Original Article

The effect of improved water and sanitation on diarrhea: Evidence from pooled Ethiopia Demographic and Health Surveys – A multilevel mixed-effects analysis

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Abstract

Background: In Ethiopia, diarrhoea is the leading cause of illness and hospital admissions among children, and the persistence of diarrheal epidemics in urban and rural areas warrants an exploration of the impact of WASH facilities over recent years.

Objective: The study aimed to assess the effect of improved water sources and sanitation on the occurrence of diarrhea in Ethiopia, while controlling for household and child-related factors and accounting for higher-level variables.

Methods: A total of 42,282 study subjects were pooled from the four rounds of the Ethiopian Demographic and Health Survey. A multilevel mixed-effects logistic regression model was run to identify the effect of water and sanitation on diarrhea, after adjusting for higher-level and confounding factors. SPSS version 24 was used for data management, while Stata version 15.1 was used for descriptive and multilevel analysis.

Results: An improved water source was strongly associated with the occurrence of diarrhea in the final model, (AOR 95% CI: 1.02-1.2), while improved sanitation had a marginal association, (AOR 95% CI: 0.87-1.20). The interaction between improved water sources and improved sanitation has maintained the relevance of improved water sources, but not for improved sanitation, on diarrhea.

Conclusions and recommendations: Improved water source was a strong predictor of diarrhea. Improved water sources and improved sanitation are both required to get the maximum benefit of reducing diarrhea among children.
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Key words: Diarrhea, improved water source, improved sanitation, interaction, effect, Demographic and Health Survey

Introduction

As the fifth leading cause of death in under-5 children and contributing to about 90% of childhood mortality in low-income countries, diarrhea continues to be a global health challenge (1). Of the total 477,000 diarrheal deaths in under five children in 2016 in low- and middle-income countries, 62% were attributed to inadequate access to water and sanitation (2). Diarrhea is preventable with the application of hand hygiene, basic sanitation and the provision of safe drinking water.

Access to water, sanitation and hygiene (WASH) facilities is very limited in developing countries. In 2017, a Joint Monitoring Program (JMP) report on sub-Saharan African countries (SSAs) showed access to safely managed water sources was 27% and access to safely managed sanitation was 18%. This report showed that, in SSAs, the growth of safe water services since 2000 was about 1% per annum; for sanitation, is was less than 0.2% (3). With such a poor growth pattern, access to basic sanitation did not meet the 2015 Millennium Development Goal (MDG) in many SSAs, including Ethiopia, which implies meeting the Sustainable Development Goal (SDG) target by 2030 will be a significant challenge.

There are inconsistent findings on the benefits of accessing improved WASH. For example, one study showed that improved sanitation and drinking water quality reduced diarrhea by 22% and 37%, respectively (4). A further study showed respective reductions of 25% and 62-75% (5), while a third study showed reductions of 45%, 28% and 23% due to improved water supply, access to sanitation and improved hygiene practice, respectively (6). The variation in these results is attributable to different diarrheal transmission pathways, resulting in different degrees of effect.

In Ethiopia, diarrhea is the leading cause of illness and hospital admissions among children (7), although it has shown a declining trend – from 24% in 2000 to 12% in 2016 (8, 9). Over the same period, the provision of access to safe drinking water has shown a significant improvement, increasing from 25% in 2000 to about 60% in 2016. However, sanitation coverage (private and shared) showed no significant improvement: 14.3%, 9%, 13%, and 10.0%, in 2000, 2011, 2014, and 2016, respectively (8-11). Overall, improved sanitation is a national indicator that has shown no meaningful change over the years. Several local cross-sectional studies have shown that WASH is a predictor of diarrhea (12-14), while other studies contradict these findings (13, 15-18). In one study, the availability of latrines was a determinant, but not access to improved water sources (19). The consistent presence of diarrheal epidemics in urban centers and rural areas in Ethiopia (20, 21) warrants an exploration of the long-term effect of the progress of WASH facilities over the years. The Demographic and Health Survey (DHS) database provides a platform to investigate the issue (https://dhsprogram.com).

Objective

The purpose of this study was to explore the effect of improved water sources and improved sanitation on diarrhea, given other background determinants, in four rounds of the population-based EDHS survey, spanning the years 2000 to 2016.

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Methods

Data set: The present study used data sets of the EDHS relating to children that were downloaded from the Monitoring and Evaluation to Assess and Use Results Demographic and Health Surveys (MEASURE DHS) website (https://dhsprogram.com/data/available-datasets.cfm). The study centered on a weighted number (42,282, unweighted 39,355) of under-5 children; similar numbers of children living in 11 administrative/geographic areas were drawn from each of the four EDHSs. EDHS used a sample weight for a study population to represent results at residence, region and country level. The study subjects were those who had completed data on the occurrence of diarrhea and related determinants.

Data extraction: The identification of variables was made in consultation with the DHS recode manual (22) and the questionnaire that was used for each survey. Required variables were identified based on related literature (23-28). Relevant variables were then grouped into determinants: socio-demographic, socio-economic, child related, and water and sanitation. The EDHS data file, ETKR, was downloaded for each wave and saved in a separate file. The ETKR data file had children as a unit of analysis. The SPSS 'merge' command was used to combine the four EDHS data files using unique IDs (CASEID for individual surveys) and an ID that was purposely created for every subject in the total population.

Sampling methods: The EDHS surveys employ a complex sampling method that uses a two-stage stratified sampling involving clusters (equivalent to enumeration area) and households using random sampling to ensure spatial representation, augmented by balancing the population size via a sample weight (9). Overall, there were 2,375 clusters (540 each in 2000 and 2005; 650 in 2011; and 645 in 2016) grouped into 25 sampling strata in 11 geographic/administrative regions. Over-sampling in Somali and Dire Dawa in 2011 and 2016 increased the usual strata from 21 to 25. This complex sampling technique ensures representativeness at different levels, i.e. country, regional and urban/rural populations.

Data management and description of variables: Merging data files was critical to pool data in one long format that included the respective data characteristics. The four EDHS data sets were merged using the SPSS 'merge' command, after ensuring the consistency of each variable (by type and order) across each data set. A unique CASEID and a newly created unique ID for each case were used to check the consistency of merging by navigating over the data view. Missing data for the outcome variable (diarrhea) were restricted from analysis to control for errors affecting the distribution of other variables. The original definitions for key variables were maintained according to DHS contexts. All analysis was run with a sample weight.

Dependent variable: Mother's response for the two-week prevalence of diarrhea among under-5 children was the outcome variable. The presence of diarrhea was set to be 'Yes', while 'No' diarrhea covered both 'No' and 'Don't know'. Three thousand six hundred and ninety-four cases that did not have data on diarrhea were excluded from the analysis (8.6% of the total unweighted, 43,029).

Independent variables: These variables were categorized in groups as explanatory variables (level 1) related to subject and household characteristics, and higher-level variables intended to be used for the random modeling. Overall, there were 12 child-related variables; nine parental socio-economic and demographic variables; four WASH-related variables; four housing characteristic variables; and three variables for level 2 factors. Detailed variable description and analysis are shown in Table 1.

Operational definitions of key variables: The categorization of key variables, such as improved water sources and improved sanitation, was done according to JMP definitions (3) and the consulting DHS manual (22). The same sources were used to define diarrhea and stunting.

The type of floor in a household was considered as a proxy of improved housing. Any floor with a surface structure, such as cement, vinyl sheet, and polished wood that could be washed and cleaned, was labeled as 'improved floor'.

The physical characteristics of the "land" was classified into three categories: *kolla* (hot low land, <1,500m above sea level), *Woina Dega* (midland, 1,500-2500m above sea level), and *dega* (cold highland, >2,500m above sea level) (29, 30). Some studies indicate that agro-ecology is a determinant of diarrhea (23, 31).

Wealth index categories were condensed from five to three groups to facilitate the stability of the model. 'Poorest' and 'poor' were grouped under 'poor'; 'richest' and 'rich' were grouped under 'rich'; and the middle category was left as it was. A similar approach is used in other studies (32, 33).

Data analysis: A framework for analysis was designed to run the multilevel analysis. This framework was based on the consideration of various determinants of diarrhea, considering hierarchical relationships. The preference for this stepwise approach was decided after consulting various sources (22, 29, 30, 34, 35). Improved water sources and sanitation was considered a primary determinant of diarrhea, while others, such as parental socio-demographic determinants, household socio-economic determinants, and child-related factors, were treated as confounding factors. Their inter-relationship is indicated in Figure 1.

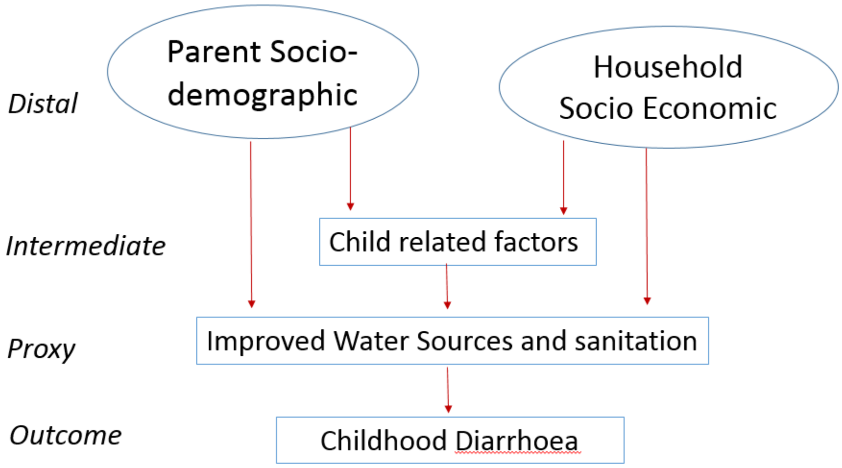

Figure 1***: Analytical framework for determinants of diarrhea, EDHS 2000-2016***
Source: Developed after reviewing literature on diarrhea and its determinants

Household data and the study subjects by households were described by summary details using Tables. Predictors of diarrhea were analyzed using a multilevel mixed effect logistic regression in order to account for variations due to the nested nature of households in a cluster. The DHS sampling method accounting two levels, cluster and household, requires to adjust the differences in the outcome during analysis (36, 37). Cluster was considered as random, while the variables related to households and individuals as variables for fixed effect. The frequency of variables in the contingency tables, co-linearity and omnibus statistics were checked for the fitness of regression models.

The analysis involved a multilevel mixed-effect logistic regression. The mixed effect analysis accounted for both random and fixed effects. The model building strategy for the multilevel mixed-effects analysis followed four phases. In the first phase of analysis, a null model was generated to evaluate the relevance of using a random effect. A null model (also called 'intercept-only model') with a random-effect variable was generated to ensure the relevance of using higher level of variable as cluster using for a random effect. The use of multilevel analysis was viable given the size of the between variation on of the intercept was significantly greater than zero, this being measured by the intra-class correlation (ICC) as 13%, which suggested using random-effect and fixed-effect variables for ICC > 10%.

In the second phase, a bivariate regression was conducted to explore the role of improved water and sanitation. In the third phase, including confounders on the background of improved water and sanitation was used to screen variables at $p<0.25$. In the fourth phase, a multivariate condensed model was fitted in the regression to rule out the relevance of improved water and sanitation given for adjusted confounders using odd ratios (OR), a 95% confidence interval (CI), and a significance value of $p<0.05$. In this analysis, it was considered 'improved safe water source' and 'improved sanitation' as 'exposure variables', while child-related and socio-demographic variables were 'confounders'. All of these were used as fixed factors to build the model. The frequency of variables in the contingency tables, collinearity and omnibus model fitness was checked for the fitness of the mixed logistics regression model. The fitness of the condensed model was significant ($F(16,2261)=61.26$, $p<0.0001$).

A condensed model was generated to indicate the determining factors with and without an interaction term between improved water sources and sanitation to explore the joint and an independent effect on diarrhoea.

The multilevel analysis involving complex sampling was considered to account the nature sampling technique that included individual and strata-based characteristics. The statistical tool of multilevel modelling of complex survey data is found in the work of Rabe-Hesketh & Skrondal (38). It is understood that diarrhea varies by clusters, districts, urban and rural settings, and regions across Ethiopia. The sampling strata (cluster, urban/rural, domain) account spatial variability diarrhea to account random effect while allowing individual variables to independently associate with diarrhea. The analysis was mixed in such a way that the model considered level 2 factors as random factors, and level 1 factors as fixed factors or determinants. The application of complex sampling using a regression analysis is a common practice to ensure adequate sample size (36, 37, 39, 40). The model building strategy is indicated in the supplementary file that can be available on request of EJHD. SPSS was used version 24 for data management, while Stata version 15.1 was used for descriptive and multilevel analysis.

Results

Respondents' characteristics: Respondent's background data showed changes over the various surveys, including the educational status of respondents and partners, and their occupations (see Table 1).

Table 1: **Percent distribution of major background characteristics of respondents, EDHS 2000-2016 (data weighted)**

Variables/Survey year	Variable code*	EDHS 2000 (%)	EDHS 2005 (%)	EDHS 2011 (%)	EDHS 2016 (%)	χ^2 test, p-value
Age of respondents						
15-24		26.7	24.8	24.0	22.3	
	v012					0.001
25-34		47.0	49.5	52.0	53.2	
35-49		26.3	25.7	24.0	24.5	
Living in urban setting	v025	10.6	7.4	13.0	11.2	0.077
Educational status of respondent – Primary and above	v106	18.4	21.4	31.1	34.2	0.001
Educational status of partner – Primary and above	v701	36.5	41.9	50.4	51.8	0.001
Respondent currently married	v501	91.9	93.4	87.4	93.9	0.001
Respondent currently working	v714	55.9	23.2	34.3	27.1	0.001
Respondent occupation – agriculture employee	v717	44.1	18.8	27.2	22.7	0.001
Partner occupation – agriculture employee	v705	88.7	88.1	80.2	74.1	0.001
No. of respondents, weighted		10,737	10,096	11,031	10,418	42,282

*Original EDHS variable code

Water and sanitation characteristics: Variations in improved water sources occurred across the EDHS surveys, with a marked increasing trend. However, there was less of an increase in 'improved floor' and the practice of disposing of child feces into a latrine. Changes in improved sanitation did not show any pattern (see Table 2).

Table 2: **Percent distribution of household-level drinking water source and sanitation, and wealth index, EDHS 2000-2016 (data weighted)**

Variables/Survey year	Variable code	EDHS 2000 %	EDHS 2005 %	EDHS 2011 %	EDHS 2016 %	χ^2 test, p-value
Access to improved water source	V113	20.6	29.0	46.6	56.2	0.001
Time to get to water source <30 minutes	V115	43.7	45.2	35.3	37.3	0.001
Access to improved sanitation	V116	14.3	9.0	12.7	10.2	0.001
Child feces disposed into a latrine	V465	21.9	20.0	33.7	38.6	0.001
Improved floor	V127	5.0	5.2	8.4	12.0	0.001
Ecology cluster						
<1,500m above sea level	V040	NA	8.3	16.6	17.1	
1,500-2,500m above sea level		NA	67.4	71.6	68.8	0.001
>2,500m above sea level		NA	24.3	11.8	14.1	
Wealth index						
Poor	V190	39.1	42.9	44.5	46.9	
Middle		22.4	21.9	20.7	20.7	0.001
Rich		38.5	35.2	34.8	32.4	
No. of respondents, weighted		10,737	10,011	10,715	10,267	41,730

Description of child-related characteristics: Overall, there has been a marked change over time in the improvement of child health, while little change was observed in the composition of sex, age, and the birth order of study subjects (see Table 3).

Table 3: **Percent distribution of backgrounds of under-5 children, EDHS 2000-2016**

	Variable code	EDHS 2000 (%)	2005 (%)	2011 (%)	2016 (%)	χ^2 test, p-value
Sex						
Male	B4	50.8	50.7	51.4	51.3	0.868
Female		49.2	49.3	48.6	48.6	
Age in months						
<0.6		10.0	11.9	11.7	11.7	
6-11	HW1	10.3	10.2	10,4	10.5	0.090
12-60		79.6	77.9	77.9	77.8	
Breastfeeding	V404	75.7	77.3	73.6	69.6	0.001
Birth order						
1		18.4	16.7	19.2	18.8	
2-3	Bord	30.3	30.6	31.3	30.4	0.066
4-5		22.0	23.7	23.0	24.0	
6+		29.2	29.0	26.7	26.8	
Number of under-5s						
<2	V137	34.6	32.8	35.3	38.0	0.013
2		50.7	50.5	47.4	44.7	
3+		14.8	16.7	17.3	17.3	
DPT3*	H7	21.9	9.4	17.3	42.7	0.001
Stunting	HW5	51.2	46.4	38.5	32.9	0.001
Wasting	HW11	10.7	10.5	8.6	8.8	0.001
Cough	H31	33.8	18.3	19.7	20.0	0.001
Diarrhea	H11	23.7	18.0	13.4	11.8	0.001
No. of children, weighted		10,737	10,096	11,031	10,418	42,282

* Diphtheria-tetanus-pertussis vaccination

Multilevel mixed-effects analysis: The final model had socio-demographic, economic and child-related factors that were found to be significant when analyzed independently in a model comprising ‘diarrhea’, with ‘improved water source’ and ‘improved sanitation’ as the main exposure variables. Improved water source was a significant predictor after adjusting for confounders (AOR (95% CI), 1.15 (1.02-1.29), suggesting that diarrhea among those who had no improved water source was 1.15 times more likely compared to those with an improved water source. The status of improved sanitation could not be a predictor (p=0.242), after controlling for confounders. Its effect on diarrhea was not significant (AOR (95% CI), 1.02 (0.87-1.20) (see Table 4).

Table 4: **Condensed model: Predictors of diarrhea – multilevel mixed-effects logistic regression, EDHS 2000-2016**

Variables	Diarrhea Yes	No	AOR (95% CI), without interaction	AOR (95% CI), with interaction
Improved water (n=41,728)				
Yes	2,258	13,627	1.0	1.0
No	4,738	21,106	1.15 (1.02-1.29)**	1.13 (1.01-1.28)*
Improved sanitation (n=41,385)				
Yes	759	4,043	1.0	1.0
No	6,173	30,410	1.02 (0.87-1.20)	0.95 (0.76-1.19)
Age of respondents (n=42,282)				
15-24	1,848	8,488	1.35 (1.11-1.63)*	1.35 (1.11-1.62)*
25-34	3,578	17,741	1.21 (1.05-1.39)*	1.21 (1.05-1.39)*
35-49	1,644	8,984	1.0	1.0
Currently working (n=42,271)				
Yes	2,707	12,241	1.0	1.0
No	4,361	22,962	0.89 (0.80-0.99)**	0.89 (0.80-0.99)**
Residence (n=42,281)				
Urban	565	3,919	1.0	1.0
Rural	6,504	31,293	1.21 (0.98-1.50)	1.19 (0.96-1.47)
Age in months (n=36,541)				
<6	477	3,634	0.72 (0.58-0.86)*	0.72 (0.63-0.81)*
6-11	1,097	2,695	2.03 (1.77-2.33)*	2.03 (1.77-2.33)*
12-60	4,564	24,074	1.0	1.0
Currently breastfeeding (n=42,282)				
Yes	5,617	25,683	1.0	1.0
No	1,452	9,527	0.71 (0.63-0.81)*	0.71 (0.63-0.81)*
Birth order (n=42,282)				
1	1,211	6,517	0.72 (0.59-0.88)*	0.72 (0.59-0.88)*
2-3	2,165	10,809	0.90 (0.76-1.05)	0.90 (0.76-1.05)
4-5	1,736	8,040	1.02 (0.88-1.17)	1.02 (0.88-1.17)
>6	1,958	9,846	1.0	1.0
Number of under-5s (n=42,282)				
1	2,574	12,294	1.0	1.0
2	3,397	17,029	0.77 (0.69-0.86)*	0.77 (0.69-0.86)*
>3	1,098	5,889	0.65 (0.55-0.77)*	0.65 (0.55-0.77)*
Stunting (n=33,608)				
Yes	2,700	11,305	1.28 (1.16-1.42)*	1.28 (1.16-1.42)*
No	3,069	16,533	1.0	1.0
Cough (n=42,275)				
Yes	3,325	6,400	3.76 (3.41-4.14)*	3.76 (3.41-4.14)*
No	3,743	28,808	1.0	1.0

*p<0.001; **p<0.05

Discussion

The results showed that the prevalence of diarrhea has multiple predictors that are related to parental socio-demographic, child-related factors, and improvement in water and sanitation. Among these, the provision of basic sanitation plays the greatest role in interrupting the feco-oral transmission of diarrhea when an infective agent is handled in a sanitary way.

However, the effect of water and sanitation on the transmission of diarrhea varies widely in the literature. In one study, a median reduction of diarrheal morbidity was 22% with the use of all WASH interventions, with the greatest reduction (37%) contributed by improvements in water quality and availability (4). Various WASH interventions assessed in a systematic review indicated a reduction of diarrhea varying between interventions (41). In a further study, the intervention of supplying clean water to households had consistent and sustained benefits in reducing diarrhea (42).

The rate at which transmission is reduced varies for multiple reasons, the main one being the extent of contamination of drinking water and cleanliness of the environment. The level of fecal contamination has a non-linear relationship with the level of diarrheal diseases affected by sanitation interventions (43). Clean water from a source may get contaminated when collecting and taking it home, in storage, or when using an unclean cup for drinking (44). The demographic, physical and health status of a child are important predictors of diarrhea, as is the external factor of providing a clean and safe environment.

In the final model, improved water source was a significant predictor, while improved sanitation was not. This is consistent with other studies (42, 45). Access to improved water sources promotes personal and food hygiene However, the increased odds of diarrhea are not appreciable in the present assessment, this being about 5% among those households not using improved water sources relative to users of improved water sources. It might be that improved water sources are not providing fully safe water, or that there are other risk factors that may contribute. Safe water in this discussion refers to the biological quality. Evidence from a national survey in Ethiopia showed that about 68% of improved water sources complied with the WHO's guideline on the absence of fecal contamination (46). A relatively recent assessment showed fecal contamination in about 65% of water samples taken from improved water sources in North Gondar Zone (47). The 2019 JMP report showed a very low estimate of access to improved water sources, about 14%, meeting the definition of safely managed drinking water sources, although the reduction of open defecation has gone down to 57% (31). This JMP report also showed that the proportion of the population using a safely managed water service in Ethiopia is 14%, which is very low relative to Nigeria (23%) and Ghana (53%). Also, there was a large disparity in the microbial water quality between point of collection and point of use: 14% and 6%, respectively (31).

It is not a surprise that improved sanitation could not be a significant contributor to diarrhea in Ethiopia, where open defecation is still very high, access to improved latrines is very low, and the handling of child feces is very poor (9, 31). In addition, the quality of latrines in rural areas is such that their structure rarely survives a year, and are easily flooded in the rainy season, thereby contaminating drinking water sources. The seasonality of diarrhea because of water contamination caused by flooding has been described elsewhere (48-50) . Run-off water as a factor in contracting diarrhea has also been described in a in a neighborhood country (51) .

The interaction term between improved water sources and improved sanitation could not show an appreciable effect on diarrhea compared to the impact of access to an improved water source alone. This finding is contrary to related studies which show that the combined intervention, including hand hygiene, has a significant impact on reducing the transmission of diarrhea (5). This implies that that the utilization of hygiene and sanitation facilities depends on the behavior of users. Diarrhea reduction among children was much stronger in households that used latrines compared to those who had access to latrine facilities (18, 52). This is well understood given the multiple paths of transmission of diarrhea, in which restricting the fecal contamination of the environment alone could not play a significant role. Limited access to basic sanitation will not bring significant public health changes until access reaches the level of 80% coverage, which is assumed to provide herd protection among the community from the impact of diarrhea (53). This is given the role of increased coverage that will restrict open defecation in the environment. Nevertheless, there is an argument in the literature that 100% compliance with WASH services is required to maximize the prevention of childhood diarrheal illness and deaths (54). Achieving improvements in child survival in developing countries, where poor sanitation infrastructure prevails, is challenging, and it is unlikely to bring about a sufficient increase in coverage and utilization so that the SDG target can be met.

The strength of this study is the use of complex survey data and a multilevel mixed-effects analysis to identify most relevant predictors of diarrhea. In addition, the availability of an adequate sample size provided by the EDHSs improved the precision and accuracy of estimates. The community-level factors, such as access to health facilities, income and education, were not used for analysis. Hand washing practice and household-level water treatment were not used due to inconsistency across the various EDHSs. These variables are believed to affect the pattern of diarrhea, given that combined interventions optimize maximum benefits.

Conclusions and recommendations

Improved water sources are predictors of diarrhea, while improved sanitation has a marginal association. The effect of improved sanitation was not significant, with an interaction term with improved water sources showing the relevance of other factors in the occurrence of diarrhea, including improved water sources. There is a need to maintain the requirements of safely managed drinking water sources. Overall, the quality of latrines, and their increased coverage and utilization require improvement to demonstrate an optimum joint effect on diarrhea with improved water sources.

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