PLOS WATER

RESEARCH ARTICLE

Unequal access to improved water and sanitation in a post-conflict context of Liberia: Evidence from the Demographic and Health Survey

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Citation: Amoak D, Bruser G, Antabe R, Sano Y, Luignaah I (2023) Unequal access to improved water and sanitation in a post-conflict context of Liberia: Evidence from the Demographic and Health Survey. PLOS Water 2(4): e0000050. https://doi.org/10.1371/journal.pwat.0000050

Editor: Debora Walker, PLOS: Public Library of Science, UNITED STATES

Received: May 2, 2022

Accepted: March 3, 2023

Published: April 3, 2023

Data Availability Statement: This data is publicly available through the Demographic and Health Survey Program. The link to the data is is: https://dhsprogram.com/Countries/Country-Main.cfm?ctry_id=22&c=Liberia&Country=Liberia&cn=&r=1.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

Abstract

Public health and wellbeing in Liberia have been compromised by a lack of access to safe drinking water, sanitation, and hygiene (WASH), compounded by 14 years of civil unrest. After almost two decades of relative peace and stability, disparities in WASH access persist and diseases linked to WASH such as Ebola, cholera, and COVID-19 have posed major public health challenges. Yet, there is nascent research in the context of post-war Liberia examining the determinants of access to WASH. To contribute to WASH policy in Liberia, this study examined the predictors of improved water and sanitation using the 2019–20 Liberia Demographic and Health Survey. Using the complementary log-log link function, we found that some socioeconomic and geographical factors were associated with access to improved water and sanitation. For example, poorer and rural households were less likely to have access to improved water and sanitation compared to their wealthier and urban counterparts, respectively. Based on these findings, we discussed policy implications and potential directions for future research.

Introduction

Access to safe water, sanitation, and hygiene (WASH) is a fundamental human right, playing a key role in accomplishing the Sustainable Development Goals (SDGs) by 2030. Recent estimates suggest that over 25% of the global population lack access to safe drinking water (i.e., clean, accessible drinking water on-site, whenever needed) and about 46% do not have access to a safely managed sanitation facility (i.e., a sanitation facility that safely disposes of excreta off-site or on-site) [1,2]. Although progress has been made resulting in the reduction of the share of people without basic drinking water from 1.1 billion in 2000 to roughly 771 million people in 2020 [2], these global figures mask regional disparities. In particular, sub-Saharan Africa (SSA) accounts for most of the remaining population who lack access to improved

water and sanitation, making it difficult to meet SDG 6 (i.e., clean water and sanitation for all) [2–4].

A recent report by the World Health Organization (WHO) indicates that Liberia is one of the countries in SSA where access to WASH services is persistently and critically low. The report estimated that 90% of the country's population does not have access to safely managed drinking water and sanitation services [5]. For instance, only 4% of the population has access to piped water, forcing 13% to depend on untreated surface water and another 40% to commute more than 30 minutes to get clean water [6]. In addition, as much as 82% of the populace do not have access to safely managed sanitation facilities, causing 40% to engage in open defecation [7]. These national statistics illustrate the specific and unique precarity of populations who do not have access to improved water and sanitation in Liberia. This precarity is further heightened for vulnerable and structurally exposed populations as they bear the brunt of the social, economic and health implications associated with poor access to WASH. For example, the majority (i.e., 60%) of people who engage in open defecation are residents of rural areas, possibly pointing to the uneven social infrastructural deployment in Liberia [8].

Reflecting on the precarity of WASH accessibility in Liberia, it is suggested that the enduring effect of the 14-year civil war in Liberia had a significant impact on the water and sanitation infrastructure in two distinct ways: Firstly, it resulted in the direct destruction and disintegration of pre-existing infrastructure, as well as a deterioration of the associated institutions [9]. Secondly, the conflict induced substantial migration of people from rural areas into urban centers, including makeshift camps and informal settlements, which further exacerbated the burden on urban utilities [10,11]. The 2008 national census reported that the proportion of the population with access to piped water declined, plummeting from 15 percent in 1986 (pre-war) to less than 3 percent in 2008 (post- war) [11]. Additionally, WASH investments post-civil war has been consistently low, with approximately less than 0.1% of GDP allocated towards the provision and maintenance of sanitation services [12]. Coupled with this challenge, available evidence also shows that the rate of population growth in Liberia outpaces the implementation and provisioning of WASH services [13]. Consequently, studies have highlighted the difficulty in eradicating open defecation across several communities in the country [11,14].

Inadequate access to improved water and sanitation services in Liberia have been identified as a significant obstacle to the efficient delivery of quality healthcare and the containment of disease outbreaks, as evidenced by the Ebola epidemic and the COVID-19 pandemic in the last decade. For instance, a country report on WASH and Covid-19 linkages revealed that inaccessibility to safe water is associated with infrequent handwashing which is an essential part of the toolkit for mitigating the spread of infectious diseases such as COVID-19 [15]. In analyzing the Ebola epidemic in Liberia, Kanagasabai et al. [16] also found that better access to improved WASH services in health centers could have reduced Ebola infections and mortality. Furthermore, poor WASH conditions not only instigated fear and panic among healthcare workers and patients regarding the potential exposure to disease but impeded the utilization of health services, such as antenatal care and malaria treatment during the Ebola outbreak [17,18]. It was also highlighted that the use of dug-out well systems, particularly in densely populated regions like Monrovia, are mostly located in close proximity to toilet facilities (i.e., pit latrines), resulting in elevated bacterial levels in water that compromise its potability, and subsequently precipitate numerous ailments, including diarrhoea [8,19]. Similarly, an investigation into the 2018 gastroenteritis outbreak in Firestone District of Liberia found the cause to be elevated levels of E.coli and Shigella from drinking untreated water from creeks and hand pumps [20]. Consequently, many Liberians are at risk for neglected tropical diseases and their associated chronic morbidities because of poor infrastructure development, including inadequate water

and sanitation infrastructure [21]. Elsewhere, studies have revealed that poor WASH accessibility heightens women and girls' vulnerability to domestic abuse and gender-based violence [22–24]. Poor access to WASH also increases exposure to toxic contaminants, poor nutrition and food insecurity [25–27].

Multi-scalar, intersecting and contextual complexities spanning socioeconomic and geographical dimensions can facilitate or hinder WASH access [28]. In SSA, the unequal distribution of social infrastructure in some regions, counties and districts have been found to influence people's access to WASH services [13]. Specifically in the context of Liberia, this challenge may have been further compounded by the 14-year civil war. For instance, counties such as Montserrado and Grand Cape Mount were exposed to intensified conflict, violence and social infrastructure destruction, which may have heightened challenges with access to WASH relative to other counties that were less affected by the war [29]. Furthermore, the presence of international and non-governmental organizations geared toward the provision of social infrastructure in some counties could be contributing to increased access to improved water and sanitation [30]. Similarly, research pointing to an urban bias in the provisioning of social infrastructure in SSA could work to create an additional barrier for rural residents to access WASH services in Liberia [13,31,32]. In contrast to the pre-war period that emphasized rural development [33], the post-war development context of Liberia is characterised by an urban bias where the provisioning of improved water and sanitation services are mainly limited to wealthier urban households [34]. As a result, Liberia's remote regions remain underserved, and the country's inadequate and deteriorating road network presents a significant barrier to growth in those areas [34]. This demonstrates the possible contribution of geographical characteristics on access to improved water and sanitation.

Moreover, socioeconomic status emerges in the literature as an important and key determinant of access to WASH services. In many contexts in SSA including Liberia, poor provisioning and extension of social infrastructure by the government forces private citizens to pay out-of-pocket for these services. This reality restricts people with socioeconomic disadvantages from accessing improved water and sanitation. In Nigeria, Ghana, and Ethiopia there is evidence that poorer households experience significantly higher risks of exposure to non-improved water and sanitation, relative to their richer counterparts [35,36]. Wealthier households also spend a reduced amount of time collecting water relative to poorer households [36]. In addition to household wealth, formal education may provide the foundation to understand the social, economic, cultural, and health benefits of having improved water and sanitation on-site. In Nigeria, Eswatini and Ghana, it has also been found that educated households tend to have better access to improved water and sanitation as they are more aware of potential deleterious health impacts of ingesting untreated and unclean water and using non-improved sanitation [37–39]. Finally, the literature has established that access to improved water sources tends to be positively associated with improved sanitation [36].

While the above studies are important and useful in unpacking the complex and nuanced nature of access to improved water and sanitation, the literature has afforded little attention to WASH accessibility in the context of post-war Liberia. This void in the literature is particularly worrying in the policy context of Liberia's Poverty Reduction and Growth Strategy where the government aims to ensure safe, equitable, affordable and sustainable water supply and sanitation services for all Liberians by 2023 [40]. To this end, we use data from the Liberia Demographic and Health Survey to investigate the prevalence and determinants of access to improved water and sanitation. We aim to generate insights that can better inform and help achieve the government's 2023 policy targets on WASH and the Sustainable Development Goal 6 by 2030.

Methods and materials

Data

We used the 2019/2020 Liberia Demographic and Health Survey (LDHS), which is a nationally representative survey consisting of male and female respondents aged 15–49 and 15–54, respectively. The LDHS was implemented by the Liberia Institute of Statistics and Geo-Information Services and Liberia Ministry of Health, with technical assistance from the DHS Program. The data collection process took place between October 2019 and February 2020, before the WHO declared COVID-19 a global pandemic. Overall, 9,207 occupied housing units were selected to participate in the LDHS, and 9,068 were successfully interviewed, resulting in a 99% response rate. These data were collected through a series of standardized questionnaires at the individual and household levels. For the purpose of our study, we focused on household-level responses, which corresponded to a total sample of 8,867 households.

Measures

There are two dependent variables. For one, the respondents were asked to indicate their source of drinking water. Based on this question, we constructed a binary variable called 'sources of drinking water' (0 = non-improved sources; 1 = improved sources). Informed by the WHO definition, non-improved sources include unprotected dug well, unprotected spring, and mostly surface water sources such as rivers, ponds, and streams. By contrast, improved sources include piped water in the yard, plot or neighbour, protected wells, bottled water, mineral water in a sachet, protected spring and rainwater. For another, the respondents were asked to indicate their type of toilet facility. Based on this question, we constructed a binary variable called 'sanitation facilities' (0 = non-improved facilities; 1 = improved facilities). Consistent with the WHO definition, non-improved facilities include flush to somewhere else, pit latrine without slab/open pit, bucket toilet, hanging toilet/latrine and others. Improved facilities include flush to a piped sewer system, septic tank, pit latrine, ventilated improved pit latrine, pit latrine with slab, and composting toilet.

Based on the literature above, we include three sets of covariates in this study, namely socioeconomic, geographical, and demographic factors. Socioeconomic factors include level of education (0 = no education/preschool; 1 = primary; 2 = secondary; 3 = higher) and household wealth quintile (0 = richest, 1 = richer, 2 = middle; 3 = poorer; 4 = poorest). For models to predict sanitation facilities, we also included source of drinking water as a socioeconomic factor (0 = non-improved sources; 1 = improved sources). We also considered region of residence (0 = Grand Gedeh; 1 = Bomi; 2 = Bong; 3 = Grand Bassa; 4 = Grand Cape Mount; 5 = Grand Kru; 6 = Lofa; 7 = Margibi; 8 = Maryland; 9 = Montserrado; 10 = Nimba; 11 = River Cess; 12 = Sinoe; 13 = River Gee; 14 = Gbarpolu) and place of residence (0 = urban; 1 = rural) as geographical factors. In addition to these two factors, time to water source (0 = 30 minutes or less; 1 = more than 30 mins) was included as a geographical factor for models predicting the source of drinking water. Finally, we added four demographic variables including gender (0 = female; 1 = male), age (0 = 18–29; 1 = 30–39; 2 = 40–49; 3 = 50+), marital status (0 = single; 1 = married; 2 = widowed; 3 = divorced), and household size (0 = 7+; 1 = 6–4; 2 = 3–1).

Inclusivity in global research

Additional information regarding the ethical, cultural, and scientific considerations specific to inclusivity in global research is included in the (S1 Text).

Data analysis

We employed univariate, bivariate, and multivariate analysis in this study. Univariate analysis was conducted to describe the characteristics of our analytical sample. We also employed bivariate analysis to understand the unadjusted associations between the dependent and independent variables. Multivariate analysis was further conducted to examine the net relationships on the dependent and independent variables while adjusting for a series of demographic, socioeconomic, and geographical factors. For bivariate and multivariate analysis, we found that the dependent variables (i.e., source of drinking water and sanitation) were not symmetrically distributed. Specifically, as shown in Table 1, the higher category of "source of drinking water" was more probable (i.e., 78%), although that of "sanitation" was less probable (i.e., 35%). In this case, using a simple logit link function which assumes symmetry could potentially produce biased parameter estimates. To address this concern, we relied on the complementary log-log link function, which is considered more suitable when the dependent variable follows an asymmetrical distribution. Using STATA 16, sampling weights were used to adjust for the complex sampling structure of the data in statistical analyses. The findings observed after running regression analysis are reported in odds ratios (ORs). Any ORs larger than "one" indicate that households are more likely to have improved water sources and sanitation facilities while those smaller than "one" imply lower odds of doing so.

Findings

Table 1 shows univariate findings. We find that 78% and 35% of households had improved sources of drinking water and sanitation facilities, respectively. In addition, 34% were female-headed households. The largest age category was 50 years and above (31%), followed by 30–39 (27%), and 40–49 (22%). About seven in ten households (66%) were also married. More than half of households were in urban areas (57%). The largest number of people lived in Montserrado (36%), followed by Nimba (13%) and Bong (9%).

Table 2 shows bivariate findings. Overall, a range of socioeconomic, geographic, and demographic factors were associated with sources of drinking water as well as sanitation facilities. For socioeconomic factors, we find that households with secondary, primary, and no education were all less likely to have improved sources of drinking water and sanitation facilities, compared to their counterparts with higher education. Household wealth was also significantly associated with sources of drinking water and sanitation facilities, pointing out that poorer households were less likely to have access to improved drinking water sources and sanitation facilities, compared to their richer counterparts. In terms of geographical factors, we find that households in Grand Gedeh had the highest odds of having improved drinking water sources, except that the difference between Montserrado and Grand Gedeh was not statistically significant (OR = 1.01, $p>0.05$). For sanitation facilities, however, the odds were the highest for Montserrado (OR = 2.15, $p<0.001$). It is also noteworthy that households that have non-improved sources of drinking water were less likely to have improved sanitation facilities (OR = 0.21, $p<0.001$). Rural households were also less likely to have improved drinking water sources (OR = 0.38, $p<0.001$) and sanitation facilities (OR = 0.22, $p<0.001$), compared to their urban counterparts. For demographic factors, we find that male-headed households were less likely to have improved drinking water sources in comparison to their female-headed counterparts (OR = 0.86, $p<0.001$). In addition, older households (i.e., 40–49 and 50+) were less likely to have improved drinking water sources and sanitation facilities, compared to the youngest cohort (i.e., 15–29). Similarly, married, widowed, and divorced households were all less likely to have improved drinking water sources and sanitation facilities, compared to their single counterparts. Finally, compared to the largest households (i.e., 7+), smaller households (i.e.,

Table 1. Sample characteristics.

	Percentage
Source of drinking water	
Non-improved	22
Improved	78
Sanitation facilities	
Non-improved	65
Improved	35
Level of education	
Higher	12
Secondary	40
Primary	27
No education	32
Household wealth	
Richest	10
Richer	13
Middle	20
Poorer	26
Poorest	31
Time to get water	
30 minutes or less	90
More than 30 minutes	10
Region of residence	
Grand Dedeh	3
Bomi	4
Bong	9
Grand Bassa	6
Grand Cape Mount	4
Grand Kru	2
Lofa	8
Margibi	6
Maryland	3
Montserrado	36
Nimba	13
River Cess	2
Sinoe	3
River Gee	1
Gbarpolu	2
Place of residence	
Urban	57
Rural	43
Gender	
Female	34
Male	66
Age	
15–29	19
30–39	27
40–49	22
50+	31

(*Continued*)

Table 1. (Continued)

	Percentage
Marital status	
Single	16
Married	66
Widowed	9
Divorced	9
Household size	
7+	21
6–4	41
3–1	38
Total	8,867

https://doi.org/10.1371/journal.pwat.0000050.t001

6–4 and 3–1) were also less likely to have improved drinking water sources and sanitation facilities.

Multivariate results for sources of drinking water are shown in Table 3. In Model 1, we estimate the associations between two socioeconomic factors (i.e., education and household wealth) and sources of drinking water while accounting for demographic factors. Results indicate that middle (OR = 0.58, $p<0.001$), poorer (OR = 0.42, $p<0.001$), and poorest (OR = 0.18, $p<0.001$) households were less likely to have improved drinking water sources, compared to their richest counterparts; however, the relationship between education and sources of drinking water was no longer statistically significant. We further examine how drinking water sources are related to several geographical factors while accounting for demographic factors in Model 2. It is shown that households in Bong (OR = 0.39, $p<0.001$), Grand Bassa (OR = 0.21, $p<0.001$), Grand Cape Mount (OR = 0.49, $p<0.001$), Grand Kru (OR = 0.34, $p<0.001$), Lofa (OR = 0.44, $p<0.001$), Margibi (OR = 0.44, $p<0.001$), Maryland (OR = 0.59, $p<0.001$), Montserrado (OR = 0.56, $p<0.001$), Nimba (OR = 0.38, $p<0.001$), River Cess (OR = 0.28, $p<0.001$), Sinoe (OR = 0.36, $p<0.001$), River Gee (OR = 0.60, $p<0.001$), and Gbarpolu (OR = 0.38, $p<0.001$) were all less likely to have improved sources of drinking water, compared to those in Grand Gedeh. In addition, compared to their urban counterparts, households in rural areas were less likely to have improved sources of drinking water (OR = 0.44, $p<0.001$). We fully adjusted for socioeconomic, geographical, and demographic factors in Model 3 and found that the patterns observed in Models 1 and 2 remained largely robust in terms of statistical significance. For demographic factors, it is interesting that older households —i.e., 40–49 (OR = 0.87, $p<0.05$) and 50+ (OR = 0.84, $p<0.05$)—were less likely to have improved drinking water sources, compared to the youngest cohort (i.e., 15–29).

Multivariate results for sanitation facilities are shown in Table 4. In Model 1, we estimate the associations between three socioeconomic factors (i.e., education, household wealth, and sources of drinking water) and sanitation facilities while accounting for demographic factors. We find that households with secondary (OR = 0.65, $p<0.001$), primary (OR = 0.62, $p<0.001$), and no education (OR = 0.62, $p<0.001$) were all less likely to have improved sanitation facilities, compared to those with higher education. Similarly, compared to their richest counterparts, richer (OR = 0.60, $p<0.001$), middle (OR = 0.35, $p<0.001$), poorer (OR = 0.16, $p<0.001$), and poorest (OR = 0.06, $p<0.001$) households were all less likely to have improved sanitation facilities. Importantly, we also find that households without improved sources of drinking water were less likely to have improved sanitation facilities in comparison to those with improved sources (OR = 0.73, $p<0.001$). We further examine how sanitation facilities are related to several geographical factors while accounting for demographic factors in Model 2.

Table 2. Bivariate analysis of 'source of drinking water' and 'sanitation facilities' in Liberia.

	Source of drinking water			Sanitation facilities		
	OR	95% CI		OR	95% CI	
Level of education						
Higher	1.00			1.00		
Secondary	0.66***	0.58	0.76	0.40***	0.35	0.45
Primary	0.46***	0.40	0.53	0.22***	0.19	0.26
No education	0.44***	0.38	0.50	0.21***	0.19	0.25
Household wealth						
Richest	1.00			1.00		
Richer	0.89	0.73	1.09	0.56***	0.48	0.65
Middle	0.59***	0.49	0.70	0.31***	0.27	0.37
Poorer	0.41***	0.34	0.48	0.13***	0.11	0.16
Poorest	0.18***	0.15	0.21	0.04***	0.03	0.05
Time to get water						
30 minutes or less	1.00					
More than 30 minutes	1.08	0.97	1.20			
Source of drinking water						
Improved				1.00		
Non-improved				0.21***	0.18	0.25
Region of residence						
Grand Gedeh	1.00			1.00		
Bomi	0.73**	0.60	0.90	0.54***	0.41	0.70
Bong	0.45***	0.38	0.53	0.71***	0.57	0.87
Grand Bassa	0.23***	0.19	0.28	0.66***	0.53	0.82
Grand Cape Mount	0.44***	0.36	0.53	0.60***	0.48	0.76
Grand Kru	0.31***	0.25	0.38	0.16***	0.11	0.22
Lofa	0.48***	0.40	0.57	0.60***	0.48	0.75
Margibi	0.57***	0.47	0.68	1.22	0.99	1.50
Maryland	0.72***	0.60	0.85	0.87	0.70	1.07
Montserrado	1.01	0.86	1.19	2.15***	1.81	2.56
Nimba	0.55***	0.46	0.65	0.94	0.76	1.17
River Cess	0.25***	0.21	0.31	0.48***	0.37	0.63
Sinoe	0.36***	0.30	0.43	0.46***	0.36	0.58
River Gee	0.69***	0.57	0.84	0.66***	0.52	0.84
Gbarpolu	0.35***	0.29	0.43	0.43***	0.33	0.56
Place of residence						
Urban	1.00			1.00		
Rural	0.38***	0.35	0.40	0.22***	0.20	0.24
Gender						
Female	1.00			1.00		
Male	0.86***	0.80	0.91	0.95	0.86	1.05
Age						
15–29	1.00			1.00		
30–39	0.92	0.84	1.01	1.05	0.92	1.21
40–49	0.82***	0.75	0.90	0.86*	0.74	0.99
50+	0.78***	0.72	0.85	0.85*	0.74	0.97
Marital status						
Single	1.00			1.00		

(*Continued*)

Table 2. (Continued)

	Source of drinking water			Sanitation facilities		
	OR	**95% CI**		**OR**	**95% CI**	
Married	0.67***	0.61	0.73	0.63***	0.55	0.72
Widowed	0.70***	0.62	0.80	0.58***	0.48	0.70
Divorced	0.69***	0.61	0.79	0.61***	0.50	0.75
Household size						
7+	1.00			1.00		
6–4	0.91**	0.84	0.98	0.83**	0.74	0.94
3–1	0.89**	0.82	0.97	0.87*	0.77	0.98

*p<0.05

**p<0.01

***p<0.001.

https://doi.org/10.1371/journal.pwat.0000050.t002

Results indicate that households in Bomi (OR = 0.76, p<0.05), Bong (OR = 0.65, p<0.001), Grand Bassa (OR = 0.72, p<0.01), Grand Kru (OR = 0.23, p<0.001), Lofa (OR = 0.58, p<0.001), Maryland (OR = 0.68, p<0.001), Nimba (OR = 0.69, p<0.01), River Cess (OR = 0.76, p<0.05), Sinoe (OR = 0.54, p<0.001), River Gee (OR = 0.58, p<0.001), and Gbarpolu (OR = 0.62, p<0.001) were all less likely to have improved sanitation facilities, compared to those in Grand Gedeh. In addition, compared to their urban counterparts, households in rural areas were less likely to have improved sanitation facilities (OR = 0.29, p<0.001). We fully adjusted for socioeconomic, geographical, and demographic factors in Model 3 and found that the patterns in Models 1 and 2 did not substantially change although the difference in accessing improved sanitation facilities between Grand Gedeh and Montserrado was suppressed, making this statistically significant (OR = 0.57, p<0.001). A further analysis reveals that urban-rural residence was responsible for this modification.

Discussion

While Liberia is implementing several measures to make improved water and sanitation available to the populace, the current state of its WASH facilities threaten the goal of ensuring safe, equitable, affordable and sustainable water supply and sanitation services for all Liberians by 2023 as outlined in Liberia's Poverty Reduction and Growth Strategy [40]. Given evidence of the country's heightened risk to WASH-related illnesses, there is a need for an appraisal of the factors influencing access to improved water and sanitation. Using data from the 2019/20 LDHS, we contribute to WASH policymaking in post-conflict Liberia by examining the factors that influence access to improved water and sanitation. Our results point to the complex interplay of structural conditions through the mediums of socioeconomic and geographic factors that shape access to improved water and sanitation in the context of Liberia.

Our analysis highlights that household heads with higher levels of educational attainment were more likely to have access to improved sanitation facilities than those with lower levels of education. This finding is consistent with Armah et al. [13] and Adams et al. [36], pointing to the positive relationship between higher educational attainment and access to improved sanitation services in SSA. In explaining this relationship, studies have suggested that a higher level of educational attainment is a medium for people to understand the social and health benefits of using improved water and sanitation. Specifically, Agbadi et al. [39] argued in the context of Ghana that household heads with higher educational attainment were not only more likely to recognize improved WASH as necessary to securing their health and well-being, but were also

Table 3. Multivariate analysis of 'source of drinking water' in Liberia.

	Model 1			Model 2			Model 3		
	OR	95% CI		OR	95% CI		OR	95% CI	
Level of education									
Higher	1.00						1.00		
Secondary	1.01	0.83	1.22				1.02	0.83	1.26
Primary	0.99	0.81	1.20				1.03	0.83	1.27
No education	0.96	0.79	1.17				1.01	0.82	1.26
Household wealth									
Richest	1.00						1.00		
Richer	0.88	0.71	1.09				0.94	0.75	1.18
Middle	0.58***	0.48	0.71				0.65***	0.51	0.83
Poorer	0.42***	0.34	0.51				0.52***	0.40	0.67
Poorest	0.18***	0.15	0.22				0.24***	0.19	0.31
Time to get water									
30 minutes or less				1.00			1.00		
More than 30 minutes				0.98	0.86	1.12	0.89	0.77	1.04
Region of residence									
Grand Gedeh				1.00			1.00		
Bomi				0.80	0.64	1.01	0.70**	0.55	0.90
Bong				0.39***	0.32	0.47	0.40***	0.32	0.50
Grand Bassa				0.21***	0.17	0.26	0.20***	0.16	0.25
Grand Cape Mount				0.49***	0.39	0.60	0.42***	0.34	0.53
Grand Kru				0.34***	0.27	0.42	0.35***	0.28	0.44
Lofa				0.44***	0.36	0.54	0.42***	0.34	0.52
Margibi				0.44***	0.35	0.55	0.35***	0.27	0.46
Maryland				0.59***	0.48	0.73	0.56***	0.44	0.70
Montserrado				0.56***	0.46	0.69	0.40***	0.32	0.51
Nimba				0.38***	0.31	0.47	0.41***	0.32	0.51
River Cess				0.28***	0.23	0.35	0.28***	0.22	0.35
Sinoe				0.36***	0.30	0.45	0.34***	0.27	0.43
River Gee				0.60***	0.47	0.76	0.60***	0.46	0.77
Gbarpolu				0.38***	0.31	0.48	0.38***	0.30	0.48
Place of residence									
Urban				1.00			1.00		
Rural				0.44***	0.40	0.47	0.69***	0.62	0.76
Gender									
Female	1.00			1.00			1.00		
Male	0.91	0.82	1.01	0.96	0.88	1.06	0.96	0.87	1.07
Age									
15–29	1.00			1.00			1.00		
30–39	0.92	0.81	1.04	0.95	0.83	1.08	0.90	0.79	1.03
40–49	0.87*	0.76	0.99	0.91	0.80	1.03	0.87*	0.76	1.00
50+	0.84*	0.73	0.96	0.89	0.77	1.01	0.85*	0.73	0.98
Marital status									
Single	1.00			1.00			1.00		
Married	0.87*	0.76	0.99	0.87*	0.76	0.99	0.88	0.76	1.01
Widowed	1.04	0.86	1.27	0.97	0.80	1.18	1.08	0.88	1.33
Divorced	1.03	0.87	1.22	0.99	0.84	1.18	1.10	0.92	1.31

(*Continued*)

Table 3. (Continued)

	Model 1			Model 2			Model 3		
	OR	**95% CI**		**OR**	**95% CI**		**OR**	**95% CI**	
Household size									
7+	1.00			1.00			1.00		
6–4	1.00	0.90	1.12	0.90	0.81	1.00	1.00	0.89	1.12
3–1	0.92	0.82	1.04	0.80***	0.71	0.89	0.90	0.80	1.02
Wald x2	1021.828***			1025.33***			1266.29***		
Log pseudolikelihood	-2901.9225			-3066.1305			-2721.1499		

*p<0.05

**p<0.01

***p<0.001.

https://doi.org/10.1371/journal.pwat.0000050.t003

more likely to have the resources that enable the provisioning of these facilities within their residence. However, it is noteworthy that the association between educational attainment and access to improved water sources was fully attenuated when we accounted for household wealth. This observation may be indicating that there is a unique educational pathway where educated households may use their human capital attained through education to achieve higher levels of wealth, which can further enable them to gain access to improved water sources.

Furthermore, our findings indicated that wealthier households were more likely to access improved water and sanitation than poorer households. This finding is consistent with previous WASH studies elsewhere in SSA, which suggest that higher household wealth ensures better access to WASH services [4,35,36,41,42]. For instance, studies such as Munamati et al. [42] asserted that wealth greatly influences households' chances of using better sanitation facilities as affording this opportunity may compete with other basic necessities on the household's budget, including securing food, shelter and health care [43]. These findings may be extended to the context of Liberia where existing infrastructural development is inadequate. Consequently, obtaining improved water and sanitation services may come at an increased cost, placing an additional financial burden on poorer households. Poorer households that are unable to bear this additional cost are often forced to seek cheaper alternatives—many of which are non-improved. These results have further implications as our findings also identify a positive correlation between a household's access to improved water sources and the use of improved sanitation.

In line with earlier studies in SSA [2,36,44,45], our findings reveal that geographical characteristics defined by county and rural-urban residence in Liberia were associated with access to improved water and sanitation. For instance, compared to Grand Gedeh, all other counties were less likely to have access to improved water and sanitation. This finding may be explained by the differential exposure of Liberian counties to the 14 years of civil war that witnessed the destruction of social infrastructure including the provisioning of WASH facilities. For instance, while the rest of the counties in Liberia were documented to have experienced intensified conflicts, evidence points to the fact that Grand Gedeh was relatively unaffected by the impacts of the civil war [29]. Furthermore, the involvement of non-governmental and other international organizations in the provisioning of WASH services in Grand Gedeh may have worked over time to support and improve the establishment of water and sanitation infrastructure [30]. Similarly, it was revealed that rural residents were less likely to have access to improved water and sanitation. This finding may not be too surprising within the context of

Table 4. Multivariate analysis of 'sanitation facilities' in Liberia.

	Model 1			Model 2			Model 3		
	OR	95% CI		OR	95% CI		OR	95% CI	
Level of education									
Higher	1.00						1.00		
Secondary	0.65***	0.55	0.76				0.65***	0.56	0.77
Primary	0.62***	0.51	0.77				0.63***	0.51	0.78
No education	0.62***	0.51	0.75				0.64***	0.52	0.78
Household wealth									
Richest	1.00						1.00		
Richer	0.60***	0.51	0.70				0.57***	0.49	0.68
Middle	0.35***	0.30	0.41				0.31***	0.26	0.38
Poorer	0.16***	0.13	0.19				0.15***	0.12	0.19
Poorest	0.06***	0.04	0.07				0.05***	0.04	0.07
Source of drinking water									
Improved	1.00						1.00		
Non-improved	0.73***	0.60	0.88				0.77**	0.64	0.93
Region of residence									
Grand Gedeh				1.00			1.00		
Bomi				0.76*	0.58	1.00	0.53***	0.40	0.71
Bong				0.65***	0.52	0.81	0.68**	0.53	0.88
Grand Bassa				0.72**	0.58	0.91	0.67**	0.52	0.87
Grand Cape Mount				0.90	0.71	1.14	0.74*	0.58	0.95
Grand Kru				0.23***	0.16	0.32	0.26***	0.18	0.37
Lofa				0.58***	0.46	0.73	0.71**	0.55	0.92
Margibi				1.07	0.86	1.33	0.81	0.64	1.03
Maryland				0.68***	0.54	0.85	0.55***	0.43	0.71
Montserrado				1.16	0.96	1.40	0.57***	0.46	0.71
Nimba				0.69**	0.55	0.87	1.08	0.84	1.37
River Cess				0.76*	0.58	1.00	0.88	0.66	1.18
Sinoe				0.54***	0.42	0.70	0.51***	0.39	0.67
River Gee				0.58***	0.44	0.75	0.62***	0.47	0.81
Gbarpolu				0.62***	0.47	0.81	0.70*	0.52	0.93
Place of residence									
Urban				1.00			1.00		
Rural				0.29***	0.26	0.32	0.74***	0.65	0.84
Gender									
Female	1.00			1.00			1.00		
Male	0.96	0.83	1.10	1.04	0.91	1.18	0.94	0.82	1.08
Age									
15–29	1.00			1.00			1.00		
30–39	0.99	0.83	1.17	1.10	0.93	1.29	1.02	0.86	1.21
40–49	0.91	0.76	1.10	0.99	0.83	1.19	0.95	0.79	1.15
50+	1.06	0.87	1.28	1.09	0.92	1.30	1.09	0.90	1.32
Marital status									
Single	1.00			1.00			1.00		
Married	0.91	0.76	1.08	0.88	0.73	1.04	0.89	0.74	1.06
Widowed	1.06	0.83	1.36	0.84	0.66	1.08	1.02	0.79	1.31

(*Continued*)

Table 4. (Continued)

	Model 1			Model 2			Model 3		
	OR	**95% CI**		**OR**	**95% CI**		**OR**	**95% CI**	
Divorced	0.98	0.77	1.25	0.86	0.68	1.09	0.94	0.73	1.20
Household size									
7+	1.00			1.00			1.00		
6–4	0.89	0.78	1.03	0.79***	0.69	0.91	0.92	0.80	1.06
3–1	0.83*	0.72	0.97	0.74***	0.64	0.86	0.88	0.75	1.03
Wald x2	1323.09***			1233.86***			1715.85***		
Log pseudolikelihood	-4409.9903			-5075.9113			-4320.7518		

*p<0.05

**p<0.01

***p<0.001.

https://doi.org/10.1371/journal.pwat.0000050.t004

an urban bias in the provisioning of social infrastructure including WASH facilities in SSA [31,46–48]. Specifically, Stuart et al. [49] pointed to rural areas in Asia and SSA as exhibiting the slowest progress in meeting the SDG goal of ending open defecation which may be as a result of their poor access to improved water and sanitation services. In the absence of universal water and sanitation facilities, the place a person resides strongly influences a household's ability to access WASH. This finding has implications for meeting SDG 6.1, which aims to achieve equitable and inclusive access to water and sanitation resources for vulnerable populations [50,51].

Limitations

There are some noteworthy limitations to this study. First, because the LDHS is self-reported, it may be subjected to respondent bias. For instance, it is possible that some respondents would have had difficulty recalling pertinent questions about water and sanitation (e.g., the travel time). Further, temporal order could not be considered in this analysis as the LDHS is a cross-sectional survey. Future longitudinal studies may be helpful to addressing this challenge. In addition, due to social desirability, some respondents may not report open defecation as it is often associated with stigma and discrimination. Finally, as this study is quantitative in nature, we were unable to exhaust all the factors that could potentially be associated with access to improved water and sanitation. To address this limitation, future studies may benefit from employing in-depth qualitative analysis to describe lived experiences, potentially enabling us to unpack underlying mechanisms that explain unique enablers and barriers to accessing improved WASH. Despite these limitations, our study is among the first to examine the factors associated with access to WASH in post-conflict Liberia.

Conclusions

Faced with the challenges of entrenched poverty and inadequate infrastructural development, Liberia grapples with extending improved water and sanitation to every household. Our findings revealed that inaccessibility to WASH in post-conflict Liberia may be explained by socioeconomic and geographic conditions which may be suggestive of the enduring impacts of years of civil war on the development of social infrastructure including WASH facilities. Based on our findings, we propose suggestions for policy makers to improve upon the state of WASH in the unique context of Liberia. First, while the long-term goal of the government

should aim to reduce socioeconomic inequalities, within the short term there is an urgent need to introduce policy-specific interventions that identify and provide WASH services to poorer households. Second, given the observed positive association between higher educational attainment and access to improved sanitation, it is essential for policy makers to provide a platform for households with low educational attainment to learn and familiarize themselves with the health benefits of accessing improved sanitation. Finally, we observed geographical barriers to WASH accessibility, seemingly affecting rural residents as well as those who live in counties that were impacted by the war. This calls for immediate attention to structurally address this unique challenge by allocating resources to increase infrastructural development in these areas. Overall, addressing these policy targets may be useful for achieving the goals outlined in Liberia's Poverty Reduction and Growth Strategy as well as SDG 6.

Supporting information

S1 Text. Inclusivity global research.
(DOCX)

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