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Are ceramic water filters effective in preventing diarrhoea and acute malnutrition among under-five children in Sudan?

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Access to safe drinking-water at home is essential during the outpatient treatment of children with acute malnutrition due to their increased vulnerability to infections and disease. The study aimed to evaluate the effectiveness of ceramic water filters with safe storage in preventing diarrhoea and acute malnutrition among under-five children in Kassala state, Sudan. It was designed as an open-label randomized controlled trial, comparing two study groups. Data was collected through face-to-face interviews and direct observations, then processed and analysed using Epi Info 7.2.0.1. Use of water filters is a potential predictor of number of diarrhoea episodes per child ($P < 0.001$). The intervention group had a lower diarrhoea occurrence ($P < 0.001$), better monthly average weight gain ($P = 0.012$) and average mid-upper arm circumference increase ($P = 0.001$), and lower prevalence of acute malnutrition at the end of the study ($P = 0.001$) compared with the control group. Ceramic water filters with safe storage can be effective in preventing diarrhoea and acute malnutrition, and beneficial to children admitted to Community Management of Acute Malnutrition programmes in Kassala state. More research is needed to understand the pathways to achieving these outcomes. Other WASH interventions may be needed to interrupt the primary vectors of diarrhoea disease transmission in this setting.

Keywords: water, filters, diarrhoea, malnutrition

Tackling malnutrition in all its forms remains one of the greatest public health challenges. Globally, nearly half (45 per cent) of deaths among under-five children are linked to malnutrition (WHO, 2018). Estimates from 2018 are alarming: 149 million children under five are chronically malnourished or stunted (defined as low height-for-age), over 49 million children under five are acutely malnourished or wasted (defined as low weight-for-height) and nearly 17 million are severely wasted (UNICEF/WHO/World Bank, 2019). About 65 per cent of all stunted children and 73 per cent of all wasted children live in lower-and-middle-income countries (UNICEF/WHO/World Bank, 2019), including Sudan.

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At the same time, ensuring access to safe drinking-water for all, a fundamental precondition for good health and well-being, remains one of the most critical global issues. It has been estimated that 159 million people drink water directly from surface sources such as streams and lakes, more than 844 million people still lack even a basic drinking-water service, while 2.1 billion do not have safe water at home (WHO/UNICEF/JMP, 2017). All these expose them to unnecessary risk of contracting infectious diseases such as diarrhoea. Diarrhoeal diseases, largely attributable to unsafe drinking-water, inadequate sanitation, and poor hygiene (Prüss-Ustün et al., 2014), are the second leading cause of death in children under five and a leading cause of malnutrition (WHO/UNICEF/JMP, 2017). Interactions between infections such as diarrhoea and malnutrition have long been described as a vicious circle, each being a risk factor for the other (Dewey and Mayers, 2011). Malnourished children are more susceptible to repeated bouts of diarrhoea, whereas frequent illness in return causes poor nutritional intake and reduced absorption, further deteriorating nutritional status. Interventions aiming to improve the quality of drinking-water at the household level have demonstrated a positive impact on reducing diarrhoea incidence (Clasen et al., 2007, 2015).

Access to safe drinking-water at home is of particular importance during the outpatient treatment of children with acute malnutrition in both its forms – moderate acute malnutrition (MAM) and severe acute malnutrition (SAM) – due to their increased vulnerability to water-borne diseases and infections. If contracted, infectious diseases like diarrhoea increase the risk of mortality in malnourished children along with reducing the efficacy of nutritional treatment (Doocy et al., 2018). Recent studies demonstrated that household water, sanitation, and hygiene (WASH) interventions implemented in addition to the Community Management of Acute Malnutrition (CMAM) programme, have a potential to decrease the time-to-recovery, and improve recovery rates and the absolute weight gain of admitted children (Altmann et al., 2018). However, no effects were noticed on the diarrhoea longitudinal prevalence and post-recovery relapse, and further studies are recommended to confirm these findings (Altmann et al., 2018). To our knowledge, no point-of-use water treatment interventions have sustained an effect on preventing both diarrhoea occurrence and acute malnutrition after six months follow-up period.

Over three years (January 2014–March 2017), Sudanese Red Crescent (SRCS), with the support of the Netherlands Red Cross (NLRC), and in collaboration with the Ministry of Health (MOH) of the Republic of Sudan implemented a project with the aim to contribute to reducing child mortality due to diarrhoea and increasing community resilience to diarrhoea. The project covered multiple components including construction and rehabilitation of water supply systems, expanding latrine coverage, hygiene promotion, nutrition education, increasing food security and enhancing community disaster preparedness and response. A specific component within the project was pilot research on the effect of ceramic (or candle) filters for safe household water treatment and storage on preventing diarrhoea and acute malnutrition among under-five children.

The study area, east Kassala state, is one of the poorest in the country, characterized by frequent disease outbreaks and deteriorating nutrition, water, and sanitation indicators. Infant mortality rate is estimated at 62 per 1,000 live births, exceeding the national average of 52 per 1,000 live births (FMoH/CBS, 2010; CBS/UNICEF Sudan, 2016). Prevalence of chronic undernutrition among children under five is the highest in Sudan (48.8 per cent), while the prevalence of acute malnutrition is 18.5 per cent, well beyond the commonly used threshold for a public health emergency (CBS/UNICEF Sudan, 2016). The state is lagging behind the national average in accessing improved drinking-water sources (57.2 per cent compared with 68 per cent at the national level) and household use of improved sanitation (29.3 per cent compared with 32.9 per cent at the national level). In addition to malaria and pneumonia, acute watery diarrhoea presents the largest notified disease among children and a major reason for hospital admission (UNICEF, 2013).

The study was based on the hypothesis that the children diagnosed with acute malnutrition and admitted to the CMAM programme will benefit from a complementary WASH intervention at the household level aiming to improve the quality of drinking-water at the point-of-use. This will in turn lead to a decrease in diarrhoea occurrence and improvements in nutritional status after the six month follow-up. Study findings set a basis for actionable recommendations on how to better implement and monitor water quality interventions while targeting households affected by acute malnutrition. The findings are relevant for both humanitarian and development settings where malnutrition is prevalent and access to safe drinking-water is a concern.

Methodology

The present study evaluated the effectiveness of ceramic (or candle) water filters in preventing diarrhoea and acute malnutrition among under-five children. It was conducted over a period of six months, from June to November 2016, in Kassala state, Sudan. The study was designed as an open-label, randomized controlled trial (RCT), based on a pre- and post-project comparison of the two study groups:

1. *Intervention group*. Caretakers of children aged between 6 and 59 months admitted to the CMAM programme for outpatient treatment of acute malnutrition, who received nutrition education sessions, traditional WASH package + ceramic tulip table top filters for safe household water treatment and storage.
2. *Control group*. Caretakers of children aged between 6 and 59 months admitted to the CMAM programme for outpatient treatment of acute malnutrition, who received nutrition education sessions and traditional WASH package.

Nutrition education sessions were delivered both at the CMAM centres and in the community through a community household cascade approach. At the community level, caretakers were grouped into 15 households within close proximity, from where trained community volunteers provided nutrition education sessions covering topics such as exclusive breastfeeding, diet diversification, personal, environmental, and food hygiene, prevention and treatment of diarrhoea, and importance of regular vaccination. Both groups received the same nutrition education sessions once per week, for a period of three to four months.

In parallel, both groups benefited from a traditional WASH package, which included interventions on water supply, sanitation, and hygiene promotion. The water supply component covered construction or rehabilitation of community water systems (e.g. boreholes fitted with hand pumps) and protection of community water resources against possible external contamination. The sanitation component focused on increasing the coverage of household latrines in addition to regular campaigns for cleaning solid waste. Hygiene promotion was conducted using the Participatory Hygiene and Sanitation Transformation (PHAST) approach as well as mass communication campaigns, intended to enhance behaviour change around the use of protected water sources, handwashing with soap at key times, and use of latrines. The campaigns also focused on creating demand for sustaining WASH infrastructure.

The rationale behind providing ceramic tulip table top filters for safe household water treatment and storage in addition to the traditional WASH package was to reduce the risk of water recontamination. Before the study roll out, Kassala State Water Corporation conducted physical (colour, turbidity, pH, odour, taste, conductivity) and chemical (total dissolved solids, total hardness as $CaCO_3$, calcium hardness, alkalinity, iron, chloride, fluoride, nitrate, nitrogen oxide, ammonia, sulphate) water quality tests in the communities. Due to limited laboratory capacities in Kassala, no microbiological water analysis could be conducted. All community water sources were chlorinated before being handed over to communities. However, those communal facilities are located some distance from the households, requiring water collection, transport, storage, and handling of water at the household level. It was frequently observed that drinking-water becomes recontaminated during these distinct processes in the water chain. Recontaminated drinking-water undermines the positive health impacts of providing safe water supply in the community (Wright et al., 2004). There was therefore a need to employ an additional intervention measure that would prevent or minimize deterioration of water quality at the point-of-use.

Ceramic tulip table top filters are proved to be effective in purifying water from bacteria, parasites, and turbidity, preventing diseases such as diarrhoea (Tshishonga and Gumbo, 2017); they also have a potential to increase nutritional recovery of acutely malnourished children in an outpatient treatment programme (Doocy et al., 2018). These filters are applicable for all members of a household and are easy to use, operate, and maintain. The water storage in the bottom container ensures that water is not recontaminated. Water can be used for drinking via the tap in the lower bucket.

Caretakers receiving the intervention were instructed on how to install, use, and maintain the filters. They were provided with demonstrations and an instruction leaflet, and were monitored weekly to ensure take up of the intervention and its appropriate use.

To determine the sample size, a formula designed by Fisher (1935) was used with standard normal deviate of 2.58, which corresponds to a 99 per cent confidence interval, the proportion of a target population estimated to have particular characteristics (e.g. use of water filters in the household) to be 0.5, and degree of accuracy 0.035. This gave a sample size of 462. Due to the fact that the use of filters was a new practice in the community and considering possible non-compliance with their effective use, an additional 8 per cent was added to the initial sample size. The total sample size was 500, with 251 participants in the intervention group and 249 in the control group (see Figure 1).

The study area encompassed four localities (Hamoshkorieb, Telkook, North Delta, Rural Aroma) within Kassala state, Sudan. Out of 25 villages targeted by the project, the study was conducted in 17 villages which had operational CMAM centres. The other eight villages which did not have operational CMAM centres were excluded. Caretakers to be enrolled in the study were selected from

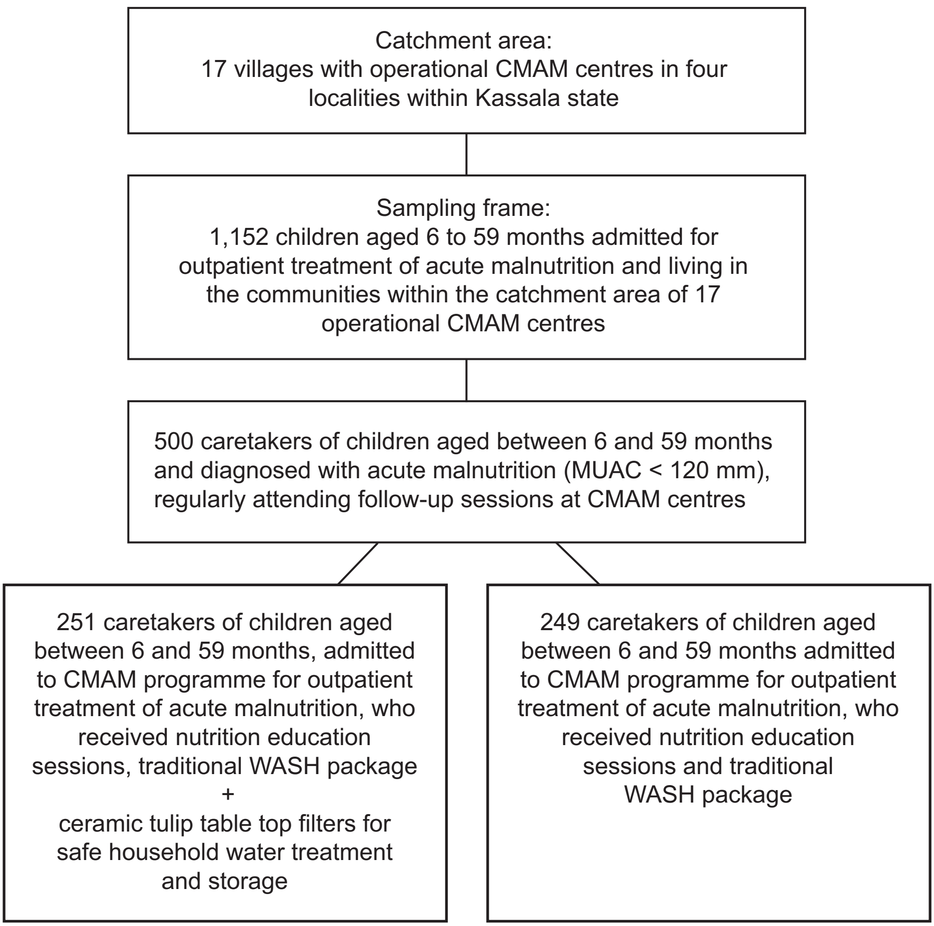

Figure 1 Selection of the study participants

a sampling frame of 1,152 children aged 6 to 59 months diagnosed with acute malnutrition and living in the communities within the catchment area of these 17 CMAM centres. The lists of children admitted to treatment were obtained from the CMAM centres. Before admission to the study, mid-upper arm circumference (MUAC) measurements of children were taken again to confirm nutritional status. Children with MUAC < 120 mm and without medical complications were considered eligible. This reduced the sampling frame from the original 1,152 children to a sampling frame of 706 eligible children. Only caretakers who regularly attended nutrition education sessions and follow-up at the CMAM centres were enrolled to the study.

Systematic random sampling was used to divide the total sample size (500) into the two groups in each village. Each alternate child, the second child on the list as per the sampling frame was selected, thereby dividing participants into two equal groups. Simple randomization was then used to assign the intervention to one group.

A baseline survey was conducted at the beginning of the study to identify possible differences in characteristics between the groups.

Data collection, analysis, and ethics

Data collection was conducted for a period of six months by trained community volunteers. A total of 33 community volunteers were trained on routine, weekly data collection during the household visits, and how to ask questions and register answers in an objective manner. Each volunteer was assigned a household for follow-up. The number of households monitored per volunteer varied depended on distance between the households. Supervision of data collection in the field was provided by the Academy of Health Sciences assigned staff and the NLRC delegate.

Information on the occurrence of diarrhoea in the preceding week was collected on a weekly basis through face-to-face interviews with caretakers from both groups. Diarrhoea was defined as ‘watery stool discharge more than three times in a day’. Interviews were based on the structured paper questionnaire, which was developed in English, translated into the local language (Arabic) for the data collection, and then translated back to English for data analysis.

Information on the use of water filters by the intervention group was also collected weekly. The actual use was determined based on direct observations performed by the volunteers and the evidence of use; that is, the storage container had water inside (an objective proxy measure of filter use). Compliance of the household with the intervention was recorded as, ‘Yes’, for those reporting using water filters and having water in the storage container, otherwise it was recorded as, ‘No’. To reduce the risk of bias, community volunteers did not inform the intervention group caretakers about their visits. If it was found that the water filter was not functional, for example because of a broken tap, the filter was replaced by the project.

Anthropometric measurements of children (weight in kg, height in cm, MUAC in cm) were copied directly from the health registers in CMAM centres and were collected monthly for both groups. For those children who were successfully discharged from the CMAM programme before the end of the study, anthropometric measurements were taken at monthly follow-up sessions. No children enrolled in the study were lost during follow-up.

Before data entry into Excel sheets, each questionnaire was checked by the supervisors for completeness, logical consistency, and possible errors, for example, omitted values. Following data collection, data was processed and analysed by an independent research consultant using Epi Info 7.2.0.1. Data was analysed looking at trends and differences between the two groups over 22 weeks (covering a period of six months) of follow-up. The number of weeks corresponded to the following months: weeks 1 and 2 = June; weeks 3–6 = July; weeks 7–10 = August; weeks 11–14 = September; weeks 15–18 = October; and weeks 19–22 = November. This should be considered when looking for seasonality patterns.

The two main outcomes to be looked at were defined as follows:

1. A diarrhoea case was a child whose caretaker reported occurrence of diarrhoea in the week preceding the household visit.
2. Prevalence of acute malnutrition was the proportion of children who had MUAC < 12.5 cm (125 mm) at the end of the follow-up.

Descriptive statistics were expressed as percentages and frequency. A standard t-test was used to compare means from the intervention and control group. Linear regression was used to identify and quantify the relationship between continuous variables of interest and one or more independent variables. M x M/2 x 2 tables were used to examine the relationship between two categorical values. A *P* value <0.05 was considered to be significant.

Approvals for the study were obtained in writing from the Ministry of Health and the Humanitarian Aid Commission (HAC) at both Kassala state level and federal state level. Written informed consents were obtained from the caretakers of eligible children before the admission to the study. Details of the study, duration, and expectations from their participation were provided. Confidentiality of the information given by the respondents was maintained and data were anonymized. Participants who did not receive water filters during the study received them at the end of the study.

Results: water filters prevent diarrhoea and acute malnutrition at six months follow-up

In total, 500 eligible children were enrolled in the study, including 249 in the control and 251 in the intervention group; 56 per cent were female and 44 per cent male, equally distributed between the groups. Average age at the baseline was 14.76 and 15.06 months in the control and intervention group, respectively, with no statistical difference between the groups ($P = 0.664$).

Data in Table 1 compares intervention and control group at the baseline by looking at the key nutrition indicators, MUAC (cm), weight (kg), and height (cm). As shown in the table, there was no significant difference between the groups at the pre-intervention period; thus the groups could be considered as comparable.

Table 1 Baseline comparison of nutrition indicators between intervention and control group

Average	*Intervention group*	*Control group*	*P value*
MUAC (cm)	10.99	11.04	0.491
Weight (kg)	6.53	6.65	0.395
Height (cm)	67.02	67.09	0.912

The two groups were similar with regards to diarrhoea prevalence at the baseline. Around 53 per cent of caretakers in both groups reported occurrence of diarrhoea in the past two weeks before the baseline survey ($P = 0.857$). There was no significant difference in sanitation practice between the groups; less than 30 per cent of households in both groups used latrines for defecation ($P = 0.921$); 33 per cent of the households in the control group practiced open defecation compared with 34 per cent in the intervention group. Less than 3 per cent of caretakers in both groups reported having a handwashing facility close to the latrine. There was no significant difference in water transport practice between the groups (keeping water containers open or closed, $P = 0.451$) or in the condition of water containers (clean or dirty, $P = 0.622$).

Physical and chemical water quality tests were conducted in 14 out of 17 villages covered by the study. Water from the community water sources (at the point of supply) was found fit for consumption, meeting both the WHO guidelines for drinking-water quality (WHO, 2011) and Sudanese standards for physical and chemical quality of drinking-water (FMoH, 2014). There was no information on water quality from the community water sources in the three remaining villages. Due to limited laboratory capacities in Kassala, no information on microbiological quality of water in the community water sources was available. Given that approximately equal numbers of children per village were selected for the intervention and control groups, it can be assumed that there was no significant difference in access to community water sources between the groups.

During 22 weeks of follow up, 97.82 per cent of the caretakers from the intervention group, on average, reported using the ceramic tulip table top filters for safe household water treatment and storage and had water in the storage container. Filter use was somewhat lower between week 4 and week 7, corresponding to the second half of July and early August. The lowest use of 94.02 per cent was recorded in week 6. Overall, the intervention group had high compliance with water filters until the end of the follow-up period.

In total, 97 per cent of the caretakers reported at least one occurrence of diarrhoea in their children. Yet, a significant difference was observed between the groups throughout the 22 weeks of follow-up. Diarrhoea was more prevalent in the control group: caretakers reported 89.91 cases of diarrhoea per week, on average, compared with 45.27 cases per week in the intervention group ($P < 0.001$). Both groups reported the highest case load in July with the peak at week 6 (Figure 2).

On average, a child in the control group was reported to have 6.92 diarrhoea episodes during 22 weeks of follow-up, compared with 3.89 diarrhoea episodes in the intervention group ($P < 0.001$).

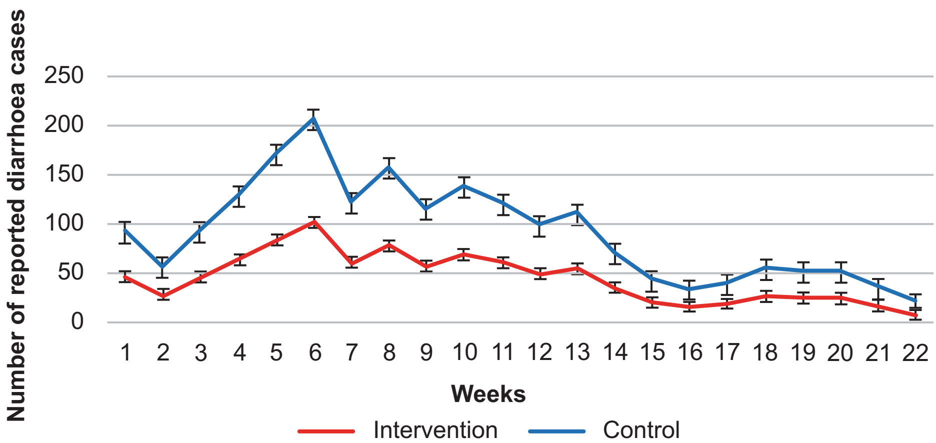

Figure 2 Difference in diarrhoea occurrence between the groups

Results from linear regression suggest that the use of water filters is a potential predictor of the number of diarrhoea episodes per child ($P < 0.001$) and indicate a moderate linear relationship (coefficient of determination = 0.274). Approximately 27 per cent of variability in diarrhoea episodes can be explained by the use of water filters. There is an inverse relationship between the use of water filters and number of diarrhoea episodes (regression or beta coefficient –3.023): as the use of water filters increases, the number of diarrhoea episodes tends to decrease.

Results also indicate that the exposure to water filters can be interpreted as 'protective' against occurrence of diarrhoea (risk ratio 0.948). The intervention group had a 5.2 per cent reduction in risk of diarrhoea compared with the control group ($P < 0.001$).

MUAC difference between the measurement taken at the end of the follow-up and the baseline or MUAC increase significantly differed between the groups (Figure 3). Average MUAC increase in the control group was 0.812 cm compared with 1.068 cm in the intervention group ($P = 0.001$). Results show that the control group had a 24.6 per cent increase in risk of being diagnosed with acute malnutrition (MUAC < 12.5 cm) at the study end line compared with the intervention group given the exposure to water filters (risk ratio 1.246; $P < 0.001$). Having MUAC < 12.5 cm was also associated with a number of diarrhoea episodes per child ($P = 0.022$).

Looking at the height difference between the measurements taken at the baseline and the end of the follow-up, the two groups were similar. Average height increase in the control group was 4.07 cm compared with 3.67 cm in the intervention group and this difference was not statistically significant ($P = 0.276$). No significant correlation was observed between the use of filters and height increase ($P = 0.936$).

At the end of the study, weight gain was 1.45 kg, on average, in the control group compared with 1.77 kg in the intervention group (Figure 4), and this difference was statistically significant ($P = 0.005$). The intervention group performed better

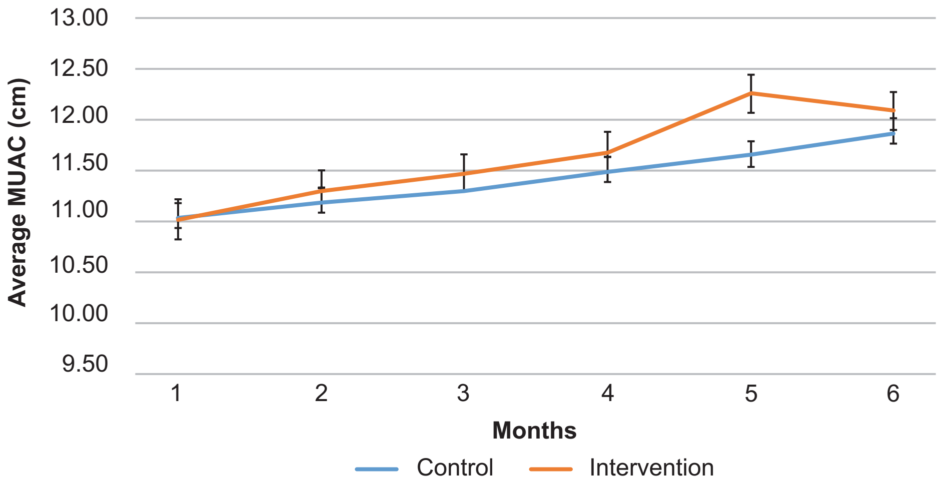

Figure 3 MUAC increase over the 6 month period

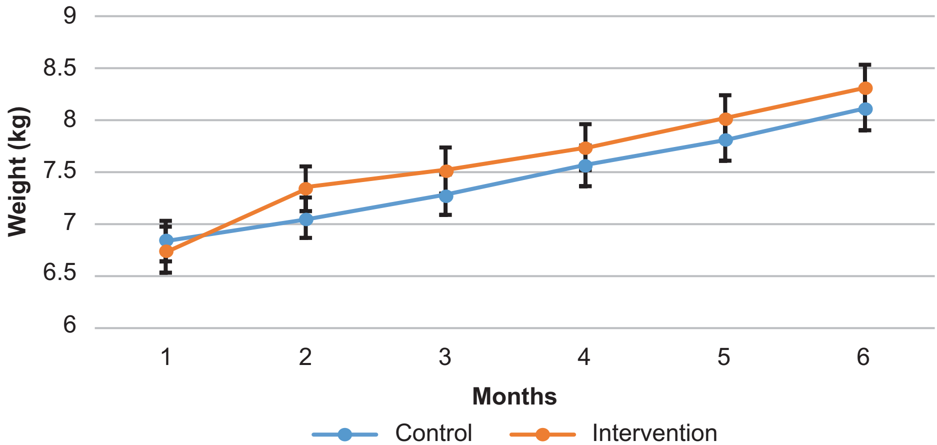

Figure 4 Average weight gain: group comparison

in terms of monthly average weight gain (kg/month): 0.262 kg/month compared with 0.215 kg/month in the control group ($P = 0.012$). Exposure to water filters was also significantly associated with reduced risk of gaining less than 0.22 kg/month ($P = 0.005$), which corresponds to the study median. Surprisingly, no significant relationship between monthly average weight gain and diarrhoea occurrence could be observed ($P = 0.832$).

Results indicate that, in total, 369 children or 73.80 per cent remained acutely malnourished (MUAC < 12.5cm) at the end of the study. Prevalence of acute malnutrition was higher in the control group, 81.9 per cent, than in the intervention group, 65.7 per cent, and this difference was statistically significant ($P = 0.001$).

Discussion

This was a pilot interventional study, designed as an open-label RCT, based on a pre- and post-project comparison of two study groups. The aim was to assess the effectiveness of ceramic tulip table top filters for safe household water treatment and storage on preventing diarrhoea and acute malnutrition among under-five children in Kassala state, Sudan.

The study was based on two hypotheses:

> **H01**: There is no significant difference in diarrhoea occurrence between those receiving the intervention and the control group.

Study results show that there was a significant difference in diarrhoea occurrence between the groups, both in number of reported diarrhoea cases per week ($P < 0.001$) and average number of diarrhoea episodes per child ($P < 0.001$). It can be concluded that the intervention group had lower diarrhoea occurrence than the control group. Linear regression indicated a moderate correlation (coefficient of determination = 0.274) between water filter use and number of diarrhoea episodes as well as an inverse relationship: when the use of water filters increases, the number of diarrhoea episodes tends to decrease. Exposure to water filters seems to have a 'protective' effect and is related to reduced risk of diarrhoea.

These results are consistent with the existing evidence and support the well-accepted link between interventions aiming to improve the quality of drinking-water at the household level and diarrhoea prevention (Clasen et al., 2007, 2015). Household water treatment and safe storage options such as biosand and ceramic filters showed a significant decrease in risk of diarrhoea in other developing countries, including neighbouring Ethiopia, Kenya, Ghana, and Democratic Republic of the Congo (Darvesh et al., 2017). However, evidence also shows that water treatment at point-of-use may reduce diarrhoea by one-quarter to one-third (Clasen et al., 2007). Therefore, despite the positive effect water filters might have had, other pathways in the faecal-oral transmission routes remain. In this setting, access and use of latrines is limited; more than a third of the population still practices open defecation and handwashing with water and soap is not a regular practice. All this can produce another source of contamination that offsets the gains of providing safe drinking-water at the point-of-use. At this stage of understanding, we believe that diarrhoea pathogens could have spread through contaminated food or environment (e.g. exposure of children to animal faeces), or from person-to-person as a result of poor hygiene, rather than through drinking-water, as reported in Chad (Dodos et al., 2018) and Nigeria (Oloruntoba et al., 2014). This might also explain why we could not observe zero cases of diarrhoea in the intervention group, given the high compliance with the intervention. Water filters were necessary but not sufficient to prevent diarrhoea; thus other WASH interventions are needed to interrupt the primary vectors of diarrhoea disease transmission for children living in this context.

> **H02**: There is no significant difference in prevalence of acute malnutrition between those receiving the intervention and the control group.

When it comes to the three nutrition indicators observed and analysed in this study, results show the following:

1. There was a significant difference in average MUAC increase between the groups ($P = 0.001$). Higher MUAC increase was observed in the intervention group.
2. There was no significant difference in height increase between the groups ($P = 0.276$).
3. Weight gain was greater in the intervention than in control group ($P = 0.005$). The intervention group performed better in terms of monthly average weight gain ($P = 0.012$).

At the end of the study, the intervention group had a lower prevalence of acute malnutrition defined as MUAC < 12.5 cm than the control group ($P = 0.001$). The control group had a 24.6 per cent increase in risk of acute malnutrition compared with the intervention group given the exposure to water filters ($P < 0.001$).

The assumption behind this hypothesis was that exposure to water filters will lead to lower diarrhoea occurrence in children and this will, in return, lead to better performance of the intervention group in terms of nutrition indicators compared with the control group. In this study, we observed the significant relationship between the use of water filters and diarrhoea occurrence. However, higher MUAC increase and better weight gain in the intervention group can only be partially attributed to exposure to water filters and reduced diarrhoea. This is because the hypothesis that safe drinking-water at point-of-use would reduce diarrhoea occurrence, thereby resulting in better weight, did not hold. We did not observe a significant relationship between monthly average weight gain and diarrhoea occurrence ($P = 0.832$). This surprising outcome is challenged by studies in Guatemala and The Gambia which found a negative correlation between weight gain and diarrhoea: children with a low prevalence of diarrhoea grow more in weight than those with a high prevalence of diarrhoea (Nel, 2010). A similar conclusion was reached by El Samani et al. who studied children under five in a Sudanese rural community and found suggestive evidence of a dose-response relationship between nutritional status and diarrhoea, but without strong conclusions on the direction of this relationship (El Samani et al., 1988). We hypothesize that other contextual factors (e.g. better child feeding and care practices or improved food hygiene) might have contributed to greater weight gain in the intervention group than decreased diarrhoea occurrence due to water filters. Further research is needed to explore the causal pathways leading to these outcomes and confirm these findings.

The study has several limitations which should be considered when reading and interpreting the results.

1. Validity of a very high compliance with the intervention. Several measures were implemented to promote regular use of water filters. Each household was assigned a volunteer who resided within the village. Their role was to follow up on the intervention households every week to ensure take up of the intervention. Throughout the study, reported use of the water filters

ranged between 94 per cent and 100 per cent. However, these figures rely on self-reported data and are prone to self-report bias which is introduced when study participants either do not respond truthfully or give answers they feel the researcher wants to hear (choosing socially desirable answers). Validity of these answers cannot be confirmed given that data on water quality at the point-of-use was not collected. Thus, despite the measures implemented to ensure compliance, we cannot conclude with certainty to what extent water filters were really used.

2. Due to the non-blinded study design it is possible that receipt of water filters served as a reminder or incentive for improved feeding and care practices, and positively affected overall hygiene behaviour in the household. Different hygiene and/or feeding behaviours of caretakers in the intervention group compared with the control group may have biased the study and contributed to the observed differences in diarrhoea occurrence and nutrition indicators.
3. Data on diarrhoea occurrence may be prone to bias. For example, allocation to the control group may have led to diarrhoea episodes being remembered more accurately out of frustration due to not receiving water filters. Alternatively, allocation to the intervention group may have led caretakers to not report diarrhoea episodes or community volunteers to not record diarrhoea episodes under the expectation that the intervention is effective. Due to such biases, even a diarrhoea reduction of 50 per cent observed in unblinded trials may be compatible with no true effect (Schmidt and Cairncross, 2009). Also, infants have naturally loose stools making it difficult for caretakers to accurately identify diarrhoea episodes (Levy, 2015).
4. Water quality analyses were missing. It cannot be concluded with certainty that lower diarrhoea occurrence in the intervention group is due to the use of water filters because a direct relationship between exposure to the water filters, improved water quality at the point-of-use, and reduced diarrhoea occurrence could not be observed. Missing water quality analyses at the baseline might raise a question of whether the intervention group performed better because it had better water treatment, handling, and storage practices or access to better water quality at the point-of-use from the beginning. There are different variables in the use of filters which should have been assessed, such as regular cleaning and maintenance to prevent bacteria growths in the filter, and recontamination of water (Zinn et al., 2018) by, for example, using contaminated water vessels to get the water from the filter. Without this information, we cannot make any strong assertions about the channel through which water filters affect a child's diarrhoea risk and nutritional status. Finally, having no information about microbiological quality of water in the community water sources could have confounded our results. In case the control group were exposed to higher levels of microbial contamination at the point of supply, we might have overestimated the effect of water filters.

Implications and recommendations for field practitioners

Despite its limitations, the study results highlight some important patterns and generate actionable recommendations for similar initiatives and projects:

1. *Study design*. For similar studies, it is recommended to conduct a cluster RCT instead of allocating individual participants into study groups. In contexts like this, it may minimize 'contamination' between intervention and control participants. To illustrate, caretakers of both study groups reside in the same community; after learning about water filters from their neighbours, caretakers from the control group might have wanted to adopt a similar practice themselves. This kind of 'contamination' of control participants reduces the point estimate of the intervention's effectiveness.
2. *Data collection*. Risk factors for diarrhoea and malnutrition vary with different seasons (e.g. dry and rainy), thus collecting and analysing data taking into account seasonality and variations in the local context would provide good learning points. If time or resources do not allow conducting routine bacteriological water quality analysis at the point-of-use, a challenge is to ensure reliable measurement of correct and consistent water filter use by applying direct observation only. This requires intensive training of data collectors and applying objective criteria on what filter use means. It may also require pairing data collectors or supervising them during household visits. This may, however, increase the monitoring costs of the study.
3. *Validity of data*. If feasible, it is recommended to follow up on reported diarrhoea episodes. Additional information on what caretakers do after recognizing the signs and symptoms of diarrhoea in their children, for example whether they refer to a health facility or prepare oral rehydration solution at home, can help verify the validity of self-reported data on diarrhoea occurrence.
4. *Sustainability of the intervention*. In this context, ceramic tulip table top filters for safe household water treatment and storage were well accepted, increasing the demand for household water filters within the community. However, local capacities and efforts to produce these kinds of filters in Sudan are limited, creating the issues of access and affordability. The model used in the study is not a common local item but an imported filter and its use over a longer period of time may not be possible due to the inability to repair broken parts or buy spare parts locally. Sustainability and appropriateness of similar interventions could be improved by providing items available at the local market and offering an opportunity to buy them locally at an affordable price once the study is over.

Conclusions

Ceramic tulip table top filters for safe household water treatment and storage can be effective in preventing diarrhoea and acute malnutrition among under-five children in Kassala state, Sudan. The study findings suggest that introducing point-of-use water treatment may be beneficial to children admitted to CMAM programme in similar contexts.

More research is needed to understand the pathways to achieving these outcomes, given that lower occurrence of diarrhoea was not found to be associated with better weight gain of children in the intervention group as hypothesized. Despite the positive effect water filters might have had, other pathways in the faecal-oral transmission routes remain; thus other WASH interventions are needed to interrupt the primary vectors of diarrhoea disease transmission for children living in this context.

Our results show that although the intervention was well accepted and used, there is still potential for improving its sustainability and appropriateness, and therefore potential in increasing its effect. Finally, the findings inform implementation programming in both humanitarian and development settings where malnutrition is prevalent and access to safe drinking-water is a concern.

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