODIS implementation in this study have strong internal consistency and reliability.

2.3.1. Response Variable

The dependent or response variable used in this study was the total number of reported barriers perceived by each of the household heads in the study area (STK District). Eight questions measured the barriers and were used to generate the count dependable variable (barrier perceptions). The perceived barriers were presented on a Likert scale (strongly disagree, disagree, neutral, agree, strongly agree). For purposes of analysis, all responses under strongly disagree, disagree, and neutral were combined and recoded as "No (0)", while responses under agree and strongly agree were combined and recoded as "Yes (1)". A "no" means that it is not a perceived barrier, while a "yes" means that it is a perceived barrier. The response variable (barrier perceptions) was generated by combining the eight different questions that measured barriers to the implementation of DSODISs in the STK District. The maximum number of perceived barriers reported by a respondent was six, while the minimum was zero.

2.3.2. Key Predictor/Explanatory Variables

The key predictor variable considered in this study was "household water source and household monthly income (water income)". The choice of the key explanatory variable and all other variables, including the sequence of entry of the predictors in the regression model, was based on the literature, parsimony, model fit, practical significance, and theoretical relevance. The key explanatory variable "water income" was derived from combining two variables—household water source (unimproved, improved) and household monthly income (low, high). This yielded four mutually exclusive groups, namely unimproved low income, unimproved high income, improved low income, and improved high income. The variable household water source had five categories (dugout/ponds/lake/dam/canal, river/stream, public tap/stand pipe, borehole/ tube well, protected well). For parsimony, observations under dugout/ponds/lake/dam/canal and river/stream were combined and recoded as "unimproved", while observations under public tap/stand pipe, borehole/ tube well, and protected well were combined and recoded as improved. Household income was measured as a continuous variable; however, for purposes of analysis, it was grouped into two distinct categories using World Bank criteria: low income (earning <1.9 USD a day) and high income (earning >1.9 USD a day) [16]. A conversion rate of 1 USD = 15 Ghanaian cedi was used to extrapolate the equivalent monthly income of households from the collated data into the two distinct sub-groups (low and high income).

2.3.3. Compositional and Contextual Factors

The compositional factors considered in this study were age in years (below 25, 25–30, 31–37, 38–44, 45–54, above 54), sex (male, female), being born in the community (no, yes), marital status (single, married, divorced, widow/widower), highest educational attainment (no formal education, primary, secondary, higher), and household size (low, medium, high).

Compositional factors consist of biosocial and sociocultural attributes of a population, and, whereas biosocial traits have an underlying biological or physical component, sociocultural attributes are attributes acquired by one's position in the social system [17–19]. Except for individual ethnicity, all biosocial factors are rooted in biology. Biosocial factors include sex, age, race, and ethnicity. Sociocultural factors include customs, beliefs, lifestyles, income, education, occupation, and values [18–20].

Contextual factors are simply geographical location and/or environmental conditions. For this study, the contextual factors considered were time lived in the community in years (0–19, 20–29, 30–39, 40 or more) and community zones (Sawla, Gindabuo, Kalba, Tuna/Sanyeri). For parsimony, and to establish sufficient cases in each sub-group, some of the variable observations were combined and recoded, such as marital status (divorced and widow/widower were combined). Household size was measured as a continuous variable but grouped into low household size (0–5 members), medium household size (6–10 members), and high household size (above 10 members) for analysis purposes. Community zones were derived by grouping the district into four zones in which the 27 communities were included based on their closeness to each other. The zones and communities were Zone 1—Sawla zone (Blema, Digzie, Jambar, Jobriyiri, Konkrompe, Liimetey, Nyange, Nyage kura), Zone 2—Gindabuo zone (Jokokura, Vomgbe, Paradore, Negber, Kancheng, Ne-on, Vondiel), Zone 3—Kalba zone (Nasoyiri, Tuonbo, Kunfunsi, Jeiyiri, Jingo, Kalba), and Zone 4—Tuna/Sanyeri zone (Nafaa, Nakwabi, Nahare, Yipala, Soma, Jokolpo).

2.4. Data and Statistical Analyses

The qualitative data were transcribed and cross-checked for completeness and accuracy. Transcribed data were analyzed thematically. For consistency of the recorded data, all of the transcribed data were rechecked by three experienced researchers to validate the correctness of the audio records. Regarding the quantitative data, inferential and multivariate statistical analyses were used to evaluate the associations between reported barrier perceptions and water income while controlling for theoretically relevant compositional and contextual factors. The data were subjected to both univariate/descriptive (Pearson's chi squared and Cramér's V statistics) and multivariate analyses (Poisson regression) to evaluate the associations and proportions between predictor variables and reported barrier perceptions. All data coding, cleaning, and analyses were performed using Microsoft Excel and Stata (StataCorp, College Station, TX, USA, version 15) SE software.

Multivariate Regression

Poisson regression was used to assess the relationship between reported barrier perceptions and the interactive effect of household main water source and income (water income). The model output was estimated using incidence rate ratios (IRRs). An IRR greater than 1 means a higher number of reported barrier perceptions, an IRR less than 1 indicates a lower number of reported barrier perceptions, and an IRR equal to 1 means that the predictor does not affect the number of reported barrier perceptions.

The preferred Poisson model was determined by comparing Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC) statistics after performing the main Poisson and negative binomial regression models. The model with the lower AIC or BIC was taken as the preferred model [18,21]. The analyses' outputs show that the Poisson regression model best fitted the data when the AIC or BIC statistics were determined. Hence, the Poisson regression model was used at the multivariate level. The study employed a statistical significance level (*p* value) set at 0.05, with a 95% confidence interval (CI). Three models were run: water income and biosocial factors (model 1), sociocultural factors (model 2), and contextual factors (model 3).

2.5. Ethical Statement

The purpose of this research was disclosed to the communities' authorities and participants. Oral and written consent was obtained from each participant before the research commenced, and all respondents willingly took part in the study. Written and oral consent was equally sought for audio recording of the participants' responses, and their anonymity was assured.

3. Results

3.1. Descriptive Statistics for the Qualitative Data

The total number of respondents included in the qualitative study was 26 after reaching the saturation point. Table 1 shows the demographic characteristics of the respondents for the qualitative study. Eighty five percent of the respondents were married, sixty five percent had no formal education, and the majority (73%) were farmers. The extended household type (58%) constituted over half of the households among the respondents (Table 1). The mean age ($\pm$ SD) and age range of the respondents were 38 years ($\pm$ 5) and 30–46 years, respectively. The time range for the interviews was 39–67 min, with an average of 53 min. Figure 1 shows the primary and secondary water sources of the respondents.

Table 1. Demographic characteristics of respondents for the qualitative study (n = 26).

Variable	Frequency	Proportion (%)
Gender		
Male	13	50
Female	13	50
Marital status		
Single	03	12
Married	22	85
Widow/widower	01	04
Educational attainment		
No formal education	17	65
Primary	02	08
JHS/middle	04	15
Tertiary	03	12
Occupation		
Civil servant	01	04
Farmer	19	73
Student	01	04
Trader	05	19
Household type		
Female-centered	02	08
Nuclear	06	23
Extended	15	58
Polygamous	03	12
Number of infants in the household (>5 years)		
No infants	05	19
1	07	07
2	06	23
3	04	15
4	02	08
6	02	08

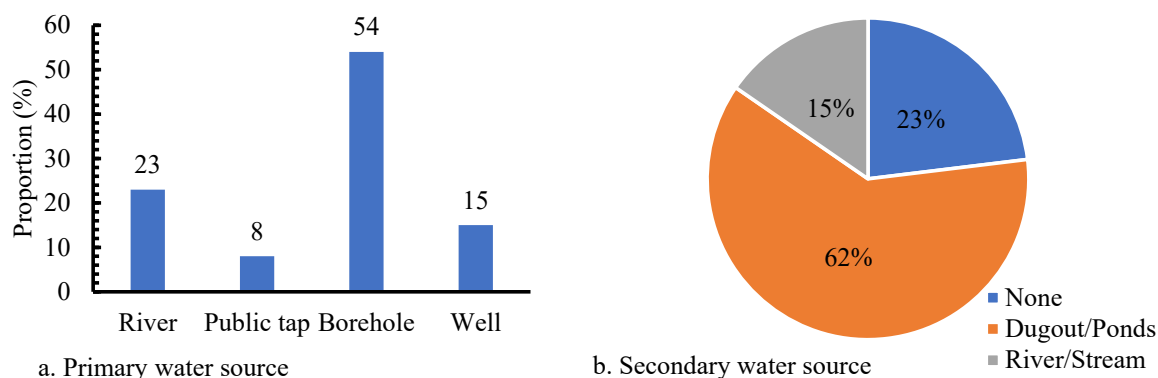


Figure 1. Respondents' household water sources. (a) primary water source; (b) secondary water source.

3.2. Participants' Opinions About Water Quality

The concept of water quality and how it influences the participants' choice of water for household use was assessed, and the responses were categorized into subthemes.

3.2.1. Knowledge of Water Quality

All of the respondents correctly described quality water as water free of contaminants. One of the respondents reported: "Good quality water is water that, when consumed, benefits the body" (Respondent 1). Another respondent added: "Borehole water is good quality water. In our community, we rely on the Black Volta for drinking water, but the water is not clean water" (Respondent 4).

3.2.2. Water Treatment at Home

Almost all of the respondents were aware of simple water treatment methods to improve water quality before use. Proportions of 38% and 77% of the study participants use an unimproved water source as their primary or secondary water source, respectively. Knowledge of simple water treatment methods such as addition of alum, filtration, and boiling was reported. One respondent stated: "We add alum to it to make it safer, but sometimes the water is still muddy and tastes bad" (Respondent 5). "We boil and filter water from the dam before using it" (Respondent 24). "We boil, filter, or add alum before using water from the Black Volta" (Respondent 7).

3.2.3. Sources of Water Contamination

The respondents' descriptions of additional water contamination in the home and at source showed the level of their knowledge of sources of water contamination. Respondent 10 reported that "when we and the animals drink from the same source, it makes the water more polluted". "Dirty environments as a results of chickens excretory, dirty containers and plastic bags, children playing and dropping of items into stored water are some sources of water contamination at homes" (Respondent 20).

3.3. Enablers of Effective Implementation of DSODIS

Responses on the enablers of implementing DSODIS were analyzed and categorized into subthemes, such as willingness to pay for implementation of DSODIS household and community participation in implementing DSODIS, and willingness to use water from DSODIS.

3.3.1. Willingness to Pay for DSODIS

All of the respondents showed a high level of commitment to contribute money to the long-term use of DSODIS in their communities. Although a greater proportion of them

were farmers, a strong willingness was expressed. On the amount the respondents were willing to contribute, almost all respondents suggested a dialogue of community members to arrive at a specific amount. However, other respondents highlighted the challenges faced in their professional activities and added that, if higher monetary commitment is required, many will not be able to afford it.

3.3.2. Household and Community Participation

The respondents expressed their support with regard to DSODIS implementation. This drive was a result of the advantages that the respondents perceived for DSODIS implementation. The highlighted advantages of DSODIS included no need to spend on alum acquisition or fuel for boiling water, as well as better water quality. A supportive statement from one of the respondents was that “we will welcome and support anyone who comes to improve our water access. In fact, the community will be willing to put measures in place to improve and maintain our water quality” (Respondent 24). “The chief can form a committee to be in charge of mobilizing resources for maintenance” (Respondent 16). “We will get a committee to take charge of its maintenance” (Respondent 9).

3.3.3. Willingness to Use Water from DSODIS

All 26 respondents expressed their willingness to use water from DSODIS. One reported statement was, “we will drink and use water from a DSODIS, we don’t buy the sun” (Respondent 18). Another respondent reported “we would drink and use water from this system. At times, health workers tell us that our illnesses are caused by the water we drink. I do agree with what the health workers tell me” (Respondent 11). Respondent 21 reported “I will be willing to use water from DSODIS. We don’t treat our water before drinking”.

3.4. *Barriers to Effective Implementation of DSODIS*

The reported barriers are presented in subthemes as environmental, technological, economic, and political and legal barriers.

3.4.1. Environmental Barriers

The respondents reported that the district largely experiences two distinct seasons (dry and wet seasons), and, therefore, they envisaged confronting issues during the wet season, when sunlight is mostly low. Other identified environmental barriers included too turbid water (unprotected water sources) and geographical locations. One of the respondents reported “DSODIS relying on the sun to clean our water sounds good because it would be free and easy to use. However, I worry about what we will do on cloudy days when there isn’t enough sunlight” (Respondent 2). Others also reported shade (shadow of tall trees) effects as a barrier to DSODIS implementation in communities characterized by tall trees that provide shade to the community members: “Sunlight, good water, but what if there’s no sun or the shadow of our big trees fall on the water system? How will I get the water?” (Respondent 12), adding “I think for an efficient DSODIS to work efficiently, a central point should be chosen for installation to overcome such barriers which community members will be willing to support”.

3.4.2. Technological Barriers

Another barrier reported by the respondents was the lack or inadequacy of human resources (experts) in rural communities to oversee the continuous functioning of DSODIS if implemented. Some communities have nonfunctional boreholes because they cannot manage them, and no expert has visited to monitor their household water conditions. Nonetheless, the respondents were of the view that implementing DSODIS should be complemented with training of community youths to properly manage the water infrastructure.

Some of the statements made were as follows: “One major barrier I foresee with DSODIS is should there be a breakdown, maintenance will be difficult” (Respondent 18). “No quality checks are done on our water. The community would be willing to have some youth trained in maintenance services” (Respondent 3).

3.4.3. Political and Legal Barriers

Some respondents raised political and legal concerns with respect to the implementation of DSODIS in the district. Respondents stated that politics and legal issues are hindering their access to improved water sources. Some added that they were promised improved water sources several times and never saw them realized. Respondent 23 reported “we have few educated people in our community, due to that, we are not having the men to lobby for us”. Another respondent added “we have no visionary leaders in the community to spearhead our grievances, the idea of DSODIS to our rural communities will not be accepted by the government officials in the district” (Respondent 14).

3.4.4. Economic Barriers

The respondents also reported economic barriers to the effective implementation of DSODIS. Even though DSODIS are welcome, the economic status of the rural inhabitants may serve as a barrier. Some expressed that “we will not be able to maintain DSODIS if each person is asked to contribute any amount above one hundred Ghana cedis (equivalent to USD 7) after installation” (Respondent 8). Again, Respondent 25 added “due to our economic situation, it seems impossible for DSODIS implementation by ourselves. Government, NGO, and individuals are the main source of hope if our water system will have to improve”.

3.5. Descriptive Statistics for Quantitative Data

The distribution of reported numbers of perceived barriers and independent variables is presented in the contingency table (Table 2). Out of the eight items for measuring barrier perceptions, the highest number of reported barrier perceptions was six, while the minimum reported barrier perceptions was zero.

The results show that households that use unimproved water sources with low income reported the highest (8%) proportion of zero barrier perceptions, while households that use unimproved water sources with high income, together with households that use improved water sources with high income, reported the lowest proportion of zero barrier perceptions (1%). Similarly, households with unimproved water sources with high income (3%) and households with improved water sources with low income (21%) reported the lowest and highest proportions of two barrier perceptions, respectively.

Furthermore, the results output (Table 2) reveal that the highest (35%) and lowest (26%) reported proportions of three barrier perceptions were households with unimproved water sources with low income and households with improved water sources with high income, respectively. The results also show that households with unimproved water sources with low income (7%) reported the lowest proportion of four barrier perceptions, while households with unimproved water sources with high income (58%) reported the highest proportion of four barrier perceptions. The results also indicate that households that use unimproved water sources with low income (5%) reported the highest proportion of five barrier perceptions, while two categories (households that uses unimproved water sources with high income, and those with improved water sources with high income) reported the lowest proportions of five barrier perceptions (1%). The lowest proportion (0%) reported for six barrier perceptions was households that use unimproved water sources with high income. The three other categories all reported a proportion of 1% for six barrier perceptions.

Table 2. Percentage distribution of reported number of barriers in the implementation of DSODISs by predictor variables (n = 1155).

	Number of Reported Barrier Perceptions							
Variable	Zero (%)	One (%)	Two (%)	Three (%)	Four (%)	Five (%)	Six (%)	Inferential Statistics
Main water source and income								
Unimproved low income	08	17	27	35	07	05	01	$\chi^2 = 208.1646$ ($p = 0.000$; Cramér's V = 0.2451)
Unimproved high income	01	03	08	28	58	01	00	
Improved low income	06	21	19	33	16	04	01	
Improved high income	01	12	15	26	45	01	01	
Gender								
Male	05	17	18	28	30	02	01	$\chi^2 = 5.3804$ ($p = 0.496$; Cramér's V = -0.0683)
Female	04	15	18	33	27	03	01	
Born in this community (born)								
No	04	09	16	26	40	03	02	$\chi^2 = 31.6394$ ($p = 0.000$; Cramér's V = 0.1655)
Yes	04	17	18	32	26	03	00	
Age group (years)								
24 and below	06	23	20	45	05	01	00	$\chi^2 = 108.6041$ ($p = 0.000$; Cramér's V = 0.1371)
25–30	02	18	19	39	20	01	00	
31–37	03	18	19	25	33	01	00	
38–44	06	13	15	25	37	03	01	
45–54	04	08	19	29	31	07	01	
55 and above	10	18	15	38	18	03	00	
Highest educational attainment								
No education	05	15	20	31	25	03	01	$\chi^2 = 52.1189$ ($p = 0.000$; Cramér's V = 0.1226)
Primary	02	15	17	22	43	00	01	
Secondary	01	22	14	33	28	01	00	
Higher	02	12	10	36	33	06	02	
Marital status								
Single	05	20	18	36	20	01	00	$\chi^2 = 26.2437$ ($p = 0.010$; Cramér's V = 0.1066)
Married	04	14	18	30	31	03	01	
Divorced/widow/widower	12	22	16	25	22	04	00	
Household size								
Low household size (0–5)	04	21	21	35	17	01	01	$\chi^2 = 93.2434$ ($p = 0.000$; Cramér's V = 0.2019)
Medium household size (6–10)	04	12	17	27	36	04	00	
High household size (>11)	05	07	13	29	42	02	02	
Lived in the community (years)								
0–19	04	08	16	28	38	04	01	$\chi^2 = 40.7603$ ($p = 0.002$; Cramér's V = 0.1085)
20–29	04	21	16	36	21	02	01	
30–39	03	16	19	29	30	03	00	
40 or more	06	12	20	29	30	03	00	
Community zones								
Sawla	03	16	17	34	26	04	01	$\chi^2 = 26.8762$ ($p = 0.081$; Cramér's V = 0.0881)
Gindabuo	04	14	17	27	35	02	01	
Kalba	03	12	20	33	31	01	00	
Tuna/Sanyeri	07	19	19	27	24	02	01	
n	1155							

The chi-squared statistic (χ^2) results show that water income ($\chi^2 = 208.1646, p < 0.05$), being born in the community ($\chi^2 = 31.6394, p < 0.05$), age group ($\chi^2 = 108.6041, p < 0.05$), educational attainment ($\chi^2 = 52.1189, p < 0.05$), marital status ($\chi^2 = 26.2437, p < 0.05$), household size ($\chi^2 = 93.2434, p < 0.05$), and years lived in the community ($\chi^2 = 40.7603, p < 0.05$) were all significant, indicating that there is a relationship between these variables and the reported number of barrier perceptions. These associations range from moderate (water income, being born in the community, household size) to weak (age group, marital status, education, years lived in the community) associations with the reported number of barrier perceptions. However, sex and community zones were not statistically significant. The Pearson chi-squared statistical results rejected the hypothesis that the reported number of barrier perceptions is independent of household water use and income, as well as compositional and contextual factors. Hence, household water source and income influence the number of reported barrier perceptions. The probability values indicate that the obtained values for the reported number of barrier perceptions were not by chance, and that, if the analyses were run repeatedly, the same results would be generated.

3.6. Multivariate Analyses

Three models were run at the multivariate level (Table 3). The interactive effects of household water source and household monthly income and biosocial factors (model 1), sociocultural factors (model 2), and contextual factors (model 3) were developed to assess their relationship with the reported number of perceived barriers to the implementation of DSODISs. The Poisson regression model output (Table 3) shows the IRR, robust standard error (SE), probability values, and CIs of the models.

The results output for Model 1 reveal that households that use unimproved water sources with high income (IRR = 1.457, $p = 0.000$) and households that uses improved water sources with high income (IRR = 1.304, $p = 0.000$) are 46% and 30% more likely to report more barrier perceptions, respectively, compared with their counterparts that use unimproved water sources with low income. The results equally reveal that households in the age groups 38–44 (IRR = 1.163, $p = 0.003$) and 45–54 (IRR = 1.249, $p = 0.000$) are more likely to report more barrier perceptions compared with the reference group (less than 25 years). Similarly, females are marginally more likely to report high barrier perceptions compared with males (IRR = 1.063, $p = 0.022$). Household heads who were born in the communities (IRR = 0.910, $p = 0.004$) are 9% less likely to report more barrier perceptions compared with their counterparts in the reference group (not born in the communities).

The results for Model 2 (Table 3) controlled for sociocultural factors. The observed relationship between the interactive effect of household water source and income and the reported number of barrier perceptions in Model 1 remained robust in Model 2, and the IRR decreased marginally. Households with unimproved water sources and high income (IRR = 1.427, $p = 0.000$) and households with improved water sources and high income (IRR = 1.247, $p = 0.001$) were 43% and 25% more likely to report more barrier perceptions, respectively, compared with their counterparts that use unimproved water sources with low income. Additionally, the results indicate that the age group 45–54 (IRR = 1.179, $p = 0.041$) was 18% more likely to report more barrier perceptions compared with the reference group (less than 25 years). Regarding sex, females (IRR = 1.087, $p = 0.002$) were 9% more likely to report high barrier perceptions compared with males. Regarding the variable “born in the community”, household heads born in the communities in which they were interviewed (IRR = 0.922, $p = 0.015$) were 8% less likely to report more barrier perceptions compared with their counterparts in the reference group (no). The marital status of household heads was not a significant predictor of the number of reported barrier perceptions under this model. The model’s output also indicates that household heads with

higher educational attainment ($IRR = 1.151, p = 0.001$) were 15% more likely to report more barrier perceptions compared with the reference group (no formal education). Household size was accounted for in this model. Household heads with medium household size ($IRR = 1.110, p = 0.001$) and high household size ($IRR = 1.150, p = 0.001$) were all more likely to report more barrier perceptions compared with their counterparts in the reference category (low household size).

Table 3. Multivariate relationships between the number of reported barriers in the implementation of DSODISs and predictor variables ($n = 1155$).

Variable	Water Income + Biosocial Factors					+Sociocultural Factors				+Contextual Factors						
	IRR	SE	<i>p</i> Value	Conf. Interval		IRR	SE	<i>p</i> Value	Conf. Interval		IRR	SE	<i>p</i> Value	Conf. Interval		
	Model 1					Model 2				Model 3						
Main water source and income (ref: unimproved low income)																
Unimproved high income	1.457	0.072	0.000	1.323	1.605	1.427	0.073	0.000	1.290	1.578	1.432	0.073	0.000	1.295	1.583	
Improved low income	1.053	0.051	0.286	0.958	1.158	1.035	0.052	0.491	0.939	1.141	1.063	0.054	0.232	0.962	1.174	
Improved high income	1.304	0.062	0.000	1.188	1.432	1.247	0.065	0.001	1.127	1.380	1.295	0.068	0.000	1.168	1.436	
Age group (ref: <25 years)																
25–30	1.100	0.057	0.066	0.994	1.219	1.084	0.069	0.208	0.956	1.228	1.076	0.068	0.244	0.951	1.218	
31–37	1.084	0.056	0.117	0.980	1.198	1.063	0.078	0.406	0.920	1.228	1.036	0.077	0.638	0.895	1.198	
38–44	1.163	0.060	0.003	1.051	1.288	1.128	0.088	0.123	0.968	1.314	1.129	0.090	0.130	0.965	1.320	
45–54	1.249	0.067	0.000	1.125	1.387	1.179	0.095	0.041	1.007	1.380	1.198	0.101	0.032	1.016	1.413	
>54	1.088	0.102	0.369	0.905	1.309	1.050	0.121	0.673	0.837	1.316	1.091	0.129	0.461	0.865	1.376	
Gender (ref: male)																
Female	1.063	0.028	0.022	1.009	1.119	1.087	0.029	0.002	1.031	1.146	1.070	0.030	0.014	1.014	1.130	
Born in the community (ref: no)																
Yes	0.910	0.030	0.004	0.853	0.971	0.922	0.031	0.015	0.863	0.984	0.945	0.040	0.184	0.870	1.027	
Marital status (ref: single)																
Married						0.997	0.054	0.962	0.898	1.108	0.995	0.053	0.918	0.896	1.104	
Divorced/widow/widower						0.848	0.085	0.099	0.697	1.031	0.865	0.088	0.152	0.709	1.055	
Highest educational (ref: no formal education)																
Primary						1.035	0.036	0.324	0.967	1.107	1.024	0.035	0.497	0.957	1.095	
JHS/middle						0.997	0.044	0.942	0.915	1.086	0.991	0.043	0.834	0.909	1.080	
Higher						1.151	0.049	0.001	1.059	1.252	1.152	0.049	0.001	1.061	1.252	
Household size (ref: low household (0–5))																
Medium household (6–10)						1.110	0.034	0.001	1.045	1.180	1.110	0.034	0.001	1.045	1.179	
High household (>11)						1.150	0.047	0.001	1.063	1.246	1.159	0.047	0.000	1.072	1.254	
Lived in the community (ref: 0–19) years																
20–29											0.944	0.048	0.257	0.855	1.043	
30–39											0.966	0.050	0.507	0.873	1.069	
40 or more											0.900	0.057	0.097	0.795	1.019	
Communities zone (ref: Sawla)																
Gindabuo											1.068	0.038	0.063	0.996	1.146	
Kalba											1.003	0.033	0.921	0.940	1.071	
Tuna/Sanyeri											0.922	0.033	0.024	0.859	0.989	
n	1155					1155					1155					

When the contextual factors were accounted for in Model 3, the incidence rate observed in Model 2 for the relationship between the interactive effect of household water source and income and the number of reported barrier perceptions became more robust. Households with unimproved water sources and high income ($IRR = 1.432, p = 0.000$) and households with improved water sources and high income ($IRR = 1.295, p = 0.000$) were 43% and 30% more likely to report more barrier perceptions, respectively, compared with the reference group (unimproved low income). Accounting for age in Model 3 revealed that the age

group 45–54 ($IRR = 1.198, p = 0.041$) was 20% more likely to report more barrier perceptions compared with the reference group (less than 25 years). Regarding sex, females ($IRR = 1.070, p = 0.032$) were marginally more likely to report high barrier perceptions compared with males. Marital status, being born in the community, and years living in the community were not significant predictors of the number of barrier perceptions reported by the household heads under Model 3. The model's output also indicates that household heads with higher educational attainment ($IRR = 1.152, p = 0.001$) were 15% more likely to report more barrier perceptions compared with the reference group (no formal education). Household heads with medium household size ($IRR = 1.110, p = 0.001$) and high household size ($IRR = 1.159, p = 0.000$) were all more likely to report more barrier perceptions compared with the reference category (low household size). Household heads within the Tuna/Sanyeri zone ($IRR = 0.922, p = 0.024$) were 8% less likely to report more barrier perceptions compared with the reference group (Sawla zone).

4. Discussion

The mixed-methods approach (QUAL→QUAN) adopted in this study provided insights from the study respondents on the concept of water quality and the barriers to and enablers of effective implementation of DSODIS. Additionally, the interactive effect of household water source and income on the reported number of perceived barriers to the implementation of DSODIS in the STK District of Ghana was assessed, along with how that relationship is attenuated when compositional and contextual factors are considered. Awareness of potential barriers to the implementation of water systems at the household level, enabling factors, and household knowledge about clean water are key to ensuring the efficient implementation and management of drinking water systems [2,22]. Generally, all of the respondents had a good understanding of improved water quality and ascribed safety to water from boreholes and pipes. Since the respondents largely use unimproved water sources as either primary or secondary sources, they are practicing simple treatment methods at home, including the addition of alum, boiling of water, and filtration. Nonetheless, about 34% of the respondents included in the qualitative study said that they do not apply any treatment to their household water before use, as they assume that the water is clean, especially during the rainy season. This is highly risky, as no routine quality monitoring of the water sources is carried out, according to our discussions with the respondents. Similar findings were reported by Williams et al. [23], who found in their study carried out in Haiti that, because of the belief that water treatment was not essential, individuals did not treat their water at home [23].

Usage of water from unimproved sources poses a high risk to the health of many who depend on such sources without any treatment [17,24,25]. The respondents also reported poor water-handling practices, animal intrusions in water sources, poor sanitation practices, and unhygienic water storage containers as some of the causes/sources of their water contamination. Discussions with the study's respondents therefore deepened their understanding and choices of different treatment methods, such as solar water disinfection and other already-practiced household-level treatment methods. Several other studies in the literature report that over half of study participants in rural communities directly use unimproved water sources without treatment because of poor perceptions of their quality [26–28].

Improving the quality of water in rural communities requires exploring their indigenous knowledge to help determine whether scaling up household water treatment methods is required [2,29]. Even though the qualitative study's respondents expressed their opinions irrespective of effective water treatment status, upscaling solar water disinfection in the STK District will better improve its water quality compared to the current approaches practiced.

All 26 study respondents agreed that DSODISs are a better and robust technology that can ensure their access to quality water, as no centralized systems are envisioned in the near future, and, hence, they are willing to use water from DSODISs for household purposes. A study that assessed about 1155 household heads' willingness to adopt and use water from a DSODIS in the STK District found 97% willingness [12]. These findings support earlier findings by Bitew et al. [2] and Christen et al. [30], who reported study participants' willingness to adopt solar water disinfection as an alternative to other household water treatment methods.

Particularly, filtration with cloth, as reported by this study's respondents, is not an effective treatment method, as microbial contaminants are not treated and could affect one's health if consumed, as indicated in the literature [2,31,32]. The sources of contamination reported by the respondents are essential and add insights to the fact that household water needs to be protected from source to storage or point of use. Hence, if DSODISs exist and the population lacks knowledge about possible sources of water contamination, then poor-quality water is more likely to be consumed once stored for future use because of poor handling practices. Contamination can occur in water outlets or collection containers, even when sourced from improved water sources [33]. As the respondents had good knowledge of contamination sources, better water-handling practices are expected within households in the study area. This finding is consistent with studies by Orgill et al. [34], Rufener et al. [35], and Bitew et al. [2] in peri-urban Cambodia, rural Bolivia, and rural Ethiopia, respectively.

Some enablers of DSODIS implementation were reported by the study's respondents. The respondents expressed their opinions that DSODIS implementation is possible in the STK District. DSODIS could therefore serve as a suitable technology to provide improved water to communities without improved water sources. Similar observations were made in rural Cambodia, where solar water disinfection was reported to be efficient and culturally acceptable among the population [36], as well as that of Kathmandu Valley, Nepal [37]. The present study found that a positive attitude is an enabler of effective DSODIS implementation for sustained and improved water in rural communities. DSODISs are considered to represent a robust intervention approach for providing quality water. The study's respondents also showed individuals' and communities' willingness to support the implementation of DSODIS as an enabling factor. These findings are in consonance with those of other studies that reported individuals' commitment to continuous solar water disinfection to improve their household water quality [38,39]. Factors such as community interest, knowledge, attitude, involvement, and values are important enabling factors for implementing and upscaling water disinfection systems [2,40,41]. DSODIS are globally accepted by many water consumers, and their implementation and sustenance can be achieved through training and promotional actions through water, sanitation, and hygiene (WASH) programs [2,42,43] as individuals and communities show interest in accepting and adopting the technology.

The willingness of water consumers to contribute to the acquisition of required materials for a water system, along with its maintenance, is an important factor in its implementation. The respondents in this study highlighted their commitment, and that of their communities, to contributing financially to the implementation of DSODIS to ensure continuous access to good-quality water. Community-level committees to oversee the mobilization of resources from households were suggested to facilitate the maintenance of DSODIS. This finding supports those of other studies that showed participants' willingness to pay for materials required for household water treatment systems [2,35,37].

It was obvious from the respondents that the most typical barrier was the cloud cover during the wet season. The STK District of Ghana has two main distinct seasons

(the dry season—September–March, and the wet season—April–August) in a year [44]. This environmental barrier can be overcome by integrating solar panels in DSODIS. This has the potential to keep them functional [14,45]. The reported environmental barriers are supported by similar works in the literature [2,11,32,45–47]. Most rural areas are characterized by tall thick trees that provide shade for the indigenes. These trees also have the potential to cast shadow and limit the amount of sunlight in water disinfection systems, as reported by Bitew et al. [2] and Ojomo et al. [5]. Overcoming this barrier will warrant that a suitable geographical location should be used to ensure efficient sunlight for the water treatment system. The quality of water from the main source is a limiting factor for the efficiency of implementing DSODISs and even centralized systems. Turbid water affects the depth of penetration of the sunrays needed to disinfect the contaminants in the water [48,49]. In this study, some respondents shared their experiences of competing with farm animals for the same water. Hence, they have to get to the water source before the animals to avoid collecting too-turbid water.

Another barrier reported by the respondents was the fact that human resources (experts) to oversee the continuous functioning of DSODIS, if implemented, are lacking in rural communities. Some communities have nonfunctional boreholes because they cannot manage them, and no expert has visited to monitor their household water conditions. Nonetheless, the respondents were of the view that implementing DSODIS should be complemented with training of the community youth to properly manage the water infrastructure. Water practitioners and engineers suggest that acceptance, support, and behavioral changes are necessary to overcome the technological barriers associated with the implementation of decentralized treatment technologies [50]. This finding supports those of other works in the literature that reported that the characteristics and promotion of water treatment technologies could be challenging for water users, as they may lack knowledge on how to manage and promote these water technologies [51,52].

Political and legal concerns with respect to DSODIS implementation in the district were raised. The respondents opined that politics and legal issues are hindering their access to improved water sources and could potentially influence DSODIS implementation. DSODIS implementation in the STK District is limited; hence, the bureaucracy involved in the implementation of such technologies could be Herculean. This finding is supported by the works of Marston and Cai [53], who reported that legal barriers hinder the implementation of water reallocation to communities that are water-stressed.

This study also found economic barriers to the effective implementation of DSODISs. Even though DSODISs are welcome, the economic status of the rural inhabitants may serve as a barrier to their implementation and maintenance.

The results established associations between household-level characteristics and reported barrier perceptions in the quantitative study, showing that water income, being born in the community, age group, educational attainments, marital status, household size, and years lived in the community were associated with reported barrier perceptions. These findings are supported by other works in the literature [54,55].

We found that household heads with unimproved water sources and high income, as well as those with improved water sources and high income, were more likely to report more barrier perceptions compared with the reference group (unimproved low income). This means that DSODIS barrier perceptions are concentrated among rich households, regardless of their household water quality, compared to poor ones. This finding is in consonance with the literature, which suggests that having wealth increases one's ability to pay for essential services such as water even when the local authority or government is not providing this service [19,56,57]. This suggests that rich households without improved

water sources are faced with more barriers to accessing improved water that they could have afforded if they were in urban communities.

Female-headed households were more likely to report more perceived barriers to DSODIS implementation compared to their male counterparts. Generally, Ghanaian women, and to some extent sub-Saharan African (SSA) women, have the responsibility of managing household water and other chores at the household level. This direct linkage with acquiring household water suggests that women could pay more attention to perceived barriers to implementing improved water systems than their male counterparts, especially when the woman is recognized as the household head.

Household heads with higher educational attainment were more likely to report more barrier perceptions compared with their counterparts with no formal education. This could be attributed to the fact that educated people have more knowledge about decentralized water systems. Awareness of decentralized water infrastructure increases the likelihood of reporting more barrier perceptions.

The results show that household heads within the age group 45–54 were more likely to report more barrier perceptions compared with the reference group (less than 25 years). Also, household heads with medium household size and high household size were all more likely to report more barrier perceptions compared with the reference category (low household size). These findings may be a result of their economic status, with more responsibility to provide for their households compared to the younger household heads. The literature supports the idea that governments and relevant stakeholders need to deliberately adopt strategies that target deprived areas and population groups to achieve improve water access universally [19,58].

5. Limitations of the Study

The enablers of and barriers to the implementation of DSODIS in the STK District of Ghana were explored qualitatively. The reported barrier perceptions among households in the STK District were equally evaluated using quantitative approaches. The design of this study did not allow for making any inferences from governmental and private staff working in the water sector. Also, individual experts in the field of water infrastructure development were not interviewed. The design focused on the perceptions of individuals who largely depend on unimproved water sources. Additionally, no inferences were made regarding government support and legal frameworks. Reported perceptions may be subject to bias in terms of social desirability [2]. To limit this bias, the respondents in the qualitative study were asked probing questions to express alternative points of view. Until saturation points were reached, the respondents addressed all of their perceived enablers of and barriers to DSODIS implementation in the district in detail. The sample size was equally increased in the quantitative study in order to give a better representation of the STK District. DSODIS intervention in the study area is a new concept for improving household water quality and access; hence, it is possible that the respondents may not have properly internalized the enablers of and barriers to DSODIS.

6. Conclusions

In conclusion, the respondents in the qualitative study had a better understanding of water quality and were willing to use water from DSODIS. This study is the first of its kind, to the best of our knowledge, to use mixed methods in the assessment of the enablers of and barriers to effective implementation of DSODIS, evaluating the interactive effects of household water source and income on the reported number of perceived barriers to the implementation of DSODIS, as well as how the relationship was attenuated when theoretically relevant factors (compositional and contextual) were considered. The respondents'

understanding of the concept of water quality and how it influences household water choice, treatment methods for household water, and sources of water contamination was explored. Based on our findings, the enablers of effective DSODIS implementation in the STK District of Ghana include willingness to pay for DSODIS, household and community participation, and willingness to use water from DSODIS. The identified barriers to the implementation of DSODIS were environmental, technological, political and legal, and economic barriers. We found statistically significant associations between household-level characteristics (water income, being born in the community, age group, educational attainments, marital status, household size, and years lived in the community) and reported barrier perceptions. The results from the modeled data showed that household heads with unimproved water sources and high income were 43% more likely to report more barrier perceptions than the reference group (households with unimproved water sources and low income). Similarly, households with improved water sources and high income were 30% more likely to report more barrier perceptions compared with those with unimproved water sources and low income. Respondents in the age group 45–54 were 20% more likely to report more barrier perceptions compared with the reference group (less than 25 years). Regarding gender, females were marginally more likely to report high barrier perceptions compared with males. The results further show that household heads with higher educational attainment were 15% more likely to report more barrier perceptions compared with the reference group (no formal education). Household heads with medium and high household sizes were all more likely to report more barrier perceptions compared with the reference category (low household size). Household heads within the Tuna/Sanyeri zone were 8% less likely to report more barrier perceptions compared with the reference group (Sawla zone). We suggest that piloting a DSODIS could help identify the most appropriate settings for implementation in the STK District. Promoting enablers and mitigating barriers will be necessary for the effective implementation of DSODIS in rural parts of Ghana for the achievement of access to quality water for all. The findings from this study provide valuable information for policymakers and stakeholders aiming to provide quality water in rural Ghana, where centralized systems cannot be installed.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/solar5020025/solar5020025/s1>, Supplementary Material S1: Structured interview guides; Supplementary Material S2: Questionnaire.

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References

1. Eichelberger, L.; Hickel, K.; Thomas, T.K. A community approach to promote household water security: Combining centralized and decentralized access in remote Alaskan communities. *Water Secur.* **2020**, *10*, 100066. [CrossRef]
2. Bitew, B.D.; Gete, Y.K.; Biks, G.A.; Adafrie, T.T. Barriers and Enabling Factors Associated with the Implementation of Household Solar Water Disinfection: A Qualitative Study in Northwest Ethiopia. *Am. J. Trop. Med. Hyg.* **2020**, *102*, 458–467. [CrossRef] [PubMed]
3. World Health Organization; UNICEF. *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*; World Health Organization: Geneva, Switzerland, 2017; ISBN 978-92-4-151289-3. Available online: <https://www.who.int/publications/i/item/9789241512893> (accessed on 19 March 2025).
4. Afitiri, A.-R. Assessing Surface Water Quality in the Birim North District of Ghana Using Spatial Modelling. MPhil Thesis, University of Cape Coast, Cape Coast, Ghana, 2019. Available online: <https://ir.ucc.edu.gh/xmlui/handle/123456789/4568> (accessed on 30 July 2024).
5. Ojomo, E.; Elliott, M.; Goodyear, L.; Forson, M.; Bartram, J. Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation. *Int. J. Hyg. Environ. Health* **2015**, *218*, 704–713. [CrossRef] [PubMed]
6. Afitiri, A.-R.; Armah, F.A.; Afrifa, E.K.A.; Ekumah, B. The joint effect of natural and human-induced environmental factors on surface water quality in the Birim North District of Ghana. *Water Pract. Technol.* **2020**, *15*, 605–618. [CrossRef]
7. Nyarko, K.B. *Drinking Water Sector in Ghana: Drivers for Performance*; Taylor & Francis: Leiden, The Netherlands, 2007. Available online: <http://cdm21063.contentdm.oclc.org/cdm/ref/collection/phd1/id/41798> (accessed on 21 August 2022).
8. CWSA. Annual Reports—Community Water and Sanitation Agency. Available online: <https://www.cwsa.gov.gh/publications/annual-reports/> (accessed on 2 December 2024).
9. Okofo, L.B. Hydrogeological Assessment for Evaluating the Feasibility of Managed Aquifer Recharge in Northeastern Ghana. Ph.D. Thesis, BTU Cottbus-Senftenberg, Brandenburg, Germany, 2023. Available online: <https://opus4.kobv.de/opus4-btu/frontdoor/index/index/docId/6244> (accessed on 26 July 2024).
10. Cobbinah, P.B.; Okyere, D.K.; Gaisie, E. *Population Growth and Water Supply: The Future of Ghanaian Cities*; IGI Global Scientific Publishing: Pennsylvania, PA, USA, 2020; pp. 96–117. Available online: <https://www.igi-global.com/gateway/chapter/231298> (accessed on 19 March 2025).
11. Afitiri, A.-R.; Appah Aram, S.; Martienssen, M. Systematic review of the effects of advanced oxidation processes integration with solar water disinfection for improved drinking water production. *Waste Manag. Bull.* **2024**, *1*, 52–59. [CrossRef]
12. Afitiri, A.-R.; Afrifa, E.K.A. Households' willingness to use water from a solar water disinfection treatment system for household purposes. *World* **2024**, *5*, 1181–1193. [CrossRef]
13. Hendrickson, C.; Oremo, J.; Akello, O.O.; Bunde, S.; Rayola, I.; Akello, D.; Akwiri, D.; Park, S.-J.; Dorevitch, S. Decentralized solar-powered drinking water ozonation in Western Kenya: An evaluation of disinfection efficacy. *Gates Open Res.* **2020**, *4*, 56. [CrossRef]
14. Chaúque, B.J.M.; Rott, M.B. Solar disinfection (SODIS) technologies as alternative for large-scale public drinking water supply: Advances and challenges. *Chemosphere* **2021**, *281*, 130754. [CrossRef]
15. Cook, S.; Tjandraatmadja, G.; Ho, A.; Sharma, A. *Definition of Decentralised Systems in the South East Queensland Context*; Urban Water Security Research Alliance Brisbane: Brisbane, Australia, 2008. Available online: https://sswm.info/sites/default/files/reference_attachments/COOK%20et%20al%202009%20Definition%20of%20Decentralised%20Systems%20in%20the%20South%20East%20Queensland%20Context.pdf (accessed on 20 August 2024).
16. *World Bank Monitoring Global Poverty: Report of the Commission on Global Poverty*; The World Bank: Washington, DC, USA, 2016; ISBN 978-1-4648-0961-3.
17. Afitiri, A.-R.; Armah, F.A.; Ekumah, B.; Nyieku, F.E.; Yawson, D.O.; Odoi, J.O. Cumulative effects of environmental factors on household childhood diarrhoea in Ghana. *Water Pract. Technol.* **2020**, *15*, 1032–1049. [CrossRef]
18. Ahadzi, D.F.; Afitiri, A.-R.; Ahadzi, E. Organizational safety culture perceptions of healthcare workers in Ghana: A cross-sectional interview study. *Int. J. Nurs. Stud. Adv.* **2021**, *3*, 100020. [CrossRef]
19. Armah, F.A.; Ekumah, B.; Yawson, D.O.; Odoi, J.O.; Afitiri, A.-R.; Nyieku, F.E. Access to improved water and sanitation in sub-Saharan Africa in a quarter century. *Heliyon* **2018**, *4*, e00931. [CrossRef] [PubMed]
20. Pol, L.G.; Thomas, R.K. *The Demography of Health and Health Care*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2001.
21. Armah, F.A.; Ung, M.; Boamah, S.A.; Luginaah, I.; Campbell, G. Out of the frying pan into the fire? Urban penalty of the poor and multiple barriers to climate change adaptation in Cambodia and Tanzania. *J. Environ. Stud. Sci.* **2017**, *7*, 69–86. [CrossRef]
22. WHO. *Guidelines for Drinking-Water Quality*, 4th ed.; WHO: Geneva, Switzerland, 2024. Available online: <https://www.who.int/publications/i/item/9789241548151> (accessed on 4 December 2024).

23. Williams, H.A.; Gaines, J.; Patrick, M.; Berendes, D.; Fitter, D.; Handzel, T. Perceptions of health communication, water treatment and sanitation in Artibonite Department, Haiti, March–April 2012. *PLoS ONE* **2015**, *10*, e0142778. [[CrossRef](#)] [[PubMed](#)]
24. Acharya, D.; Singh, J.K.; Adhikari, M.; Gautam, S.; Pandey, P.; Dayal, V. Association of water handling and child feeding practice with childhood diarrhoea in rural community of Southern Nepal. *J. Infect. Public Health* **2018**, *11*, 69–74. [[CrossRef](#)]
25. Ballesteros, M.; Brindley, C.; Sánchez-Pérez, J.A.; Fernández-Ibañez, P. Worldwide Research Trends on Solar-Driven Water Disinfection. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9396. [[CrossRef](#)]
26. Coetzee, H.; Nell, W.; Bezuidenhout, C. An assessment of perceptions, sources and uses of water among six African communities in the North West Province of South Africa. *Water SA* **2016**, *42*, 432–441. [[CrossRef](#)]
27. Rojas, L.F.R.; Megerle, A. Perception of water quality and health risks in the rural area of Medellín. *Am. J. Rural Dev.* **2013**, *1*, 106–115. [[CrossRef](#)]
28. Rothstein, J.D.; Leontsini, E.; Olortegui, M.P.; Yori, P.P.; Surkan, P.J.; Kosek, M. Determinants of caregivers' use and adoption of household water chlorination: A qualitative study with peri-urban communities in the Peruvian Amazon. *Am. J. Trop. Med. Hyg.* **2015**, *93*, 626–635. [[CrossRef](#)]
29. Rosa, G.; Huaylinos, M.L.; Gil, A.; Lanata, C.; Clasen, T. Assessing the Consistency and Microbiological Effectiveness of Household Water Treatment Practices by Urban and Rural Populations Claiming to Treat Their Water at Home: A Case Study in Peru. *PLoS ONE* **2014**, *9*, e114997. [[CrossRef](#)]
30. Christen, A.; Duran Pacheco, G.; Hattendorf, J.; Arnold, B.F.; Cevallos, M.; Indergand, S.; Colford, J.M.; Mäusezahl, D. Factors associated with compliance among users of solar water disinfection in rural Bolivia. *BMC Public Health* **2011**, *11*, 210. [[CrossRef](#)]
31. Alvear-Daza, J.J.; Sanabria, J.; Gutiérrez-Zapata, H.M.; Rengifo-Herrera, J.A. An integrated drinking water production system to remove chemical and microbiological pollution from natural groundwater by a coupled prototype helio-photochemical/H₂O₂/rapid sand filtration/chlorination powered by photovoltaic cell. *Sol. Energy* **2018**, *176*, 581–588. [[CrossRef](#)]
32. Wolf, J.; Prüss-Ustün, A.; Cumming, O.; Bartram, J.; Bonjour, S.; Cairncross, S.; Clasen, T.; Colford, J.M., Jr.; Curtis, V.; De France, J.; et al. Systematic review: Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: Systematic review and meta-regression. *Trop. Med. Int. Health* **2014**, *19*, 928–942. [[CrossRef](#)] [[PubMed](#)]
33. Kondo Nakada, L.Y.; Urban, R.C. Priority areas for the use of solar water disinfection (SODIS) in Brazil: A spatial approach. *J. Water Sanit. Hyg. Dev.* **2024**, *14*, 950–962. [[CrossRef](#)]
34. Orgill, J.; Shaheed, A.; Brown, J.; Jeuland, M. Water quality perceptions and willingness to pay for clean water in peri-urban Cambodian communities. *J. Water Health* **2013**, *11*, 489–506. [[CrossRef](#)] [[PubMed](#)]
35. Rufener, S.; Mäusezahl, D.; Mosler, H.-J.; Weingartner, R. Quality of drinking-water at source and point-of-consumption—Drinking cup as a high potential recontamination risk: A field study in Bolivia. *J. Health Popul. Nutr.* **2010**, *28*, 34–41. [[CrossRef](#)]
36. McGuigan, K.G.; Samaiyar, P.; du Preez, M.; Conroy, R.M. High compliance randomized controlled field trial of solar disinfection of drinking water and its impact on childhood diarrhea in rural Cambodia. *Environ. Sci. Technol.* **2011**, *45*, 7862–7867. [[CrossRef](#)]
37. Rainey, R.C.; Harding, A.K. Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal. *Int. J. Environ. Health Res.* **2005**, *15*, 361–372. [[CrossRef](#)]
38. Borde, P.; Elmusharaf, K.; McGuigan, K.G.; Keogh, M.B. Community challenges when using large plastic bottles for Solar Energy Disinfection of Water (SODIS). *BMC Public Health* **2016**, *16*, 931. [[CrossRef](#)]
39. Brockliss, S.; Luwe, K.; Ferrero, G.; Morse, T. Assessment of the 20L SODIS bucket household water treatment technology under field conditions in rural Malawi. *Int. J. Hyg. Environ. Health* **2022**, *240*, 113913. [[CrossRef](#)]
40. Kraemer, S.M.; Mosler, H.-J. Persuasion factors influencing the decision to use sustainable household water treatment. *Int. J. Environ. Health Res.* **2010**, *20*, 61–79. [[CrossRef](#)]
41. Mosler, H.-J.; Kraemer, S.M.; Johnston, R.B. Achieving long-term use of solar water disinfection in Zimbabwe. *Public Health* **2013**, *127*, 92–98. [[CrossRef](#)] [[PubMed](#)]
42. Meierhofer, R.; Landolt, G. Factors supporting the sustained use of solar water disinfection—Experiences from a global promotion and dissemination programme. *Desalination* **2009**, *248*, 144–151. [[CrossRef](#)]
43. Tamas, A.; Mosler, H.-J. Why do people stop treating contaminated drinking water with Solar Water Disinfection (SODIS)? *Health Educ. Behav. Off. Publ. Soc. Public Health Educ.* **2011**, *38*, 357–366. [[CrossRef](#)] [[PubMed](#)]
44. GSS. 2010 Population & Housing Census: Demographic, Social, Economic & Housing Characteristics; Ghana Statistical Service: Accra, Ghana, 2013.
45. García-Gil, Á.; García-Muñoz, R.A.; McGuigan, K.G.; Marugán, J. Solar water disinfection to produce safe drinking water: A review of parameters, enhancements, and modelling approaches to make sodis faster and safer. *Molecules* **2021**, *26*, 3431. [[CrossRef](#)]
46. McGuigan, K.G.; Conroy, R.M.; Mosler, H.-J.; du Preez, M.; Ubomba-Jaswa, E.; Fernandez-Ibañez, P. Solar water disinfection (SODIS): A review from bench-top to roof-top. *J. Hazard. Mater.* **2012**, *235–236*, 29–46. [[CrossRef](#)]
47. Chaúque, B.J.M.; Brandão, F.G.; Rott, M.B. Development of solar water disinfection systems for large-scale public supply, state of the art, improvements and paths to the future—A systematic review. *J. Environ. Chem. Eng.* **2022**, *10*, 107887. [[CrossRef](#)]

48. Dawney, B.; Cheng, C.; Winkler, R.; Pearce, J.M. Evaluating the geographic viability of the solar water disinfection (SODIS) method by decreasing turbidity with NaCl: A case study of South Sudan. *Appl. Clay Sci.* **2014**, *99*, 194–200. [[CrossRef](#)]
49. Dessie, A.; Alemayehu, E.; Mekonen, S.; Legesse, W.; Kloos, H.; Ambelu, A. Solar disinfection: An approach for low-cost household water treatment technology in Southwestern Ethiopia. *J. Environ. Health Sci. Eng.* **2014**, *12*, 25. [[CrossRef](#)]
50. Contzen, N.; Kollmann, J.; Mosler, H.-J. The importance of user acceptance, support, and behaviour change for the implementation of decentralized water technologies. *Nat. Water* **2023**, *1*, 138–150. [[CrossRef](#)]
51. Hoffmann, S.; Feldmann, U.; Bach, P.M.; Binz, C.; Farrelly, M.; Frantzeskaki, N.; Hiessl, H.; Inauen, J.; Larsen, T.A.; Lienert, J.; et al. A research agenda for the future of urban water management: Exploring the potential of nongrid, small-grid, and hybrid solutions. *Environ. Sci. Technol.* **2020**, *54*, 5312–5322. [[CrossRef](#)]
52. Pickering, A.J.; Crider, Y.; Amin, N.; Bauza, V.; Unicomb, L.; Davis, J.; Luby, S.P. Differences in field effectiveness and adoption between a novel automated chlorination system and household manual chlorination of drinking water in Dhaka, Bangladesh: A randomized controlled trial. *PLoS ONE* **2015**, *10*, e0118397. [[CrossRef](#)] [[PubMed](#)]
53. Marston, L.; Cai, X. An overview of water reallocation and the barriers to its implementation. *WIREs Water* **2016**, *3*, 658–677. [[CrossRef](#)]
54. Hurland, K.; Martin, N.; Dreibelbis, R.; Valliant, J.; Winch, P. *What Factors Affect Sustained Adoption of Safe Water, Hygiene and Sanitation Technologies? A Systematic Review of Literature*; University College London: London, UK, 2015.
55. Murray, A.L.; Napotnik, J.A.; Rayner, J.S.; Mendoza, A.; Mitro, B.; Norville, J.; Faith, S.H.; Eleveld, A.; Jellison, K.L.; Lantagne, D.S. Evaluation of consistent use, barriers to use, and microbiological effectiveness of three prototype household water treatment technologies in Haiti, Kenya, and Nicaragua. *Sci. Total Environ.* **2020**, *718*, 134685. [[CrossRef](#)] [[PubMed](#)]
56. Mulenga, J.N.; Bwalya, B.B.; Kaliba-Chishimba, K. Determinants and inequalities in access to improved water sources and sanitation among the Zambian households. *Int. J. Dev. Sustain.* **2017**, *6*, 746–762.
57. Tuyet-Hanh, T.T.; Lee, J.-K.; Oh, J.; Van Minh, H.; Ou Lee, C.; Hoan, L.T.; Nam, Y.-S.; Long, T.K. Household trends in access to improved water sources and sanitation facilities in Vietnam and associated factors: Findings from the Multiple Indicator Cluster Surveys, 2000–2011. *Glob. Health Action* **2016**, *9*, 29434. [[CrossRef](#)]
58. Pullan, R.L.; Freeman, M.C.; Gething, P.W.; Brooker, S.J. Geographical Inequalities in Use of Improved Drinking Water Supply and Sanitation across Sub-Saharan Africa: Mapping and Spatial Analysis of Cross-sectional Survey Data. *PLoS Med.* **2014**, *11*, e1001626. [[CrossRef](#)]

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