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Research Paper

Effectiveness of home water treatment for the control of diarrhea in children under five years: an intervention study in a rural health zone of Tshopo in the Democratic Republic of Congo

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ABSTRACT

Villages that were once certified as 'sanitized' have lost their status and now have high rates of diarrheal diseases. The goal of this study was to evaluate the effectiveness of water treatment and safe management in reducing diarrheal diseases in children aged 0–59 months. An intervention study with non-randomized allocation of subjects was conducted from 1 September 2023 to 29 February 2024 in two villages in Tshopo province. The control village was the one selected in the similar context in terms of water supply, hygiene and sanitation. The incidence of diarrhea was calculated in each village per 100 person-weeks. Systematic water treatment combined with hygienic storage and reduction of storage time to 24 h reduced the prevalence of diarrhea from 49.6 to 9% in children aged 0–59 months. Village category (IRR = 1.89, 95% CI: 1.8–1.98), education level (IRR = 1.101, 95% CI: 1.05–1.5), marital status of household head (IRR = 1.13, 95% CI: 1.02–1.24) and household size (IRR = 1.08, 95% CI: 1.07–1.08) were associated with diarrhea. Water treatment and safe management are effective measures to reduce diarrheal morbidity and should be recommended in the context of poor household access to improved water sources.

Key words: children 0–59 months, diarrhea prevention, safe management, water treatment

HIGHLIGHTS

- Home water treatment improves water quality.
- The use of standardized containers protects water against contamination.
- Hand and container hygiene, water storage time of 24 h reduce water contamination.
- Systematic processing, storage and hygienic handling reduce diarrhea.
- The involvement of representatives of the population improves community support.

1. INTRODUCTION

Childhood diarrhea remains a health challenge despite national programs and international initiatives to prevent diseases and reduce infant and child mortality, mainly driven by the World Health Organization and the United Nations Children's Fund (WHO 2018). It is the second leading cause of death among children under 5 years of age worldwide and is responsible for 525,000 child deaths per year, particularly in rural areas of sub-Saharan Africa (WHO 2018).

Several authors recognize the role played by water in the incidence of diarrhea in children. Indeed, communities with poor access to drinking water have a higher prevalence of diarrhea (Azage *et al.* 2016).

According to the World Health Organization, drinking water quality is a concern for human health in developing countries. Interventions to improve drinking water quality provide significant health benefits (WHO 2004).

Untreated drinking water exposes children to diarrhea (Sinharoy *et al.* 2016). Ensuring a good supply of safe water and better sanitation constitutes a preventive action, the main effect of which is to reduce the number of episodes of diarrhea and thereby to reduce the number of deaths (WHO/SDE/WSH/04.04 2004; Komarulzaman *et al.* 2016), because 11% of deaths in children under five are due to diarrhea (WHO 2013).

Diarrhea can be prevented and treated with inexpensive means (Isanaka *et al.* 2012). Diarrhea prevention practices such as proper sanitation, safe water supply and hygiene education are effective health interventions that reduce the risk of diarrhea in children under 5 years of age by 27–53% (Darvesh *et al.* 2017).

Nearly one-tenth of the disease burden could be prevented by improving access to safe drinking water, hygiene and sanitation and water management to reduce the risk of waterborne infectious diseases (WHO/SDE/WSH/04.04 2004).

A systematic study carried out in 2005 concluded that diarrheal episodes are reduced by 39% by the treatment and good conservation of water at home (Fewtrell *et al.* 2005).

Coverage of improved water points exceeds 90% in several parts of the world while it remains at 61% in sub-Saharan Africa (UNICEF & WHO 2014).

In Benin, an experiment that provided clean, closed containers for transporting and storing water in homes showed a significant reduction in the presence of *Escherichia coli* in water samples (IOB/BMZ 2011).

The systematic review of 14 studies evaluating the effect of water quality on diarrhea (Quick *et al.* 2002; Clasen *et al.* 2005, 2006, 2015; Fewtrell *et al.* 2005; Peletz *et al.* 2013; Cha *et al.* 2015; Speich *et al.* 2016; Darvesh *et al.* 2017; Wolf *et al.* 2018, 2022; Pickering *et al.* 2019; Soboksa *et al.* 2020; Solomon *et al.* 2020) found that the median percentage reduction in diarrhea by water treatment was 39% with a range of 9–75% and the modal reduction was 37%. Clasen *et al.* (2005) concluded that water treatment, particularly flocculation or disinfection, was more effective in reducing the risk of diarrhea than improving water sources.

In the Democratic Republic of Congo (DRC), data related to access to an improved drinking water source vary across studies. According to the Multiple Indicator Cluster Survey (National Institute of Statistics 2018), 59% of the population uses drinking water from improved sources; this proportion is very low in rural areas (33%) (National Institute of Statistics (INS) 2018).

During previous studies carried out in the coverage area of the National Healthy School and Village Program, in the Tshopo province, despite the use of improved sources, it was observed that (i) water was highly contaminated throughout the supply chain, especially during storage for 48 h or more, as evidenced by the presence of coliforms (Basandja *et al.* 2021a); (ii) the high prevalence of diarrhea in children under 5 years of age at 13% (95% confidence interval (CI): 10–16%) associated with the absence of water treatment, the use of unimproved toilets and water storage for more than 24 h (Basandja *et al.* 2021b); (iii) good knowledge of the importance of water treatment at home (79%, 95% CI: 73–85%) but practice was low (17%, 95% CI: 12–22%); (iv) households reported, in the majority of cases, that the lack of chemicals was the main reason for not treating water at home (Basandja *et al.* 2021a).

Nationally, only 6% of households treat water (National Institute of Statistics (INS) 2018) and no information is available in the literature, either at the national or local level, on the proportion of households that have standardized containers and manage water hygienically, on the one hand, and the fraction of reduction in diarrheal morbidity when households are taught to systematically treat water and manage water hygienically, on the other hand.

The DRC, in general, and the province of Tshopo and its rural areas, in particular, are not immune to the scourge relating to the dysfunction of the drinking water supply service, the weakness of treatment and the secure management of water in households.

To our knowledge, very few studies present evidence measuring the effect of water treatment and safe management on the prevalence of diarrhea, in the province of Tshopo, in general, and in the context of a failed sanitation program, in particular.

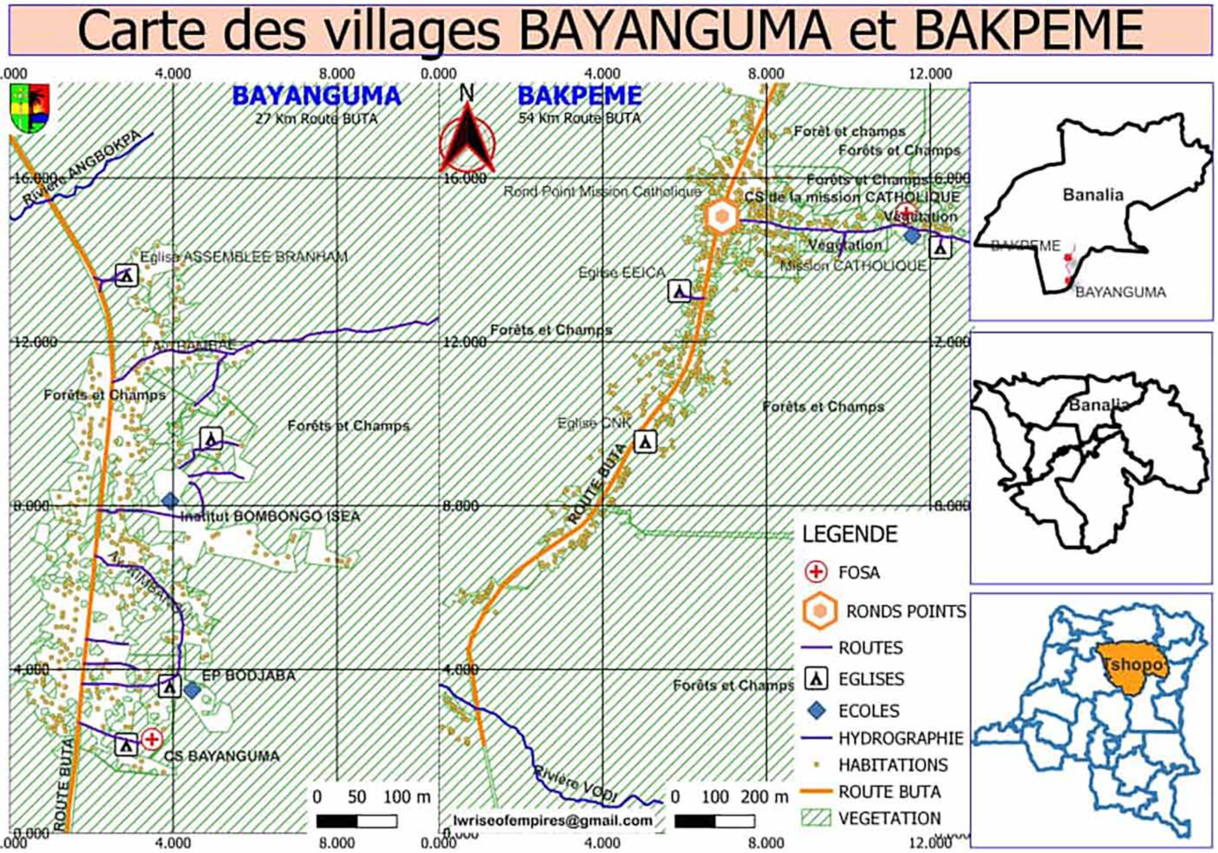
The objective of this study was to evaluate the effectiveness of water treatment and safe management as preventive measures for diarrheal diseases in children under 5 years of age in households using an intervention study.

Specifically, this means, in addition to determining the prevalence of diarrhea before and after intervention, assessing the proportion of diarrhea reduction after intervention and comparing the evolution of diarrhea between the two study villages.

2. METHODS

2.1. Study site

This study was conducted in two villages in the BENGAMISA Health Zone, in the Tshopo province.



These two villages were certified as 'sanitized' under the National Sanitized School and Village Program (NSSVP) about 5 years ago. A pre-intervention contextual study conducted in these two villages found similarities in terms of culture (belonging to the same tribe), water supply, hygiene and sanitation (loss of certification status in terms of good water supply, hygiene and sanitation practices) and in terms of the organization of community participation activities.

The two villages were selected after consultation with members of the Health Zone Framework Team (HZFT) and community representatives based on the review of village sanitation performance, community participation and analysis of diarrheal morbidity data. These two villages were served by Health Centers and had Community Relays (CORE) and Community Animation Cells (CAC) which are responsible for community awareness on health-promoting practices and the referral of disease cases to the health facility for better management.

2.2. Study population

The study population consisted of children aged 0–59 months living in villages formerly covered by the NSSVP. Data were collected from all household members to secondarily assess the effect of the intervention on the overall population living in the households.

2.3. Type and period of study

It was an experimental study with non-randomized allocation of subjects in the two categories of villages, conducted during the period from 1 September 2023 to 29 February 2024. The primary unit of analysis consisted of children aged 0–59 months living in the targeted villages. The village with a higher prevalence of diarrhea among children aged 0–59 months, pre-intervention, was selected as the intervention village. All study participants were informed of the village category to which they belonged.

2.4. Sampling

The sample size calculation was 564 in each group (exposed and not exposed to the intervention) based on the Fleiss formula for cohort studies (Fleiss *et al.* 1980) considering a 95% CI ($\alpha = 0.05$), a power of 80% ($\beta = 0.20$), $P1$ = proportion of diarrhea outside the intervention of 13% (Basandja *et al.* 2021a, 2021b), $P0$ = proportion of diarrhea in the group exposed to the intervention of 7.9% based on a reduction of 39% (Fewtrell *et al.* 2005), i.e. a relative risk of 0.61, $r = (P1/P0) = 1.64$ and $P = (P0 + rP1)/(r + 1)$.

$$\text{NFleiss} = 564\frac{\left[Z\alpha/2\sqrt{(r+1)P\,(1-P)} + Z\beta\sqrt{rP0(1-P0) + P1(1-P1)}\right]\hat{}2}{r(P0-P1)\hat{}2}$$

Considering that the study involved monitoring all household members with an average household size in the DRC estimated at 5.2 (National Institute of Statistics 2018), the minimum number of households to be included was $564/5.2 = 108.5$ rounded to 109.

2.5. Inclusion criteria for the study

The study was exhaustive where all children aged 0–59 months living in the two targeted villages were included, respectively, 357 and 411 children for the intervention and control villages.

2.6. Eligibility criteria

Included in this study were any cases of diarrhea meeting the WHO definition of diarrhea: 'passing loose or liquid stools at least 3 times a day or having stools more frequently than is usual for the affected individual', all causes and age groups included.

2.7. Variables of interest and operational definition

2.7.1. Main variable

The primary study variable was 'presence of diarrhea cases in the household' as the primary outcome measure.

2.7.2. Independent variables

– Sociodemographic characteristics of heads of households: age, level of education, marital status and profession;
– Household size (total population and children 0–59 months);
– Weekly incidence of diarrhea;
– Cumulative incidence of diarrhea during the study period;
– Water treatment (Yes or No);
– Water storage time (24 h or more);
– Households using standardized water storage containers (Yes or No).

2.7.3. Evaluation criteria

The primary and secondary evaluation criteria were checked weekly, during home visits (HVs) by the COREs.

The primary evaluation criterion was ensured by the weekly counting of cases of diarrhea in the two study villages, referring to the operational definition of diarrhea retained.

Secondary endpoints at the intervention village level included verification of availability of water purifiers throughout the study period, systematic water treatment, closure of storage container, hygienic water collection and reduction in storage time of treated water by 24 h.

2.7.4. Operational definition of variables

- *Diarrhea*: Passing loose or liquid stools at least 3 times a day or having stools more frequently than is usual for the affected individual (WHO 2013).
- *Diarrheic episode*: All recourses to the healthcare system for a diarrhea problem until it is considered resolved or until the patient stops using the healthcare system for this problem (HF 1999).

- *Diarrheal diseases*: Any disease presenting diarrhea as one of the clinical manifestations, without distinction of origin or semiological characteristics (Maramraj *et al.* 2017).
- *Water treatment*: Use of a physical or chemical method to destroy pathogenic microorganisms present in drinking water (CAWST 2018).
- *Standardized containers*: Plastic or metal bucket with a lid and a tap for hygienic water collection (UNICEF & WHO 2014).
- *Safe water management*: Storage of water in a covered plastic or metal container, collection by flow and storage duration of 24 h (UNICEF & WHO 2014).
- *Community relay (CORE)*: A volunteer living in the village, chosen by the community, who has voluntarily agreed to devote part of his time to the village's health activities. He is responsible for 15–35 households depending on the case and his work in the households is done using HVs (Ministry of Public Health 2023).
- *Community animation cell (CAC)*: A community animation cell is a group of 8–12 volunteers, elected by the village/neighborhood, representative of the community, including women and young people, responsible for visiting a group of approximately 50 families on a regular basis, to inform them and raise awareness about essential family practices, ensure the first line of epidemiological surveillance, and establish a dialogue and community feedback mechanism. It is placed under the leadership of the village/cell chief and made up of the village/cell's vital forces, including frontline workers who are community relays (CORE). At least 30% of the CAC members must be women and young people (Ministry of Public Health 2023).

2.8. Description of the intervention

The intervention envisaged within the framework of this study will consist of the systematic treatment of water, its conservation and its hygienic collection thanks to a continuous supply of water purifiers, the provision of standardized containers for the safe management of water and the sensitization of the population for the promotion of good water management practices.

Water treatment can be done by physical or chemical methods.

The destruction of microorganisms by physical methods is done by sedimentation, filtration, UV rays or boiling. Sedimentation allows the removal of larger particles of matter, while filtration allows the removal of finer granulometry particles that have not sedimented.

Boiling is also an effective way to kill the majority of pathogens, most of which are killed at temperatures above 70 °C. While boiling water is an easily controllable method (only a few minutes of boiling ensures the elimination of the majority of pathogens), its use can pose difficulties, particularly when fuels (wood, coal, gas, etc.) are scarce or too expensive for users (Meierhofer *et al.* 2005; Rajaonary & Grondin 2018).

Exposing water to sunlight will destroy most pathogens. This process is even more effective at high temperatures (although the water temperature does not necessarily have to be much above 50 °C). In tropical regions, an exposure period of about 5 h, starting at noon, is considered safe (Wegeline *et al.* 1994).

The destruction of microorganisms by chemical methods is done by the inactivation of positively charged microbial particles with the action of free residual chlorine in the water. This method is chosen due to its effectiveness, safety, availability at low cost, acceptability and ease of application.

The water chlorination technique is the most widely known and widely used water treatment technique to ensure water disinfection. Chlorine eliminates pathogenic organisms (bacteria, viruses and germs) from clear water (natural or free of suspended matter) provided that sufficient contact time is ensured (minimum 30 min) (Meierhofer *et al.* 2005; Rajaonary & Grondin 2018; Wikiwater).

Chlorine is available in different forms: solid (powder, tablets or granules of calcium hypochlorite or sodium dichloroisocyanurate or DCCNa) or liquid (bleach or sodium hypochlorite). Commercial products often have varying dilution levels.

As part of this study, we used the product 'sodium dichloroisocyanurate' 67 mg (NaDCC), dispersible tablet (Aquatabs®).

Technical

– Put clean water in a 20-liter container;
– After washing your hands with soap and water, tear open the packaging and take one 67 mg tablet;
– Soak the tablet in water and leave for 30 min;
– Empty any unused treated water after 24 h, clean the container and prepare new water.

(i) *Safe water management*

– Store water intended for drinking in a standard container (plastic bucket with lid and tap);
– Always keep the container lid closed;
– Draw water using the tap;
– Empty the container after 24 h of storing the treated water;
– Clean the container.

Economic viability of the project

The water purifier used is available in the public market, throughout the country and the region, it is currently manufactured in laboratories outside the country and sold in pharmaceutical pharmacies. However, the manufacture of this product by local laboratories is possible and could further improve market availability and reduce the cost. This would highlight the large-scale use of the results of this study within the framework of a government program, if this intervention were undertaken.

Supported by households, the box of 160 tablets costs around \$4–\$4.5 and can be consumed for an average of 5 months, which corresponds to an average monthly expenditure of \$0.8–\$0.9 per household, a burden that households can support, in the absence of a subsidy program.

2.9. Data collection and quality control

At the level of each village, the data collection team consisted of 10 Community Relays (CORE) recruited by the Health Zone and trained by the study coordination team. These COREs were placed under the direct supervision of the Health Center team in their area. The COREs organized weekly HVs, each in the households for which they were responsible, to collect data and provide water purifiers.

Interview with head of household or his representative and direct observation were techniques used for data collection.

The observation consisted of a physical count of people who were reported to have had diarrhea during the week, verification of proof of water treatment (water treatment in the presence of CORE, presentation of packets of tablets already used in exchange with other packets of tablets), safe water management (the closed water container placed on a display, water sampling through the tap, disuse after 24 h of treated water for use other than drinking).

The surveys at the beginning and end of the intervention were carried out by the coordination team which focused on the characteristics of the households and the results of the intervention at the time of the study; however, the monitoring of the effectiveness of water treatment and the weekly notification of cases of diarrhea were ensured by the COREs.

At the end of the month, this data was collected, analyzed and validated by the field coordination team composed of the principal investigator (specialist physician in public health), technical assistant (specialist physician) and two field supervisors (licensee in public health). Any aberrant data was actively sent to the field for verification and possible correction.

2.10. Data analysis

The management of potential biases was done, on the one hand, by an *a priori* similarity of context of two villages (attitude and perception of the quality of the water consumed, acceptance of water treatment, low practice of water treatment, consumption of water from unimproved sources, conditions of storage and handling of water at home and the high prevalence of diarrhea among children aged 0–59 months) and on the other hand, stratification by village category.

Data were centralized in an Excel 2016® database and then exported to STATA® 15 for analyses. The sample description was made using proportions for the variables gender, education level and marital status; the mean $\pm$ SD for age, the cumulative number of cases of diarrhea in children of 0–59 months and the overall cumulative number of cases of diarrhea (which was normally distributed) and the median and P75–P25 for the number of children and persons in the household (which was skewed).

The incidence of diarrhea was calculated in each household per 100 person-weeks, for children of 0–59 months and for all household residents, then the cumulative incidence was calculated for the study period.

The comparison of quantitative variables was made using Student's *t*, Mann–Whitney Wilcoxon and Kruskal–Wallis tests, and that of categorical variables, using Pearson's chi-square test and Fisher's exact test, according to the conditions of their applications.

To estimate the cumulative incidence of diarrhea and its association with the independent variables, the Poisson regression model (generalized linear model used for count data and contingency tables) was fitted assuming that the number of diarrhea cases for each village was distributed as a Poisson random variable with mean 'm' and variance between households depending on the presence or absence of the intervention via an equiprobable model.

A negative binomial model was used to account for overdispersion.

The cumulative incidence rates derived from the model were presented with their 95% CIs.

3. RESULTS

The median number of children aged 0–59 months was different between the two villages but all other characteristics of the sample were similar (Table 1).

The prevalence of diarrhea and the mean number of diarrhea cases were significantly high at the start of the intervention in the intervention village, and then the trend was very significantly reversed at the end of the intervention ($p < 0.05$) (Table 2).

The mean number of diarrhea cases in households during the study period was significantly higher in control village households than in intervention village households among both all household residents and children aged 0–59 ($p < 0.05$) (Table 3).

Table 1 | Sample characteristics

Variables	Terms and conditions	Intervention $N = 125$ *n* (%)	Control $N = 109$ *n* (%)	Set $N = 234$ *n* (%)	*p*-value
Sex	Male	2 (1.6)	4 (3.7)	6 (2.6)	0.421*
	Female	123 (98.4)	105 (96.3)	220 (97.4)	
Age	Mean ± SD	41.4 ± 11.8	41.8 ± 12.5	41.4 ± 13.5	0.802**
Level of education	Down	70 (56.0)	48 (44.0)	118 (50.4)	0.068***
	Normal	55 (44.0)	61 (56.0)	116 (49.6)	
Occupation	Farmer	106 (84.4)	90 (82.6)	196 (83.8)	0.191*
	Official	7 (5.6)	13 (11.9)	20 (8.5)	
	Small business	1 (0.8)	2 (1.8)	3 (1.3)	
	Resourceful	2 (1.6)	1 (0.9)	3 (1.3)	
	Other	9 (7.2)	3 (2.8)	12 (5.1)	
Number of people	Median (P75–P25)	8 (11–6)	8 (10–6)	8 (10–6)	0.139****
Number of children 0–59 months	Median (min–max)	2 (4–1)	3 (5–2)	3 (5–2)	0.001****

*Fisher's exact.
**Student's *t*-test.
***Pearson's chi2.
****Mann–Whitney Wilcoxon.

Table 2 | Prevalence of diarrhea at the beginning and end of the intervention

Household target	Village categories	Frequency (%)	Mean ± SD	95% CI	*p*-value
Start of intervention (Week 1)					
General population	Intervention $N = 1,166$	292 (25.0)	2.34 ± 2.5	1.89–2.78	0.001*
	Control $N = 837$	111 (13.3)	1.0 ± 1.1	0.80–1.23	
Children 0–59 months	Intervention $N = 357$	177 (49.6)	1.4 ± 1.5	1.14–1.69	0.001*
	Control $N = 411$	62 (15.1)	0.6 ± 0.7	0.43–0.71	
End of intervention (Week 24)					
General population	Intervention $N = 1,166$	40 (3.4)	0.32 ± 0.81	0.18–0.46	0.001*
	Control $N = 837$	265 (31.7)	2.43 ± 1.67	2.11–2.75	
Children 0–59 months	Intervention $N = 357$	32 (9.0)	0.26 ± 0.67	0.14–0.37	0.001*
	Control $N = 411$	129 (31.4)	1.18 ± 1.02	0.99–1.38	

*Student's *t*-test.

Table 3 | Cumulative frequency of diarrhea during the study period

Village category	Average	DS	95% CI	*p*-value
Number of cases of diarrhea in the total household population				
Intervention	30.0	18.9	[26.7–33.4]	0.001*
Control	50.4	26.2	[45.4–55.4]	
Number of cases of diarrhea in children aged 0–59 months				
Intervention	19.9	12.9	[17.6–22.2]	0.004*
Control	24.9	13.9	[22.3–27.6]	

*Student's *t*-test.

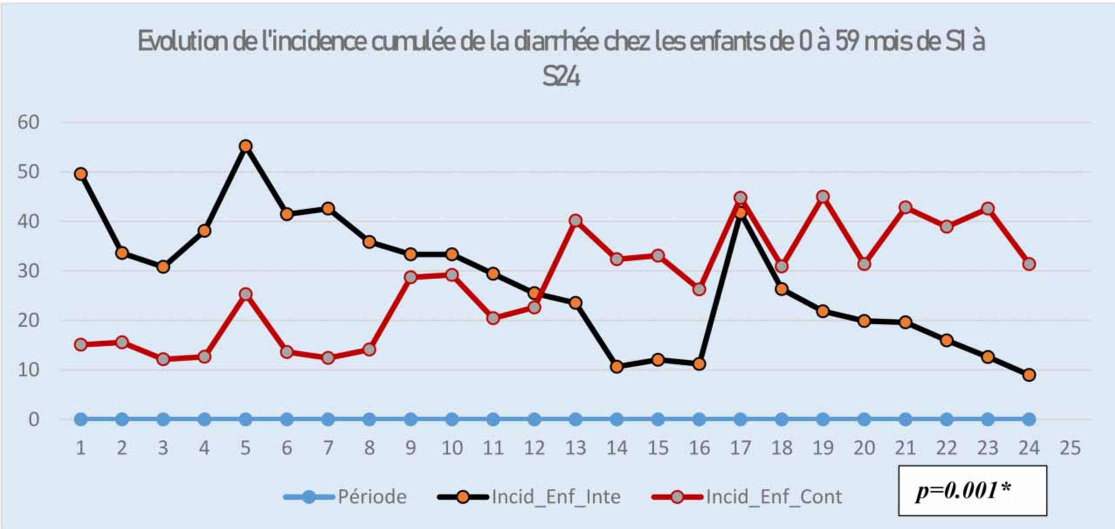


Figure 1 | Evolution of weekly incidence rate of diarrhea in children. *Kruskal–Wallis test. Incid_Enf_Inte: Weekly incidence rate of diarrhea in children aged 0–59 months in the intervention village. Incid_Enf_Cont: Weekly incidence rate of diarrhea in children aged 0–59 months in the control village.

The incidence rate curve of diarrhea in children in the intervention village showed a progressive and significant reduction in diarrhea cases from week 5 to week 16. Another peak was observed at week 17 and then a significant reduction until the end of the intervention (Figure 1).

The share of variability in diarrhea cases in households explained by the model was 49%. Households in villages without intervention had about 2 times the risk of developing diarrhea; households with a head with a low level of education (none or

Table 4 | Factors associated with diarrhea in the household by Poisson regression

Cumulative diarrhea in households	IRR	*p*-value	95% CI
Village category	1.89	0.000	1.80–1.98
Gender of head of household	0.96	0.559	0.83–1.10
Age of head of household	0.996	0.000	0.99–0.99
Level of study	1.10	0.000	1.05–1.51
Marital status	1.13	0.014	1.02–1.24
Number of people in the household	1.08	0.000	1.07–1.08
Number of children aged 0–59 months	0.774	0.000	0.766–0.783

primary), living without a spouse (divorced, single, widowed) and large households (≥5) had a high risk of diarrhea ($p < 0.05$). In contrast, households with a younger head and a small number of children had a higher risk of diarrhea at 0–59 months was associated with reduction in diarrhea ($p < 0.05$) (Table 4).

The village category takes into account the intervention package: household awareness, systematic water treatment, use of standardized containers, water collection from taps and reduction of the storage time of treated drinking water to 24 h.

4. DISCUSSION

4.1. Prevalence of diarrhea

The prevalence of diarrhea decreased from 25 to 3.4% in the general population and from 49.6 to 9% in children aged 0–59 months in intervention village households. In contrast, it increased from 13.5 to 31.7% and from 15.1 to 31.4% in the general population and in children aged 0–59 months, respectively, in the control village (Table 2).

The overall rate of diarrheal diseases and the specific rate in children under 5 years observed at the end of our intervention are rarely reported in the literature used. Our intervention substantially reduced the frequency of diarrhea in intervention village households.

Natnael *et al.* (2021) found similar prevalences in children under 5 years old, estimated at 11% (95% CI: 7.8–14.3%) and Kone *et al.* (2014) found 7 and 14% respectively in households and among children under 5 years old.

Much higher prevalences of diarrhea were observed in children by Alemu *et al.* (2023) and Ahmed *et al.* (2024), respectively, 57.3% (95% CI: 54.5–60.1%) and 51% (95% CI: 46–56%).

On the other hand, rates comparable to those presented in the control village were reported by other researchers. Melese *et al.* (2023) found this prevalence and that of intestinal parasites in children under 5 years of age to be 20.8% (95% CI: 16.8–37.8%) and 32.5% (95% CI: 28.6–37.8%), respectively; Omona *et al.* (2020) found 29.1% (95% CI: 23.7–35.0%); Thiam *et al.* (2017) 26%; Woldu *et al.* (2016) 26.1% (95% CI: 22.9–29.3%); Diouf *et al.* (2014) 32.6% and Diop *et al.* (2019) 28.3%.

Mean prevalences of diarrhea were also reported by other researchers, including Fenta *et al.* (2020) who found 14.5% (95% CI: 12.3–17.3%); Gessesse & Tarekegn (2022) 15.5%; Feleke *et al.* (2022) 17.3%; Demissie *et al.* (2021) 15.3% (95% CI: 15.1–15.4%) and Tareke *et al.* (2022) 14.28% (95% CI: 14.06–14.51%).

The observed fluctuation in the prevalence of diarrhea is generally related to the difference in the level of coverage of interventions in the field of water, hygiene and sanitation, on the one hand, and to the difference in the economic context and sociodemographic characteristics of households, on the other hand. In most cases, the relationship of diarrhea was established with access to drinking water which was low, insufficient sanitation measures and precarious hygiene conditions. Other factors related to the level of education of mothers, household size, household income level and behavior, including hygiene measures, drawing technique, storage conditions and handling of water at home, were mentioned.

Nevertheless, all these data attest that diarrheal diseases remain a perennial burden for the community, in general, and for children aged 0–59 months in particular, especially in low-income countries where water, hygiene and sanitation service coverage indicators are low (WHO 2018).

4.2. Effects of intervention on diarrhea

Systematic water treatment combined with hygienic storage and reduction of storage time to 24 h reduced the prevalence of diarrhea by 88% compared to the baseline rate (Figure 1).

The mean number of diarrhea cases (Table 3) and the time trend of the weekly incidence rate curve were different between households in intervention and control villages (Figure 1).

Clasen *et al.* (2005) observed that distributing water disinfection products at household level could reduce diarrhea by about a quarter, and for Soboksa *et al.* (2020), solar disinfection reduced the risk of childhood diarrhea by 38%.

Mbakaya *et al.* (2019) in a study among people living with HIV found that community interventions such as water treatment and safe storage were associated with a 20–53% reduction in diarrhea episodes among PLHIV.

For Tadesse *et al.* (2022), cases of diarrhea were significantly different between certified and non-certified households and that households that did not receive frequent HVs were 3.28 times more likely to develop diarrheal diseases in children (aOR = 3.28, 95% CI: 1.40–7.68).

All these results corroborate ours with a spectacular reduction from 49.6 to 9%. This great feat could be justified by (i) the combination of interventions: water treatment, storage and hygienic sampling and reduction of the storage time by 24 h; (ii) the massive adhesion of the population to the intervention (100% of households) and (iii) the regularity of follow-up visits by well-motivated RECOs. This is in line with the conclusion of Tadesse *et al.* (2022) which confirms the strength of close monitoring in the performance of community interventions.

Point-of-use drinking water treatment is the solution to the problem of waterborne diseases in conditions where some communities have sufficient water but of questionable quality. The effectiveness of water quality improvement interventions depends on the type of intervention, its duration and the degree of community support (Clasen *et al.* 2006).

Our arguments are in line with Fewtrell *et al.* (2005) who found the percentage reduction in diarrheal diseases per intervention as follows: hygiene 33%, sanitation 36%, water supply 19%, quality water 15%, multiple intervention 30% and hand washing 42% and he stressed that the impact of interventions is amplified when they are combined.

4.3. Factors associated with diarrhea

As in other studies around the world, the same factors were observed by several authors in different contexts.

4.3.1. Village category

Studies conducted in households that have participated in any health promotion program show significant differences in knowledge and favorable health practices compared with control households.

Mernie *et al.* (2022) found that the prevalence of acute diarrhea in children under 5 years of age in kebele households that implemented a CLTSH (Community Led Sanitation System) was 10.6% (95% CI: 6.6–14.7%) compared to 18.3% (95% CI: 14.8%) in those that did not implement CLTSH. The risk of diarrhea found to be associated with non-treatment of water was comparable to ours (aOR = 2.33, 95% CI: 1.21–4.49%).

Tadesse *et al.* (2022) also found that mothers from non-intervention households were 2.19 times more likely to develop diarrheal diseases in children under 5 years of age (aOR = 2.19, 95% CI: 1.34–3.57), a result that corroborates ours.

Diop *et al.* (2019) observed 66.6% of diarrhea in households where no water treatment was carried out (Diop *et al.* 2019). The results of the study conducted in South Africa had shown that water treatment (OR = 0.57, 95% CI: 0.34–0.97, $p = 0.04$) and good handwashing practices (OR = 0.59, 95% CI: 0.42–0.82, $p = 0.002$) reduced diarrhea (Nguyen *et al.* 2021).

Thiam *et al.* (2017) also found the risk comparable to ours in the absence of water treatment in the household (aOR = 1.69, 95% CI: 1.11–2.56). For Ssekandi *et al.* 2016, the absence of treatment of drinking water with chlorine presented approximately 4 times the risk of diarrhea (aOR = 3.81, 95% CI: 1.61–9.02).

Gessesse & Tarekegn (2022) in their study found that the prevalence of diarrheal diseases in model and non-model households was different, 10.9 and 20%, respectively.

Generally, the problem of water availability and quality arises acutely and to a different extent from one country to another, depending on the hydrogeological possibilities, the level of development of activities in the field of water, hygiene and sanitation and the governance in terms of water resource management. In all cases, surface water used as a source of drinking water is heavily polluted, consumed without any treatment, and is the vehicle for diarrheal diseases.

The evidence for preventing diarrhea through interventions to improve access to safe drinking water is strong, communities with low drinking water coverage should be encouraged to treat water using available, accessible, less expensive and effective methods to prevent diarrheal diseases.

The practice of water storage is an alternative used by the community that does not have a connection to a water distribution network, and it constitutes a significant source of water contamination when safe management measures are not observed.

Poor water storage practices were also identified as factors associated with diarrhea; Kone *et al.* (2014) cited the place of storage of drinking water ($p = 0.02$) and the storage container ($p = 0.03$); Ahmed Ismail *et al.* (2024) noted that storing water in jerrycans increased the risk of diarrhea approximately 5 times (aOR = 4.90, 95% CI: 1.31–8.39) and for Fenta *et al.* (2020), storing water in jerrycans increased the risk of diarrhea approximately 9 times (aOR = 8.6, 95% CI: 1.51–48.84).

The risk with jerrycans lies in the quality of cleaning; generally made of plastic, a good support for the adhesion of germs, these containers are difficult to clean, especially at the neck. Good hygiene measures must be taught to users.

The performances observed with interventions are justified by the fact that each intervention brings a package of knowledge, attitude and practices that contribute to the preservation of the health of the beneficiary populations, but the mechanisms for perpetuating the achievements of the interventions are not always adapted and are generally failing post-intervention. This remains a major challenge to be met.

4.3.2. Age of household manager and/or children

Unlike what other researchers had found, the relationship between caregiver age and diarrhea observed in our study was in the opposite direction of what Omona *et al.* (2020) and Diouf *et al.* (2014) had found - that a low prevalence of diarrhea in households was more observed in households where caregivers were aged 40 years or older.

Demissie *et al.* found variations in diarrhea by maternal age, with the risk decreasing with increasing maternal age; children whose mothers were aged 15–24 years had a higher risk (aOR = 1.26; 95% CI: 1.23–1.30) than those aged 25–34 years (aOR = 1.15; 95% CI: 1.12–1.18); Tareke *et al.* (2022) also found that children whose mothers were aged 15–24 years (aOR = 1.41, 95% CI: 1.33–1.49) and those aged 25–34 years (aOR = 1.17, 95% CI: 1.10–1.23) had different risks.

The advanced age of mothers/guardians/caregivers reflects a certain maturity and life experience that would play a beneficial role in the care provided to children.

This controversy observed in our study could be justified, among other things, by the low representativeness of subjects aged under 30 in the study (45 or 19%), on the one hand, and the imprecision with which many subjects responded to the question on age, a source of classification bias, on the other hand.

Nevertheless, future studies should control for the effect of aging on household size and shed light on its relationship with diarrhea.

4.3.3. Level of education

Several authors had found, among the factors associated with diarrhea in children under 5 years, the level of education of the mothers. Melese *et al.* (2023) had found approximately 4 times the risk of diarrhea (aOR = 3.7, 95% CI: 1.52, 8.95); Alemu *et al.* (2023) approximately 3 times the risk (aOR = 2.78, 95% CI: 1.065–3.442); Demissie *et al.* approximately 2 times the risk (aOR = 1.69; 95% CI: 1.57–1.82) for children of mothers with no education and for those with primary education (aOR = 1.73; 95% CI: 1.61–1.86).

The same is true for Tareke *et al.* (aOR = 1.10, 95% CI: 1.03, 1.18) for Ugboko *et al.* (2021) and Mulatya & Ochieng (2020).

The role of the educational level of mothers/caregivers/household managers is highlighted for the acquisition of knowledge, promotion and observance of good practices. Uneducated or less educated mothers retain educational messages poorly, forget easily and have incomplete knowledge on the importance of the different messages.

It is important to develop communication strategies adapted to the level of education and to promote the education of women.

4.3.4. Marital status

The relationship between marital status of the perpetrator and diarrhea was not found in the reviewed literature.

However, since almost all heads of household in our study are men, in the absence of a spouse, households are naturally unstable, the role of childcare, household management, hygiene and sanitation conditions are generally defective and can become a risk factor.

4.3.5. Household size

Some authors had also established the relationship between the number of people in the household and the presence of diarrhea. Notably, Omona *et al.* (2020) in Uganda, Alemu *et al.* (2023) and Feleke *et al.* (2022) respectively in Ethiopia.

These observations corroborate our data for the total number of persons in the household with the exception of the increase in the number of children from 0 to 59 months.

Indeed, overpopulated households with generally lower incomes live in cramped settings, do not have sufficient resources to improve the conditions of secure drinking water supply, hygiene measures and sanitation, on the one hand, and the observed relative promiscuity offers an ideal framework for the transmission of diseases, on the other hand. Improving the conditions of housing hygiene would contribute to reducing the risk of diseases in populated families.

5. CONCLUSION

Water treatment through chlorination and safe water management have been shown to be effective measures to reduce household diarrheal morbidity, especially among children under 5 years, in the context of poor access to improved water sources. The availability of water purifiers, awareness raising, massive support from the population for the intervention and close monitoring by community representatives are factors of success.

This is likely to enable the establishment of an effective prevention strategy within the framework of essential interventions for the control of diarrheal diseases in places with poor access to improved water points.

6. LIMITATIONS OF THE STUDY

The analysis of diarrhea considered all diarrhea according to the WHO community definition without separating by causes or age group. These secondary analyses can be the subject of future studies. Also, future studies should focus on controlling for the effect of aging and shed light on its relationship with diarrhea.

The analysis of the impact of treatment and safe water management, in our study, focused mainly on diarrheal morbidity; other studies are needed to assess the impact on the reduction of infant and child mortality, and must cover a period a little longer than that of our study. Also, our intervention does not have a registration number in a register of an organization to be titrated.

AUTHOR CONTRIBUTIONS

B. E. L.: Writing of the protocol, organization of data collection, data analysis and writing of the manuscript. P. L. K. J.: Support for writing the protocol and the manuscript and first reader. L. L. J.: Support for writing and data analysis and final reader.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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