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Survey-weighted logistic regression analysis of socioeconomic factors associated with access to improved sanitation

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ABSTRACT

Access to clean water and adequate sanitation is essential for preventing waterborne diseases and promoting public health. This study investigated the factors associated with improved sanitation in Sudan using data from the 2014 Sudan Multiple Indicator Cluster Survey (MICS), which included 98,883 individuals. Survey logistic regression was used to identify the key determinants of improved sanitation facilities. The results revealed significant disparities across social, educational, and geographic groups, with only 40.9% of Sudanese households having access to improved sanitation. Households with higher education levels were 1.77 times more likely to have improved sanitation than those without formal education, while urban households were 5.73 times more likely to have access than rural ones. Wealth showed the strongest effect, with the richest households being 208 times more likely to have improved sanitation than the poorest. Compared to countries like Oman and Egypt, Sudan's sanitation coverage remains low, particularly in rural areas. The findings highlight the importance of implementing targeted policies that prioritize rural, low-income, and less-educated populations to reduce inequalities in sanitation access.

1. Introduction

In medical research, survey logistic regression is essential for complex survey data with stratification, clustering, and unequal weighting. It estimates relationships between health outcomes and explanatory variables accurately by accounting for complex survey design elements that traditional logistic regression may miss. If survey design is overlooked in logistic regression studies, biased estimates and erroneous inferences may result. Cao et al. (2023) showed that logistic regression without measurement error adjustment biases relative risk estimations. To draw reliable logistic model conclusions, Yorlets et al. (2023) stressed the significance of accounting for covariate misclassification. Survey logistic regression supports matched case-control studies and other study designs. Wan et al. (2021) used conditional logistic regression to analyze matched data and compensate for observational study confounding variables. This method has helped epidemiologists assess exposure effects impartially. According to French and Shotwell (2022), the ordered logit model provides a sophisticated way to analyze ordinal dependent variables. Using this model in medical research, where patient responses or disease severity are ordered, helps clarify the relationship between predictors and ordinal health outcomes. Regression analysis must follow methodological criteria like the "one in ten rule" to avoid overfitting. To establish reliable and generalizable medical research models, ten occurrences per predictor variable are recommended (Cioci et al., 2021; Dhiman et al., 2022).

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Access to clean water and adequate sanitation is essential for the prevention of waterborne diseases and the improvement of overall health. A sustainable development goal is to improve sanitation, which the UNICEF Multiple Indicator Cluster Survey (MICS) says is having access to and using better sanitation facilities that keep human waste away from people (Joshi et al., 2013). Despite enhancements, the realization of the sanitation objective within the Sustainable Development Goals (SDGs) remains improbable (Van Tulder et al., 2021). Significant disparities in sanitation standards exist globally, with the most severe conditions found in Sub-Saharan Africa. In 2020, about 5% of the population had access to safely managed sanitation facilities.

Several low- and middle-income countries, which have implemented comprehensive sanitation programs, recognize sanitation as a priority for development and public health, in addition to its inclusion in the SDGs. The research on sanitation has concurrently intensified. Recent publications of numerous studies primarily assessing the effects of sanitation measures have increased the volume of primary evidence (Sclar et al., 2016; De Buck et al., 2017; Garn et al., 2017; Freeman et al., 2017; Venkataramanan et al., 2018; Chaitkin et al., 2022). Water, sanitation, and hygiene (WASH) remain essential to public health. The absence of safe water, sufficient sanitation, and proper hygiene practices significantly increases the risk of transmitting infectious diseases such as cholera, typhoid, hepatitis A, and various other waterborne illnesses (Wolf et al., 2023). According to new studies of the World Health Organization data, unsafe WASH practices caused about 829,000 deaths and 49.8 million disability-adjusted life years around the world in 2016. This is based on a death rate of 11.7 deaths per 100,000 people (Prüss-Ustün et al., 2014; Prüss-Ustün et al., 2019; Vardell, 2020). Countries with low and intermediate incomes in Southeast Asia and Africa exhibit the highest mortality rates associated with insufficient WASH, recording 15.4 and 45.8 deaths per 100,000, respectively (Chirgwin et al., 2021).

Worldwide, significant progress has been made in sanitation accessibility, with coverage rates approaching 99% in countries such as Egypt and Oman (El-Gafy, 2014). In contrast, countries such as Sudan, Nigeria, and the Congo have markedly lower sanitation access rates, particularly in rural regions (Aboah, 2024). Disparities in sanitation access across national borders are consistently linked to wealth, education, and geographic location. In Bangladesh, enhanced sanitation was significantly associated with elevated wealth index quintiles (Sheikh et al., 2022), a finding similarly noted in Sudan. Educational attainment is a significant factor; in Egypt, for instance, households headed by individuals with higher education had improved access to sanitation facilities (Piya and Lennerz, 2023). Urban-rural differences persist in low-income countries, with urban areas typically possessing enhanced sanitary infrastructure (Gordon et al., 2023). This study contributes to the existing body of research by analyzing these variables in the context of Sudan's 2014 MICS data.

The objective of this study is to explore factors that might influence access to improved sanitation, taking data from the Sudan Multiple Indicator Cluster Survey (MICS) as a use case. The choice of Sudan is due to limited literature covering these aspects and that because of its situation as low low-developing country with economic, political, and conflict issues that the country faces. This objective is addressed based on a multidimensional literature-based theoretical framework that combines important factors that are expected to govern access to improved sanitation. This framework takes household, social, and environmental aspects into account. To identify factors influencing access to improved sanitation within the theoretical framework, the study employs survey logistic regression instead of standard logistic regression. Survey logistic regression is crucial for analyzing data from complex survey designs, as it accounts for stratification, clustering, and unequal weighting, ensuring valid population-level inferences. The remainder of this article is structured as follows: the second section provides a detailed description of the methods used in the study, while the third section presents the results. The fourth section discusses the results along with their implications and recommendations. Finally, the study concludes by highlighting the key findings and identifying its limitations.

2. Methods

Study design: This study employed a retrospective cross-sectional design, utilizing data from the 2014 Sudan MICS conducted by the Central Bureau of Statistics. It is the last and most recent comprehensive nationwide household survey that provides robust data on access to sanitation in Sudan. The data was collected to calculate indicators related to women and children, supporting both global and national goals, and contributing to capacity building and system monitoring. A multistage cluster sampling method was used, first dividing the 18 states into urban and rural strata. Within each stratum, a systematic sample of enumeration areas was selected with probability proportional to size, followed by a systematic sampling of households within those areas.

Data and Variables: The study included 16,801 households with a total of 98,883 members. This study focused on Sanitation data from the Sudan MICS report, specifically examining the percentage of household members using improved sanitation facilities in general and the percentage of household members using improved sanitation facilities that are not shared as our two outcome variables. To explore variations in these outcome variables, a range of explanatory variables was considered, including the gender and educational level of the household head, area of residence (urban or rural), state of residence, number of household members, and wealth index quintile.

Statistical Analysis: Sample characteristics of the households and their members were summarized for each explanatory variable. This was followed by describing the percentage of household members using improved sanitation facilities and the percentage of household members using improved sanitation facilities that are not shared within each explanatory variable. To assess the association between these outcome variables and each explanatory variable, the Chi-square test was used, with variables considered significant if their p-values were less than 0.05. Subsequently, a univariate survey logistic regression model was applied to test the relationship between the outcome variables and each explanatory variable individually. The Wald test was used to evaluate these relationships, and unadjusted prevalence odds ratios, along with their 95% confidence intervals, were calculated and interpreted for each significant variable. IBM SPSS version 26 is used for data analysis.

Finally, a multivariable survey logistic regression models were conducted to measure the combined contribution of all significant explanatory variables in explaining variations in the outcome variables. Adjusted prevalence odds ratios and their 95% confidence intervals were reported and interpreted. The study employs survey logistic regression rather than standard logistic regression. This method is essential for analyzing data from complex survey designs, as it accounts for stratification, clustering, and unequal weighting to ensure valid population-level inferences. Unlike standard logistic regression, which assumes simple random sampling and independent observations, survey logistic regression adjusts for design effects to prevent biased estimates and inaccurate statistical inferences. It also uses robust variance estimation techniques to enhance result reliability. Thus, survey logistic regression is the appropriate method for ensuring accurate, robust, and statistically valid findings when analyzing survey data.

3. Results

The study included 16,801 households with a total of 98,883 individuals. Male heads were predominant at 86%, while female heads accounted for 14%. Educational levels varied: 46% of heads had no formal education, 28% completed primary education, 19% had secondary education, and a mere 6% attained higher education. Geographically, 31% of members were urban-based, in contrast to 69% in rural areas. The highest representation came from Khartoum and Gezira States, with 14% and 16% of households respectively, followed by western, then northern, and eastern Sudanese states. Smaller households, with less than seven members, constituted 62%, while the remaining 38% had seven or more. Wealth distribution was uniform across the quintiles, with each quintile encompassing 20% of the households (Table 1).

Table 1: Description of the study sample characteristics

Variables		Household count (%)	Members of household count (%)
Sex of household head	Male	14414 (86%)	87782 (89%)
	Female	2387 (14%)	11101 (11%)
Education of household head	None	7799 (46%)	45740 (46%)
	Primary	4730 (28%)	28007 (28%)
	Secondary	3137 (19%)	18812 (19%)
	Higher	1013 (6%)	5564 (6%)
	Missing	122 (1%)	761 (1%)
Area	Urban	5000 (30%)	30476 (31%)
	Rural	11801 (70%)	68407 (69%)
Number of household members	1-3	3343 (20%)	8192 (8%)
	4-6	7037 (42%)	35310 (30%)
	7 and more	6420 (38%)	55381 (56%)
Wealth index quintile	Poorest	3368 (20%)	19775 (20%)
	Second	3592 (21%)	19776 (20%)
	Middle	3339 (20%)	19779 (20%)
	Fourth	3209 (19%)	19773 (20%)
	Richest	3293 (20%)	19781 (20%)

Fig. 1 illustrates the percentage of household members using improved sanitation facilities (shared % and non-shared %). The highest access rates were observed in Oman (99.7%, 99.0%), Palestine (99.7%, 98.6%), Kazakhstan (99.7%, 98.0%), and Egypt (95%, 90.4%), indicating that nearly all households in these countries have access to improved sanitation. In contrast, Sudan performed poorly in this indicator, with only 40.9% of households having access to shared facilities and 32.9% to non-shared facilities. Table 2 presents an investigation into the association between sanitation variables (the availability of improved sanitation facilities and the availability of improved non-shared sanitation facilities) and all the explanatory variables. The analysis revealed that the Percentages of access to improved sanitation are significantly higher for those in households headed by males, and the percentages increase with higher household heads' education levels.

Regarding the place of residence, the percentages of the population who use improved sanitation facilities and improved non-shared facilities respectively are significantly higher in Urban (69%, 57% vs. 28%, 22% for rural), and in Northern (95%, 79%), Khartoum (85%, 66%).

The percentages of the population who use improved sanitation facilities and improved non-shared facilities significantly differ based on the household sizes, where the lowest percentages respectively (36%, 26%) for household size (1-3). Lastly, the results showed that the wealthiest households had the highest percentages of availability of both improved sanitation facilities and improved non-shared sanitation facilities (92% and 78%, respectively), with these percentages decreasing as household wealth declined.

Tables 3 and 4 present the results of the survey logistic regression, modeling the relationship between both outcome variables (the availability of improved sanitation facilities and the availability of improved and non-shared sanitation facilities) and the explanatory variables. Initially, for each model, unadjusted prevalence odds ratios (UPORs) were calculated for each explanatory variable individually, with results reported along with 95% confidence intervals (CIs). Subsequently, a multivariable survey logistic regression was performed to assess the contribution of each significant explanatory variable to the outcome variable.

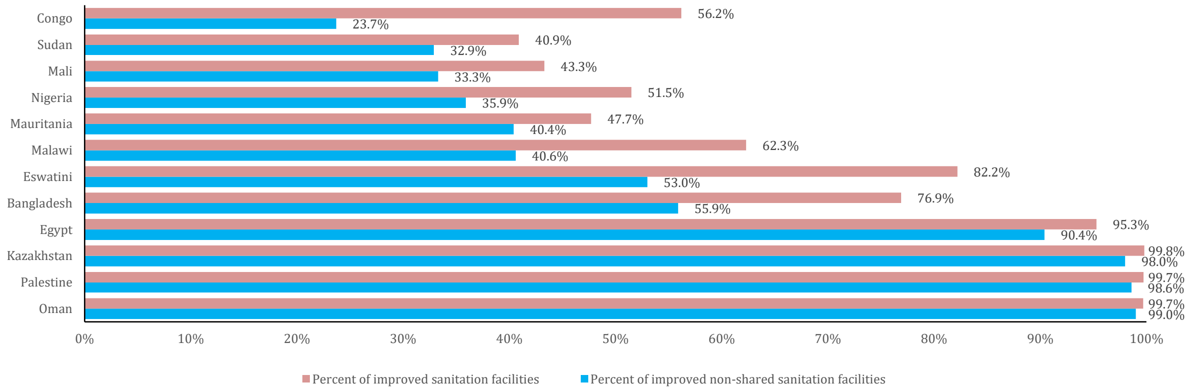

Fig. 1: Percentage of household members using improved sanitation facilities (shared and not shared)

Table 2: Results of the Chi-square test of association between access to improved sanitation and explanatory variables

Variables	Percent of household members using improved sanitation facility			Percent of household members using improved non-shared sanitation facility		
	Count	%	P-value	Count	%	P-value
Sex of household head						
Male	36380	41%	<0.005	29377	33%	<0.005
Female	4027	36%		3047	27%	
Education of household head						
None	12200	27%	<0.005	9722	21%	<0.005
Primary	11285	40%		8979	32%	
Secondary	12091	64%		9661	51%	
Higher	4607	83%		3876	70%	
Area						
Urban	21108	69%	<0.005	17356	57%	<0.005
Rural	19300	28%		15068	22%	
State						
Northern	2073	95%	<0.005	1723	79%	<0.005
River Nile	2301	62%		1840	50%	
Red Sea	1391	56%		1300	52%	
Kassala	1399	34%		1194	29%	
Gadarif	636	13%		490	10%	
Khartoum	11809	85%		9186	66%	
Gezira	8108	50%		6205	38%	
White Nile	1947	39%		1494	30%	
Sinnar	1089	29%		699	19%	
Blue Nile	1751	43%		1624	40%	
North Kordofan	1902	30%		1592	25%	
South Kordofan	624	21%		427	14%	
West Kordofan	666	12%		596	10%	
North Darfur	1071	14%		954	12%	
West Darfur	552	18%		483	16%	
South Darfur	2239	29%		1902	25%	
Central Darfur	313	19%		257	16%	
East Darfur	537	17%		456	14%	
Number of household members						
1-3	2912	36%	<0.005	2095	26%	<0.005
4-6	14315	41%		11064	31%	
7 and more	23180	42%		19265	35%	
Wealth index quintile						
Poorest	1228	6%	<0.005	1073	5%	<0.005
Second	2364	12%		1824	9%	
Middle	6235	32%		4788	24%	
Fourth	12402	63%		9309	47%	
Richest	18178	92%		15430	78%	

Table 3: Survey logistic regression analysis results investigating the association between access to shared improved sanitation and explanatory variables

Variables	Unadjusted prevalence odds ratio (UPOR)			Adjusted prevalence odds ratio (APOR)		
	Odds ratio	95% confidence interval		Odds ratio	95% confidence interval	
		Lower	Upper		Lower	Upper
Sex of household head						
Male	1.24*	1.05	1.48	1.08	0.82	1.42
Female		1			1	
Education of household head						
Primary	1.86***	1.61	2.14	0.94***	0.80	1.10
Secondary	4.95***	4.09	5.97	1.28***	1.05	1.57
Higher	13.24***	9.88	17.75	1.77***	1.28	2.45
None		1			1	
Area						
Urban	5.73***	4.26	7.72	1.22	0.90	1.66
Rural		1			1	
State						
Northern	93.68***	45.52	192.80	6.37***	2.11	19.19
River Nile	7.95***	3.40	18.58	0.37	0.10	1.29
Red Sea	6.19***	2.80	13.68	1.32	0.45	3.91
Kassala	2.51***	1.16	5.47	0.70	0.23	2.12
Gadarif	0.71	0.34	1.50	0.18***	0.06	0.52
Khartoum	28.53***	12.57	64.75	1.48	0.46	4.72
Gezira	4.85***	2.38	9.90	0.32*	0.11	0.95
White Nile	3.10***	1.47	6.51	0.48	0.17	1.39
Sinnar	1.99	0.95	4.14	0.21***	0.07	0.61
Blue Nile	3.65***	1.50	8.88	1.00	0.29	3.42
North Kordofan	2.08	0.95	4.58	1.24	0.41	3.77
South Kordofan	1.29	0.60	2.78	0.55	0.19	1.63
West Kordofan	0.64	0.29	1.42	0.55	0.18	1.70
North Darfur	0.78	0.35	1.74	0.77	0.26	2.25
West Darfur	1.09	0.45	2.63	0.44	0.14	1.36
South Darfur	2.00	0.99	4.05	1.70	0.57	5.04
Central Darfur	1.15	0.55	2.37	0.99	0.33	2.92
East Darfur		1			1	
Number of household members						
1-3	0.77***	0.67	0.88	0.84	0.70	1.01
4-6	0.95	0.85	1.05	0.90	0.78	1.05
7 and more		1			1	
Wealth index quintile						
Second	2.05***	1.44	2.93	2.53***	1.79	3.57
Middle	6.95***	4.58	10.54	9.15***	5.96	14.06
Fourth	25.40***	16.70	38.64	39.84***	25.09	63.26
Richest	171.24***	109.52	267.75	208.23***	119.38	363.21
Poorest		1			1	

*: Significant at 0.05; **: Significant at 0.01; ***: Significant at 0.005

The results show that the likelihood of accessing improved sanitation is significantly higher for those live: in households headed by male (UPOR = 1.24, 95% CI: 1.05, 1.48) compared to female, in households with higher educated head (UPOR= 13.24, 95% CI: 9.88, 17.75) compared to non-educated head, in urban areas (UPOR= 5.73, 95% CI: 4.26, 7.72) compared to rural, in Khartoum state (UPOR= 93.68, 95% CI: 45.52, 192.80), in the richest households (UPOR= 171.24, 95% CI = 109.52, 267.75) compared to poorest, whereas the likelihood is significantly lower for those in household with size 1-3 (UPOR= 0.77, 95% CI: 0.67, 0.88) compared to the size "7 or more."

After adjusting for significant explanatory variables, the multivariable survey logistic regression showed that only education level, state of residence, and wealth index quintile significantly contributed to explaining the variation in the availability of improved sanitation facilities. Specifically, households with highly educated heads are 1.77 times more likely to have improved sanitation facilities compared to those with no education. Northern, Khartoum, and Red Sea are the top three states in terms of availability of improved sanitation facilities, while Sinnar, Gezira, and River Nile are the bottom three. Additionally, the wealthiest households consistently have a higher likelihood of having improved sanitation facilities compared to those with lower wealth indices. The richest households are 208.23 times more likely to have improved sanitation facilities compared to the poorest households (CI:119.38, 363.21), and the households in the second quintile are 2.53 times more likely to have improved sanitation facilities compared to the poorest (CI:1.79, 3.57).

Table 4 presents the results of investigating the contribution of explanatory variables to the availability of improved, non-shared sanitation facilities. Unadjusted odds ratios (UPOR) were calculated using a univariate model for each explanatory variable individually. The results indicated that all explanatory variables are statistically associated with the availability of improved, non-shared sanitation facilities.

Households with male heads are 33% more likely to have improved, non-shared sanitation facilities compared to those with female heads (UPOR = 1.33, CI: 1.11, 1.59). Households with highly educated heads are 8.51 times (CI: 6.67, 10.85) more likely to have improved, non-shared sanitation facilities compared to those with no education. Additionally, households in urban areas are 4.68 times more likely to have improved, non-shared sanitation facilities (CI: 3.59, 6.11) compared to those in rural areas, Northern and Khartoum states are the top two states in terms of availability of improved non-shared sanitation facility, while Gadarif, and North Darfur are the bottom two.

The likelihood of having improved, non-shared sanitation facilities is 36% lower in households with 1 to 3 members and 14% lower in those with 4 to 6 members, compared to households with 7 or more members. In addition, wealthier households are consistently more likely to have access to improved, non-shared sanitation facilities than those in the poorest wealth quintile. Specifically, households in the richest quintile are 61.81 times more likely to have such access (95% CI: 42.19–90.56) compared to the poorest group. In the multivariable model, only sex and area were not statistically significant, while all other explanatory variables showed significant associations. Households headed by individuals with secondary education are 10% more likely to have improved, non-shared sanitation facilities compared to those headed by individuals with no education. In contrast, households headed by individuals with primary education are 3% less likely to have such facilities. The Northern and Red Sea states have the highest availability of improved, non-shared sanitation facilities, whereas Gadarif and Gezira are the lowest. The likelihood of having improved, non-shared sanitation facilities is 35% lower in households with 1 to 3 members and 23% lower in those with 4 to 6 members, relative to households with 7 or more members. Furthermore, households in the richest wealth quintile are consistently more likely to have improved, non-shared sanitation facilities, being 102.7 times more likely (95% CI: 65.05–162.14) compared to those in the poorest quintile.

Table 4: Survey logistic regression analysis results investigating the association between access to improved non-shared sanitation and explanatory variables

Variables	Unadjusted prevalence odds ratio (UPOR)			Adjusted prevalence odds ratio (APOR)		
	Odds ratio	95% confidence interval		Odds ratio	95% confidence interval	
		Lower	Upper		Lower	Upper
Sex of household head						
Male	1.33***	1.11	1.59	1.12	0.88	1.43
Female	1			1		
Education of household head						
Primary	1.75***	1.49	2.05	0.97**	0.82	1.15
Secondary	3.91***	3.28	4.67	1.10***	0.92	1.31
Higher	8.51***	6.67	10.85	1.39	1.09	1.78
None	1			1		
Area						
Urban	4.68***	3.59	6.11	1.20	0.91	1.58
Rural	1			1		
State						
Northern	22.28***	10.85	45.77	1.67	0.57	4.88
River Nile	5.81***	2.66	12.70	0.37	0.12	1.13
Red Sea	6.47***	2.97	14.09	1.61	0.57	4.53
Kassala	2.42*	1.08	5.41	0.72	0.24	2.12
Gadarif	0.64	0.29	1.41	0.19***	0.07	0.55
Khartoum	11.72***	6.04	22.72	0.64	0.23	1.79
Gezira	3.65***	1.76	7.59	0.31*	0.11	0.89
White Nile	2.51*	1.19	5.31	0.43	0.15	1.19
Sinnar	1.35	0.63	2.90	0.16***	0.06	0.46
Blue Nile	3.90***	1.63	9.32	1.17	0.36	3.80
North Kordofan	1.98	0.90	4.37	1.17	0.41	3.39
South Kordofan	0.99	0.44	2.21	0.43	0.15	1.26
West Kordofan	0.69	0.30	1.56	0.64	0.21	1.92
North Darfur	0.83	0.37	1.84	0.85	0.30	2.42
West Darfur	1.13	0.46	2.79	0.51	0.17	1.50
South Darfur	1.94	0.96	3.93	1.63	0.56	4.76
Central Darfur	1.09	0.52	2.31	0.99	0.33	2.95
East Darfur	1			1		
Number of household members						
1-3	0.64***	0.54	0.76	0.65***	0.53	0.79
4-6	0.86**	0.76	0.96	0.77***	0.66	0.90
7 and more	1			1		
Wealth index quintile						
Second	1.77***	1.25	2.50	2.25***	1.61	3.16
Middle	5.57***	3.72	8.33	8.21***	5.56	12.11
Fourth	15.50***	10.41	23.08	28.59***	19.15	42.69
Richest	61.81***	42.19	90.56	102.70***	65.05	162.14
Poorest	1			1		

*: Significant at 0.05; **: Significant at 0.01; ***: Significant at 0.005

4. Discussion

In Sudan, access to better sanitary facilities has been found to be significantly influenced by education. Higher educated people, especially those with post-secondary and university degrees, were more likely to lead households with access to better sanitation. These findings agree with the previously published data revealed that higher educated persons were 1.77 times more likely to have access to sanitation than households headed by individuals with no formal education. This is also in line with worldwide trends seen in other nations, like Egypt and Bangladesh, where improved access to sanitation is linked to higher levels of education (Hutton and Chase, 2016).

Households are more inclined to prioritize and invest in better facilities when they are educated about hygiene and sanitation practices. Furthermore, a higher level of education increases one's capacity for income, improving one's ability to pay for sanitary facilities. The impact of schooling is especially important in Sudan, where 46% of household heads in the sample had never attended formal school (Hutton and Chase, 2016). Closing this educational gap could greatly enhance the nation's overall sanitation results, especially in rural areas with less access to sanitation.

The most important predictor of access to better sanitation facilities was the wealth index, highlighting the influence of economic disparity on sanitation results in Sudan. Compared to the poorest families, households in the richest quintile had a 208-fold higher likelihood of having better sanitation. This result is consistent with patterns seen in other low-income nations like Nigeria and Bangladesh, where wealth plays a major role in determining access to better sanitation. The poor homes in Sudan are frequently forced to rely on subpar or shared facilities, while wealthier households are better able to invest in infrastructure and private sanitation solutions.

The link between access to sanitation and wealth draws attention to the financial obstacles that prevent the equitable distribution of sanitation services. Access to better sanitation is more prevalent in wealthy urban regions like Khartoum and Northern State. In contrast, access to sanitation is significantly lower in rural areas, where poverty is more common (Cha et al., 2021). Targeted initiatives are needed to address these socioeconomic gaps, such as increased funding for rural infrastructure and subsidized sanitation programs for low-income households.

There were notable regional variances in the availability of sanitation, particularly between urban and rural areas. Compared to rural homes, urban households were 5.73 times more likely to have access to better sanitation. This urban-rural gap is not specific to Sudan; it is observed in many other nations as well, as economic expansion and urbanization have concentrated infrastructure and resources in cities, underserving rural areas. For instance, whereas rural areas lag, urban centers in Kazakhstan and Oman enjoy nearly universal sanitation coverage (Challa et al., 2022; Gulis et al., 2021).

This difference is evident in Sudan, where states like Khartoum and Northern State have much greater rates of sanitation access than rural areas like Gadarif and West Kordofan. Better infrastructure, higher incomes, and a more educated populace in cities are the main causes of the urban advantage. On the other hand, problems in rural areas include lower levels of poverty, lower educational attainment, and a lack of government funding, all of which limit access to sanitary facilities.

Household size was another significant sociodemographic component affecting participants' access to improved sanitation. Compared to smaller homes, larger households consisting of seven or more individuals exhibited slightly greater access to improved sanitation, probably because of resource pooling (Al-Saidi and Saliba, 2019; Abdel-Rahman et al., 2020). However, when adjusting for wealth and education, household size alone was not a significant cofounder variable.

Although it was not as strong a predictor as money and education, the gender of the head of the home also affected access to sanitation. Compared to households led by women (36%), male-headed households had somewhat greater access to improved sanitation (41%). The gender gap might reflect larger gender disparities in economic possibilities and decision-making authority, which could limit the amount of money available to fund hygienic improvements.

The fact that there is less of a gap in sanitation access between families led by men and women, however, indicates that gender is not the primary factor influencing sanitation outcomes in Sudan. In comparison, research from many low-income contexts shows that female-headed households frequently face disproportionate disadvantages when it comes to accessing resources and services (Coghlan et al., 2009; Beattie et al., 2015; Handan et al., 2023; Mohamed, 2024). However, the main factors influencing access to sanitation in Sudan seem to be educational and economic, without gender significance.

Sudan has a 40.9% sanitation coverage rate, which is substantially lower than that of its neighbors, Oman (99%) and Egypt (95%) 36,37. Due in large part to their robust public health policies and rapid economic expansion, these nations have made significant infrastructure investments in sanitation. For example, Egypt's government's emphasis on enhancing urban infrastructure has made sanitation almost universally available in Egyptian cities (El-Gafy, 2024). Conversely, such advancements have been impeded in Sudan by its protracted political unrest, economic difficulties, and inadequate infrastructure.

When it comes to how differences in wealth and education impact people's ability to access sanitation, Bangladesh presents a similar situation to Sudan. Like Sudan, Bangladesh experiences a lack of access to better sanitation for its poorest households, whereas urban residents with greater incomes have access to better services. But because of focused government initiatives and outside assistance, Bangladesh has achieved significant strides in closing the sanitation gap between urban and rural areas, which could serve as a model for Sudan.

Based on current data, a comparison of sanitation access in Sudan with other Sub-Saharan African nations finds both parallels and variations impacted by elements including wealth, education, and urbanization. Just 40.9% of Sudanese families have upgraded their sanitary facilities; urban households are five times more likely than rural ones. Furthermore, linked with improved sanitation access are higher degrees of affluence and education. As of 2020, just 23% of urban and 19% of rural sub-Saharan Africans had safe sanitation services. This shows that a large portion of the population relies on unsafe sanitation. In 2020, Lesotho had approximately 50% of its population with safe sanitation, while Ethiopia had 7%. These data emphasize the need to improve sanitary facilities and access, especially in rural and low-income areas. These inequities must be addressed to improve public health and regional sustainable development. Studies reveal that while many sub-Saharan African health institutions achieve global objectives, their WASH availability has increased, but still lags. Health facilities must have adequate WASH services and follow safety and hygiene requirements to reduce health risks (Kanyangarara et al., 2021). Demographic and socioeconomic factors also affect sanitation access. Tracking sanitation coverage across various parameters helps identify and address access gaps (Rheingans et al., 2014). Climate variability is projected to increase diarrheal illnesses, a major source of morbidity and child mortality in sub-Saharan Africa. The risk is highest for people without better sanitation and water. These concerns require a comprehensive approach, including WASH infrastructure and service improvements (Kemajou, 2022). Poverty elimination may improve water and sanitation access. Universal access to essential services, especially sanitation, will be difficult for many low- and lower-middle-income countries (Swe et al., 2021). Sanitation and drinking water access maps indicate significant inequalities between low- and middle-income countries. These inequities must be addressed to improve public health. Finally, addressing sanitation access inequities in sub-Saharan Africa requires tailored interventions that improve WASH infrastructure and services, taking socioeconomic, demographic, and environmental factors into account, especially in rural and low-income areas.

In Sudan, getting access to better sanitary facilities is still a major public health concern. Wealth, education, and geographic position are important factors. Policymakers need to prioritize funding for underserved rural areas, support educational programs, and address socioeconomic disparities to increase the coverage of sanitation. Sudan's sanitary infrastructure is woefully inadequate in comparison to its regional peers, Egypt and Oman, and urgent effort is required to bridge this gap.

Based on the current data analysis, funding rural Sudan's sanitation infrastructure presents several major difficulties. Restricted government finances combined with political unrest and economic restrictions impede reliable funding distribution. Many rural communities lack official financial systems, which makes it challenging to gather community donations or personal investments. Donor reliance aggravates the matter even further since outside help may be erratic and inadequate. Furthermore, low demand and community prioritizing resulting from high poverty rates and poor knowledge of the long-term advantages of sanitation can lead to logistical problems in material transportation and access to remote places, aggravate these issues even more, hence raising project expenses and lowering project effectiveness. Developing sustainable finance models calls for concerted efforts among the government, NGOs, foreign donors, and local people to address these obstacles.

It will need multiple policy actions to address Sudan's inequities in sanitation access. First, it's imperative to make focused investments in rural infrastructure. Building sanitary infrastructure in underserved areas must be the government's top priority, especially in states with the least access, like West Kordofan and Gadarif (Halisçelik and Soytas, 2019). To make sure that the poorest communities are not left behind, these investments should be matched by initiatives to offer low-income households sustainable and reasonably priced sanitation solutions.

Second, education initiatives are crucial to bringing attention to the significance of hygiene and sanitation, especially in rural regions. Even in environments with limited resources, public health education can have a big impact on modifying attitudes and motivating people to place a higher priority on sanitation. Bangladesh and other nations have effectively executed public health initiatives aimed at enhancing cleanliness standards and augmenting the need for sanitation amenities (Bain et al., 2018). Sudan can use comparable tactics to enhance health outcomes and access to sanitation.

In addition, measures taken by the government to lessen socioeconomic gaps need to be strengthened. It is the government's duty to guarantee that all citizens, irrespective of their financial status or educational attainment, have access to sanitary facilities that meet fundamental human rights standards. Sudan may make great strides toward attaining universal sanitation coverage by addressing the underlying socioeconomic inequities that cause differences in sanitation access.

Lastly, Policymakers and NGOs should give building rural sanitation infrastructure priority using affordable technology and subsidies for low-income households if we are to increase sanitation access in Sudan. Long-term behavioral change can be spurred by public awareness initiatives and school-based sanitary instruction. Particularly in underdeveloped communities, hygiene depends on a consistent water supply. Resource mobilization might be improved by strengthening government, NGO, and commercial sector cooperation. Sanitary projects will be supported even more by financial incentives, more government funding, and rigorous policy execution. Regular data collecting and monitoring should direct treatments, therefore guaranteeing effective use of resources. These steps will assist Sudan in achieving sustainable development and help to lower waterborne infections.

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Compliance with ethical standards

Ethical considerations

This study utilized secondary data from the Multiple Indicator Cluster Survey (MICS) conducted in Sudan in 2014. The dataset is publicly available (https://mics.unicef.org/surveys), fully anonymized, and no additional ethical approval was required.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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