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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. Exploratory sequential mixed-methods design (QUAL→QUAN) was used to explore the enablers and barriers as well as reported barrier perceptions to effective implementation of DSODIS in the Sawla-Tuna-Kalba district (STK) of Ghana. The qualitative data (26 respondents) were analyzed thematically, and the quantitative data (1155 household heads) were subjected to a Poisson regression analysis. Enablers were categorized into themes 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, born in community, and lived 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, respectively, 43% and 30% more likely 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. The findings provide valuable information to policymakers and stakeholders aimed at providing quality water in rural Ghana, where centralized systems cannot be installed.

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

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 a community engagement[2]. A major concern to providing safe, and available water is identifying community-based indigenous

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knowledge and experience of enablers and barriers to safe water management and implementation of simple technologies. Unimproved water source treatment before use serves as a block of primary prevention and control of diarrhea and other related waterborne diseases [4], [5], [6].

Access to quality water in rural Ghana is championed by the service entity- Community Water and Sanitation Agency (CWSA). 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 CWSA, existing data shows that, water infrastructure such as boreholes fitted with hand pumps and hand-dug wells, piped schemes and mechanized systems are being improved [8], [9]. This however, does not entirely meet the growing population's increasing need for improved water, hence, pressure on existing water resources continues to increase [10].

With the increasing demand to extend coverage to other areas due to pressure on current existing water resources of the country, 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 and more particularly the Savannah region of Ghana. Solar water disinfection systems therefore remain viable options to improved water access in rural areas where centralized water systems cannot be installed [11], [12], [13]. Conventional solar water disinfection systems in continuous flow systems serve as an alternative for large-scale improved water access in rural contexts [14]. The scalability of decentralized solar water disinfection systems (DSODIS) as an intervention for rural communities lacking 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], [13], [14], [15]. Although DSODIS may improve clean water access, there is no available data to support the enablers 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 provision of potable water to all indigenes as well as meeting the sustainable development goal six (SDG6), "availability and sustainable management of water and sanitation for all". Different enablers and barriers may variously influence the effective implementation of DSODIS in rural Ghana. Nonetheless, studies that determined perceived enablers and barriers to DSODIS implementation in rural Ghana at the household level are nascent. Additionally, how the combined effects of household water source and income influence reported barrier perceptions of DSODIS implementation is limited. This present study therefore employs an exploratory sequential mixed-methods design (QUAL→QUAN) to understand households' perceptions on the enablers and barriers to effective implementation of DSODIS in the Sawla-Tuna-Kalba District (STK) of Ghana. Also, the interactive effects of household water source and income on the number of reported barrier perceptions in the implementation of DSODIS in the STK district was explored. Furthermore, this study evaluated how the relationship between household water source and income on reported barrier perceptions and DSODIS implementation is attenuated when theoretically relevant factors (compositional and contextual) were controlled for.

Promoting the enablers and mitigating the barriers are necessary for the implementation of DSODIS in rural parts of Ghana for the achievement of quality water access to all. The findings in this study will provide valuable information to policymakers and stakeholders aimed at providing quality water in rural Ghana.

2. Materials and Methods

Data source

This study uses household survey data from the Sawla-Tuna-Kalba (STK) District of the Savannah Region of Ghana. The STK District is described in Afitiri & Afrifa, [12]. Two distinct data types were collected i.e. qualitative and quantitative data. With respect to the qualitative data, 26

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household heads were included in the study based on the criteria that; i. They live in the STK District and community of residence for the past 10 years, ii. Use unimproved water source (either as primary or secondary water source), iii. Have local representativeness, iv. Can 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 i. was part/located in the STK District. ii. was rural with household population less than 500. iii. uses an unimproved water source either as a primary or secondary water source. The definition of unimproved water source in the context of this study refers to water sources that are not protected from outside contamination especially faecal 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 faecal matter. These water sources include household connections, standpipes, boreholes, protected dug wells, protected springs.

Data collection and sampling procedure

The qualitative research adopted a phenomenological approach to explore respondents' experiences about the enablers 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. A purposive sampling technique was utilized to select the 26 household heads as study respondents based on their experiences of water treatment and infrastructure, local representativeness and ability to fully express their thoughts. Participants responses were audio recorded.

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

Measures

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

The quantitative data collection instrument (questionnaire) was designed for the cross-sectional study consisting of five (5) measuring dimensions: background information including socio-demographic variables, water quality, water practice, water treatment system and barriers to the implementation of DSODIS. The barriers components of the questionnaire consisted of six identified barriers that respondents are required to answer if they are barriers in their opinion. These barriers emanated from the responses of the qualitative study and review of literature. Cronbach's alpha (α) was used to measure the internal consistency and reliability of the quantitative data on the barriers of DSODIS and a value of $\alpha = 0.790$ was obtained. This means the items measuring barriers of DSODIS implementation in this study have strong internal consistency and reliability.

Response variable

The dependent or response variable used in this study was the total number of reported barriers perceptions each of the household head in the study area (STK district) reported. Six questions measured the barriers and were used to generate the count dependable variable (barrier perceptions). The perceived barriers are presented on a Likert scale (Strongly disagree, disagree, neutral, agree, strongly agree). For analyses, all responses under strongly disagree, disagree and neutral were combined and recoded as "No (0)" and responses under agree and strongly agree were combined and recoded as "Yes (1)". A "no" means it is not a perceived barrier while a "yes" means it is a perceived barrier. The response variable (barrier perceptions) was generated by combining the six

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different questions that measured barriers in the implementation of DSODIS in the STK District. Hence, the maximum perceived barriers reported by a respondent was 6 while the minimum was 0.

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 were based on literature, parsimony, model fit, practical significance and theoretical relevance. The key explanatory variable "water income" was derived from combining two variables - household source of water (unimproved, improved) and household monthly income (low, high). This yielded four (4) mutually exclusive groups namely: Unimproved Low income, Unimproved high income, improved low income, improved high income. The variable household source of water 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" and 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 analyses it was grouped into two distinct categories using World Bank criteria, thus Low income (earn <1.9USD a day), high income (earn >1.9 USD a day) [16]. A conversion rate of 1 USD = 15 Ghana 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).

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), 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], [18], [19]. Except 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], [19], [20].

Contextual factors simply are geographical location and or environmental conditions. For this study, contextual factors considered are, lived in the community in years (0-19, 20-29, 30-39, 40 and more) and communities' 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 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. Communities zones was derived by grouping the District into four zones from which 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), Zone 4 - Tuna/Sanyeri zone (Nafaa, Nakwabi, Nahare, Yipala, Soma, Jokolpo).

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 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 relevant theoretically relevant compositional and contextual factors. The data was subjected to both univariate/descriptive (Pearson's Chi square and Cramer's V statistics) and multivariate

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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

A 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 the incidence rate ratios (IRR). An IRR greater than 1 means a higher number of reported barrier perceptions; IRR less than 1 indicates a lower number of reported barrier perceptions; and IRR equal to 1 means the predictor does not affect the number of reported barrier perceptions.

The preferred Poisson model was determined by comparing the 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 figure becomes the preferred model [18], [21]. The analyses output shows that the Poisson regression model best fit the data when the AIC or BIC statistics were determined hence 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 (model1), sociocultural factors (model 2), and contextual factors (model 3).

Ethical statement

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

3. Results

Descriptive statistics for qualitative data

The total number of respondents included in the qualitative study were 26 respondents. Table 1 shows the demographic characteristics of the respondents for the qualitative study. Eighty-five percent (85%) of the respondents were married, and 65% had no formal education, and majority (73%) are farmers. The extended household type (58%) constituted half of the type of household among respondents (Table 1). The mean (±SD) and age range of respondents were respectively 38 years (±5) and 30 - 46 (years). The time range for the interviews was 39 – 67 minutes with average time for a respondent as 53 minutes. Figures 1 shows the primary and secondary water sources of the respondents.

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

<Insert Table 1>

<Insert Figure 1>

Figure 1: Respondents household water sources

Participants opinion about water quality

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

1. Knowledge about water quality

All respondents correctly described water quality 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).

2. Water treatment at home

Almost all the respondents are aware of simple water treatment methods to improve water quality before use. A proportion of 38% and 77% of the study participants respectively lives directly on unimproved water source as their primary and secondary water sources. Knowledge of simple water treatment methods such as addition of alum, filtration, and boiling were reported. One

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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. Sources of water contamination

Study 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 "*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)

Enablers to effective implementation of DSODIS

Responses on the enablers of implementing DSODIS are 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.

1. Willingness to pay for DSODIS

All respondents showed a high level of commitment to contribute to the long-term use of DSODIS in their communities in the form of money. Though a greater proportion were farmers, a strong willingness was expressed. On the amount a respondent is 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 if higher monetary commitment is required, many will not be able to afford.

2. Household and community participation

Respondents expressed their support in regards to DSODIS implementation. This drive was as a result of the advantages the respondents perceived for DSODIS implementation. The highlighted advantages of DSODIS included no need to spend on alum acquisition, fuel for boiling water and better water quality. A supportive statement from one of the respondents was "*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. Willingness to use water from DSODIS

All 26 respondents expressed their willingness to use water from DSODIS. Some reported statements were, "*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*".

Barriers to effective implementation of SODIS

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

Environmental barriers

Respondents reported that the District largely experiences two distinct seasons (dry and wet seasons) and therefore envisage confronting issues during the wet season as sunlight is mostly low. Other identified environmental barriers were 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) effect as a barrier of DSODIS implementation as communities are characterized with 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) and added "*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*".

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Technological barriers

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

Political and legal barriers

Some respondents raised political and legal concerns of 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 severally and never saw the reality. 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.

Economic barriers

Respondents also reported economic barriers to 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 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*".

Descriptive statistics for quantitative data

The distribution of reported number of barrier perceptions and independent variables are presented in the contingency table (Table 2).

The results show that households that use unimproved water source with low income reported the highest (8%) proportion of zero (0) barrier perception while households that use unimproved water sources with high income together with households that uses improved water source and high income both reported the least 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 least 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 respectively households with unimproved water source with low income and households with improved water source with high income. The results also show that households with unimproved water source with low income (7%) reported the least proportion of four barrier perceptions while households with unimproved water source with high income (58%) reported the highest proportion of four barrier perceptions. The results also indicate that households that uses unimproved water sources with low income (5%) reported the highest proportions 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 least proportions of five barrier perceptions (1%). The least proportion (0%) reported for six barrier perceptions was households that uses unimproved water sources with high income. The three other categories all reported a proportion of 1% for six barrier perceptions.

The chi-square statistic ($\chi 2$) results output shows that water income ($\chi 2$= 208.1646, P<0.05), born in the community ($\chi 2$= 31.6394, P<0.05), age group ($\chi 2$= 108.6041, P<0.05), educational attainments ($\chi 2$= 52.1189, P<0.05), marital status ($\chi 2$= 26.2437, P<0.05), household size ($\chi 2$= 93.2434, P<0.05), and lived in the community ($\chi 2$= 40.7603, P<0.05), were all significant, indicating that there is a

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relationship between these variables and the reported number barrier perceptions. These associations range from moderate (water income, born in the community, household size) to weak (age group, marital status, education, 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 statistic results rejected the hypothesis that reported number of barrier perceptions is independent of household water use and income, compositional and contextual factors. Hence, household source of water and income influences 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 if the analyses were repeatedly ran same results will be generated.

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

<Insert Table 2>

Multivariate analyses

Three (3) models were ran at the multivariate level (Table 3). The interactive effect of household source of water and household monthly income and biosocial factors (model 1), socio-cultural factors (model 2), and contextual factors (model 3) were developed to assess their relationship with reported number of barrier perceptions in the implementation of solar water disinfection system. The Poisson regression model output (Table 3) shows the IRR, robust standard error (SE), probability values, and CIs in the models.

<Insert Table 3>

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

The results output for Model 1reveal 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 respectively 46% and 30% more likely to report more barrier perceptions compared with their counterparts that use unimproved water sources with low income. The results equally reveal that households in 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 that are 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 socio-cultural factors. The observed relationship between the interactive effect of household water source and income and reported number of barrier perceptions in Model 1 remain robust in model 2 and 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) are respectively 43% and 25% more likely to report more barrier perceptions compared with their counterparts that use unimproved water sources with low income. Additionally, the results indicate that age group 45-54 (IRR=1.179, P=0.041) are 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) are 9% more likely to report high barrier perceptions compared with males. Regarding the variable “born in the community” household heads born in the communities they were interviewed (IRR=0.922, P=0.015) are 8% less likely to report more barrier perceptions compared with their counterparts in the reference group (no). Marital status of household heads was not a significant predictor of the number of reported barrier perceptions under this model. The model output also indicates that household heads with higher educational attainment (IRR=1.151, P=0.001) are 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).

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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 barriers 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) are respectively 43% and 30% more likely to report more barrier perceptions compared with the reference group (unimproved low income). Accounting for age in Model 3 revealed that age group 45-54 (IRR=1.198, P=0.041) are 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) are marginally more likely to report high barrier perceptions compared with males. Marital status, born in the community, living in the community (years) of household heads were not significant predictors of the number of reported barrier perceptions under model 3. 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 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). Household heads within the Tuna/Sanyeri zone (IRR=0.922, P=0.024) are 8% less likely to report more barrier perceptions compared with the reference group (Sawla zone).

4. Discussion

Discussion

The mixed method approach (QUAL→QUAN) adopted in this study provided insights from the study respondents on the concept of water quality and the barriers and enablers to effective implementation of DSODIS. Additionally, the interactive effect of household water source and income on the number of reported barrier perceptions in the implementation of DSODIS in the STK district of Ghana as well as how the relationship is attenuated when compositional and contextual factors are considered has been assessed. Awareness of potential barriers to implementation of water systems at the household level, enabling factors, and household knowledge about clean water are key to ensuring efficient implementation and management of drinking water systems [2], [22]. Generally, all the respondents had good understanding of improved water quality and ascribed safe water to water from boreholes and pipes. Since respondents largely live on unimproved water sources either as primary or secondary sources, simple treatment methods at home are being practiced including addition of alum, boiling of water and filtration. Nonetheless, about 34% of the respondents included in the qualitative study do not apply any treatment to their household water before use as they assume 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 per discussions with respondents. Similar findings are 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 source possess high risk to the health of many that depend on the source without any treatment [17], [24], [25]. 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 study respondents therefore deepen 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 over half of study participants in rural communities directly use unimproved water sources without treatment because of poor perceptions of their quality [26], [27], [28].

Improving the quality of water in rural communities require exploring their indigenous knowledge to help inform if scaling up household water treatment methods is required [2], [29]. Even though the qualitative study respondents expressed their opinions irrespective of effective water

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treatment status, upscaling solar water disinfection in the STK district will better improve water quality compared to the current practiced approaches. All 26 study respondents agreed DSODIS is a better and robust technology that can inure their access to quality water as no centralized systems are envisioned in any moment soon, hence, are willing to use water from DSODIS for household purposes. A study that assessed about 1155 households' heads willingness to adopt and use water from a DSODIS in the STK district found a 97% willingness to adopt and use water from a DSODIS [12]. These findings support earlier findings by Bitew et al., [2] and Christen et al., [30] that reported study participants willingness to adopt solar water disinfection as an alternative to other household water treatment methods.

Particularly filtration with cloths as reported by study respondents is not an effective treatment method as microbial contaminants are not treated and could affect one's health if consumed as supported in the literature [2], [31], [32]. The reported sources of contamination 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 DSODIS exist and the population lack knowledge about possible water contamination sources, then poor water quality 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 respondents had good knowledge of contamination sources, better water handling practices is 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 to DSODIS implementation were reported by the study respondents. Respondents expressed their opinions that DSODIS implementation is possible in the STK district. DSODIS could therefore serve as a suitable technology to providing improved water to communities without improved water sources. Similar observations were made in rural Cambodia where solar water disinfection was reported efficient and culturally acceptable among the population [36] as well as that of Kathmandu Valley, Nepal [37]. The present study show that positive attitude is an enabler towards effective DSODIS implementation for sustained and improved water in rural communities. DSODIS is considered a robust intervention approach to providing quality water. Study respondents also showed individual and communities' willingness to support the implementation of DSODIS as an enabling factor. These findings are in consonance with that of other studies that reported individual's commitment to continuous practice of solar water disinfection to improve household water quality [38], [39]. Factors such as community interest, knowledge, attitude, involvement, and values are important enabling factors to implementing water disinfection systems and their upscaling [2], [40], [41]. DSODIS are globally accepted by many water consumers and its implementation and sustenance can be achieved through training and promotional actions through water and sanitation (WASH) programs [2], [42], [43] as individuals and communities show interest to accept and adopt the technology.

The willingness of water consumers to contribute to the acquisition of required materials of a water system and its maintenance is an important factor to the implementation. Respondents of this current study highlighted their commitment and that of their communities to contribute financially to the implementation of DSODIS to continuously access good quality water. Community level committee to oversee the mobilization of resources from households was opined to facilitate maintenance of DSODIS. This finding supports 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 to 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], [46], [47]. Most rural areas are characterized by tall thick trees that provide shade for the indigenes. This also has the potential to cast shadow and limit the amount of sunlight effect in water

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disinfection systems as reported in Bitew et al., [2] and Ojomo et al., [5]. Overcoming this barrier will warrant that a suitable geographical location should be used to have efficient sunlight effect into the water treatment system. The quality of water from the main source is a limiting factor to DSODIS implementation efficiency and even centralized systems. Turbid water affects the depth of penetration of the sun rays responsible 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 earlier before the animals to reduce collecting too turbid water.

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

Political and legal concerns of DSODIS implementation in the district were raised. 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 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 effective implementation of DSODIS. Even though DSODIS are welcome, the economic status of the rural inhabitants may serve as a barrier to the implementation and maintenance.

The results established associations between household level characteristics and reported barrier perceptions in the quantitative study. show that water income, born in the community, age group, educational attainments, marital status, household size, and lived in the community, are 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 are more likely to report more barrier perceptions compared with the reference group (unimproved low income). This means that DSODIS barrier perceptions are concentrated in the rich households regardless of the household water quality compared to the poor ones. This finding is in consonance with the literature which suggest that having wealth increases one's ability to pay for essential service such as water even when the local authority or government is not providing this service [19], [56], [57]. This suggest that the rich households without improved water sources are faced with more barriers in accessing improved water which they could have afforded if they were in urban communities.

Female headed households are more likely to report more barrier perceptions of DSODIS implementation compared to the male counterparts. Generally, Ghanaian women and to some extent Sub-Saharan Africa (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 barrier perceptions of improved water systems implementation than their male counterparts especially when the woman is recognized as the household head.

Household heads with higher educational attainment are more likely to report more barrier perceptions compared with their counterparts with no formal education. This may be attributed to

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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 result show that household heads within age group 45-54 are 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). These findings may be as a result of their economic status with more responsibility of providing for their households compared to the younger household heads. Literature supports that governments and relevant stakeholders needs to deliberately adopt strategies that target deprived areas and population groups to achieve improve water access universally [19], [58].

Limitations of the study

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

5. Conclusions

In conclusion, respondents in the qualitative study have better understanding of water quality and are willing to use water from DSODIS. This study is the first of its kind to the best of knowledge of the researchers to use mixed methods in the assessment of the enablers and barriers to effective implementation of DSODIS, evaluate the interactive effects of household water source and income on the number of reported barrier perceptions in the implementation of DSODIS and how the relationship was attenuated when theoretically relevant factors (compositional and contextual) were considered. Respondents understanding on the concept of water quality and how it influences household water choice, treatment methods adopted to household water before use, and sources of water contamination were explored. Based on our findings, the enablers to 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, born in the community, age group, educational attainments, marital status, household size, and 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, improved water sources and high income are all more likely to report more barrier perceptions compared with those with unimproved water source and low income. Respondents in age group 45-54 are 20% more likely to report more barrier perceptions compared with the reference group (less than 25 years). Regarding gender, females are marginally more likely to report high barrier perceptions compared with males. The results further show that household heads with higher educational attainment are 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). Households

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heads within the Tuna/Sanyeri zone are 8% less likely to report more barrier perceptions compared with the reference group (Sawla zone). We suggest that piloting a DSODIS can help identify the most-appropriate settings for implementation in the STK district. Promoting the enablers and mitigating the barriers are necessary to effective implementation of DSODIS in rural parts of Ghana for the achievement of quality water access to all. The findings in this study provide valuable information to policymakers and stakeholders aimed at providing quality water in rural Ghana where centralized systems cannot be installed.

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