

## Research Article

# Reservoir Chlorination of the Local Well–Tank–Faucet Systems is a Rapid and Efficient Tool for Controlling Water-related Diseases: Pathogens’ Load-clinical Response Rate Correlation

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## ABSTRACT

Chlorination is a chemical method for water disinfection that has been proved to be highly effective in controlling waterborne diarrheal diseases. Most studies have focused on wells’ chlorination or later at household level, whereas there have been relatively few researches evaluating the treatment of reservoirs water. Our study followed a mixed design with a before-and-after comparison. It was conducted in a refugee settlement, Um-Baddah Nevachah, which is located in the western outskirts of Khartoum, Sudan. Baseline total coliform test findings have paired areas of four wells that were labeled as sample or control based on fair coin-tossing. A centrally administered water treatment that contains chlorine was added to intervention wells, whereas the other set was considered as chlorine-free placebo. Data were collected 15 days later from the following four main sources: total coliform count, questionnaire-based experimental data trackers, health center records, and face-to-face interviews. The calculated sample size was 341 with corresponding controls selected by systematic random sampling. We found that both groups’ prevalences of waterborne diseases were significantly different before the intervention and they shifted later ( $p = 0.043$  vs.  $p = 0.496$ , 95% CI). These findings suggest that reservoir chlorination provides prompt disinfection of well-tank-faucet systems water. Highly credible gastroenteritis is a useful tool to detect cases of gastroenteritis in resources limit settings.

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## 1. INTRODUCTION

Drinking water should be safe and wholesome to fulfill four aspects of the World Health Organization’s Guidelines for Drinking-Water Quality (WHO-GDWQ): acceptability, microbiological, chemical, and radiological. Safe drinking water is a basic element of primary health care [1,2].

In Sudan, drinking water comes from three main sources: rains, ground, and surface water that include harvested runoff such as “Haffers.” Water should be stored, filtered, and disinfected before it is safe to be used by end consumers. The last process, filtration, is the most important step and it means killing of virulent pathogens by physical means such as filtration, or chemical methods such as chlorination and ozonation. Chlorination is the best method as it is simple, cheap, effective, and easily reversible by sulfite [3].

Inadequate disinfection results in “diseases acquired by drinking water contaminated at its source or in the distribution system, or by direct contact with environmental and recreational waters [4].” WHO classifies them into five categories: waterborne such as gastroenteritis; water-based as schistosomiasis; water-related such as malaria; water-washed, e.g., trachoma; and water-injuries (scalding and thermal injuries), and drowning [5]. Only the first group is considered in this experiment because it would be carried out in

enclosed tanks, which makes the milieu unfavorable for ailments under the remaining four categories.

Waterborne diarrheal diseases etiologies are: viral (HAV, HEV, Poliovirus, Rotavirus, and Norwalk/Norovirus), bacterial (Coliform, *Vibrio* spp., *Salmonella* spp., *Shigella* spp., *Campylobacter* spp.), or protozoal (*Giardia lamblia*, *Cryptosporidium parvum*) [6]. Pathogenesis is either due to direct contact or toxin production. Clinical features are best described as Highly Credible Gastroenteritis (HCG) when any single criterion of the following is present in 24-h duration:  $\geq 2$  loose stools,  $\geq 2$  episodes of vomiting, one loose stool together with abdominal pain or nausea or vomiting, or one episode of vomiting with abdominal pain or nausea [7]. Clinical presentations are categorized into three levels: probable cases with nonspecific gastrointestinal symptoms; suspected cases are those that meet the HCG criteria, and confirmed cases are the diagnosed ones.

The global prevalence of waterborne diseases in developing countries is about 80% of the total illnesses [8]. In Sudan, the burden of diarrheal diseases is increasing. The last health status report issued by the National Ministry of Health in 2010 showed that the reported diarrhea cases were 30,156, 56,902, and 73,987 during 2008, 2009, and 2010, respectively [9]. During 2010, prevalence of diarrhea in Sudan was 18%. The highest three period prevalences were recorded in Kassala (40%), Khartoum (39%), and Gadarif states (33%). However, Khartoum state was recorded with

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the highest number of reported cases with 25,569 of them alive and 191 dead [10]. Hospital records have also shown that diarrhea was the fourth leading cause of both outpatient and inpatient admissions at a ratio of 6.4%. Among <5-year-old children, it was the second and third leading cause treated in inpatients and outpatients, respectively. Although it has a relatively low mortality, excluding it from the list of top 10 diseases with the highest case fatality rate, the proportional mortality rate of diarrhea ranks it the fifth among 0–4 years age group [11].

A literature review reveals no significant side effects result from chlorination with 2–5 ppm residual chlorine as recommended by WHO [12,13]; rather, studies focused on the byproducts' complications restricted only to the addition of chlorine with high concentration. Halogenated trihalomethanes and haloacetic acids groups are the most harmful Chlorination Byproducts (CBPs) [14]. CBPs have been correlated with many illnesses, particularly malignant and reproductive diseases [15]. Overdependence on chlorine for water treatment might introduce new strains of bacteria that are chlorine-resistant [16]. It was suggested that chlorine stimulates mutagens' production in the distribution system as time goes by [17].

The data provided hereinbefore demonstrate how pervasive water-related ailments are in urban centers in the country [18–20]. Other studies have shown that the situation is even worse in refugee camps, yet none has investigated whether conventional intervention would work in the special settings of Sudanese refugee camps [21]. Our study questioned whether tanks' chlorination, rather than home treatment, would provide a meaningful measure to control water-borne diseases in settlements that were established long time ago.

## 2. MATERIALS AND METHODS

### 2.1. Study Design

This is a double-blind community experimental trial that follows the mixed methods study design with a control group. Self-reported HCG, total coliform counts, and local health center statistics were the primary source of quantitative input. The qualitative direct interviews constituted the core of the nested or embedded part of the study.

### 2.2. Study Area

Our trial was conducted in Um-Baddah Nevachah, which is a long-term refugee camp located in the western outskirts of the Sudanese capital, Khartoum, about 30 km away from the center. This catchment zone is a squatter area within Um-Baddah

locality in the west of Omdurman province. It is located geographically between longitudes 52°77'32.18"E and 45°26'32.16"E and latitudes 47°96'15.39"N and 56°46'15.38"N. Surrounded by Abu-Bukr Al-Siddig village in the north, Dar Al-Salam in the east, Kuwaiti Company Farm in the south, and Siddig Wadah Agricultural Project followed by a desert separating it from Northern Kordofan State in the west. The area emerged in 2000. Its current total area is about 9.8 km<sup>2</sup> (3.5 × 2.8 km) divided into six residential quarters: northern, eastern, western, central, east-southern, and north-southern. The total population is about 9000 belonging to 57 tribes. The vast majority of inhabitants belong to low socioeconomic class. Available governmental services include a single primary health center and four elementary schools. There is no electricity, but water reaches houses on wheeled barrels driven by donkeys "Karrow" as there are no water pipelines. The only drinking water sources are four wells (average depth = 260 m/well) beside a fifth one under construction. Characteristics of well systems are summarized in Table 1.

### 2.3. Study Population

Target population comprises all the residents of Um-Baddah Nevachah. Our study population ( $n = 341$  subjects) comprised residents of the western quarter who fulfill eligibility criteria.

Inclusion criteria are: residency in the study area for at least 1 month before the study period, ownership or renting of their houses, restriction to drink from one water tank, and minimal consumption of 1 glass/day. Exclusion criteria include: known immunocompromised patients, complaining of chronic diarrhea, or being on long-term antibiotic therapy.

### 2.4. Sampling

Using the total population and proportion, a sample size of 341 was calculated and drawn by a systematic random sampling from the study population ( $N = 3000$ ) with an interval of three houses; the first of each was chosen starting from the north-eastern corner of the square and heading to the south in a clockwise manner.

### 2.5. Data Collection

Enrollment into this randomized trial started by collecting an initial exploratory water sample from the western quarter tank (tank 1) following guidelines of U.S. Environmental Protection Agency (EPA) recommending disinfection of the spout by direct flaming and 70% alcohol followed by collection of 400 ml of water in a sterilized glass

**Table 1** | Characteristics of well systems in Um-Baddah Nevachah

	Well 1	Well 2	Well 3	Well 4
Location	Western quarter	East-southern quarter	Northern quarter	Agricultural project
Digging year	2009	2005	2010	Before 2000
Type	Drilled	Drilled	Drilled	Drilled
Depth	150 m	-	260 m	-
Tank volume	5000 L (5 m <sup>3</sup> )	3000 L (3 m <sup>3</sup> )	5000 L (5 m <sup>3</sup> )	5000 L (5 m <sup>3</sup> )
Pump type	Jet-pump	Jet-pump	Jet-pump	Jet-pump
Pump energy supplier	Lister (machine)	Lister (machine)	Lister (machine)	Motor (engine)
Energy source	Diesel	Diesel	Diesel	Electricity

container that was kept upside-down just before opening. Samples were tested for total coliforms using membrane filtration technique with lactose agar and Tergitol 7 used as a medium. The temperature for incubation was  $35 \pm 0.5^\circ\text{C}$  at which it was kept for about 22 h.

## 2.6. Wells Randomization and Intervention

Findings of the samples taken from the four wells systems created a baseline that was used to classify them into two groups, each consisting of two wells, one contaminated and the other uncontaminated. Intervention grouping of wells was performed by way of a simple randomization with a fair coin-tossing that allocated the two commensurate groups into either of the intervention arms. Sample wells were those of the western (well 1) and east-northern quarters (well 2). Control wells were those of the northern quarter (well 3) and agricultural project (well 4). A total of 682 questionnaires were distributed across sample and control quarters by 25 well-trained volunteers during the 3-days period that preceded the addition of chlorine and placebo.

Intervention was begun on Friday 1, June 2015. Sample tanks received the drug (chlorine tablets) with a concentration of  $1 \text{ gm}/1 \text{ m}^3$  of water to end up with 200–500 ppm as a residual chlorine. To the control tanks, a placebo was added (Maalox, an antacid containing 275 mg of Magnesium hydroxide and 135 mg of Aluminum hydroxide). Table 2 contains important features of the drug and placebo.

Four water samples were collected 30 min after chlorination and transferred into a cold chain bag for instant laboratory examination. Follow up of both groups lasted for 15 days. During 15–17 June data were collected by 25 well-trained volunteers who distributed 682 questionnaires; half of them were in the western and east-southern quarters (sample quarters), whereas the other half was in the northern, central, eastern, and north-southern quarters (control quarters). Questionnaires were redesigned after the initial test with 341 subjects ( $\approx 10\%$  of calculated sample size). Returns were 656 with a high ratio (96.19%) due to good control over volunteers by way of field and telephone contact. Information was also collected through face-to-face interviews and records of Um-Baddah Nevachah Health Center.

## 2.7. Data Analysis

All statistical tests of the questionnaire were computed by STATA-IC version 14 (StataCorp LLC, TX, USA), whereas analysis of face-to-face interviews was performed manually.

Categorical variables were reported in numbers and percentages ( $N$ , %); whereas, continuous variables were expressed either as median or mean  $\pm$  standard deviation (SD) at 95% confidence interval (CI) depending on the type of distribution. Statistical methods used were Chi-square and McNemar tests for contingency tables.

**Table 2** | Important features of the drug and placebo

Type	Brand name	Generic name	Pack size	Manufacturer	Origin	Agent
Drug	OASIS1000 Tabs (1.7 g)	NaDCC	200 Tabs	HydraChem	England	Batreeq Ltd.
Placebo	Maalox Tabs (275 + 135 mg)	Mg(OH) <sub>2</sub> + Al(OH) <sub>3</sub>	60 Tabs	Asia Pharmaceutical Industries	Sudan	Badr Drugs and Chemical Co.

Two-way independent  $t$ -test was used to compare population means of both of our study groups.

## 2.8. Ethical Considerations

Ethical clearance was obtained from Research Ethics Committee at Faculty of Medicine, University of Khartoum. We have also acquired informed and written approvals of Um-Baddah Nevachah Peoples' Committee, which represents the local authority, in addition to those of the four well's janitors prior to the commencement of the study. Written informed consents were signed by everyone engaged in our study. An alternative was fingerprinting whenever handwriting was unattainable due to illiteracy or physical disability.

## 3. RESULTS

To assess levels of water contamination, baseline samples were taken from all the four tanks systems and tested for total coliforms. Tanks 1 and 4 tests showed an outgrowth of 4 colonies/100 ml and 1 colony/100 ml, respectively. No colonization was reported in the remaining two samples collected from tanks 2 and 3.

Analysis of the 656 returned questionnaires showed important findings (Table 3). The difference between the intervention and control cases of HCG before the intervention was non-significant ( $p = 0.055$ ), whereas a comparison between both groups' cases of HCG after the intervention showed a significant difference ( $p = 0.008$ ). There was a significant difference in HCG cases of the intervention group sample before-and-after chlorination (difference =  $-82.76\%$ ,  $\chi^2 = 40.02$ ), whereas there was no significant difference

**Table 3** | Contingency tables of the intervention (a) and control cases (b) of highly credible gastroenteritis before and after chlorination

	Highly credible gastroenteritis after the intervention		Total
	+ve	-ve	
(a) Intervention			
Highly credible gastroenteritis before the intervention			
+ve	16	42	58
-ve	0	271	271
Total	16	313	329
(b) Control Cases			
Highly credible gastroenteritis before the intervention			
+ve	32	5	37
-ve	1	289	290
Total	33	294	327

in HCG cases of the control before-and-after the intervention with placebo (difference = -13.07,  $\chi^2 = 3.20$ ).

All respondents with positive HCG complained of diarrhea. Before chlorination, there was no significant difference between the intervention and control prevalence of diarrhea ( $p = 0.055$ ). After the intervention, the difference was significant ( $p = 0.012$ ). Period prevalences of diarrhea among study groups could be explained as in Figure 1.

The difference between the intervention and control prevalence of water-associated diseases before the intervention was significant ( $p = 0.043$ ). After the intervention, no significant difference was found ( $p = 0.496$ ). Table 4 shows these period prevalences.

Records of Um-Baddah Nevachah Health Center detected a decline in the proportion of water diseases from the total referred cases during the follow-up period of the study Table 5.

In addition, 32 volunteers were interviewed face-to-face and investigated if they felt any change in the prevalence of water diarrheal diseases before and after the addition of chlorine or placebo for the intervention or control, respectively. Answers showed a sensible decrease among the intervention participants (21%) and a relative no change among the controls (19%).

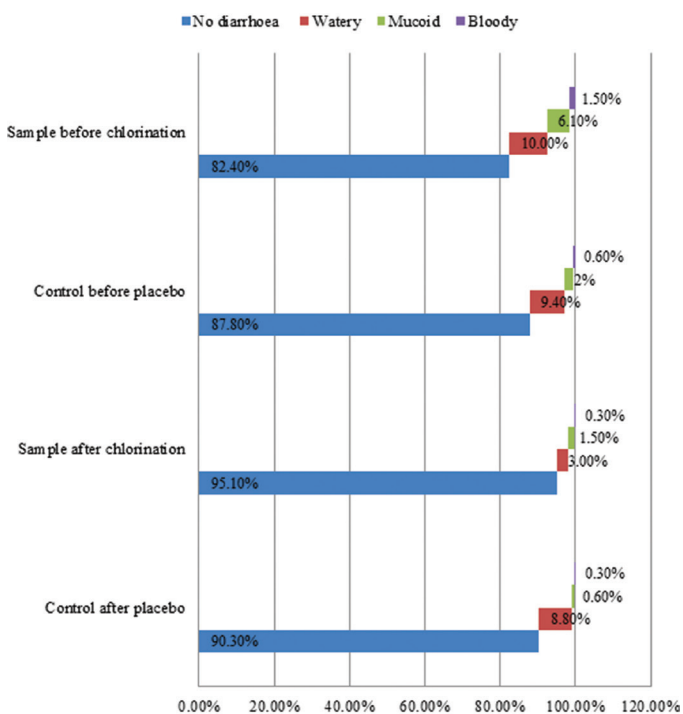


Figure 1 | Periods prevalences of diarrhea and differential of types among study groups.

Table 4 | Prevalence of water-associated diseases in Um-Baddah Nevachah among respondents during the study period

	Intervention			Control		
	Before chlorination	After chlorination	Change (%)	Before placebo	After placebo	Change (%)
Prevalence of gastroenteritis	3.40	1.80	-47.05	1.20	1.20	0
Prevalence of typhoid	0.60	0	-100.00	0	0	0
Prevalence of dysentery	2.10	0	-100.00	0.60	0.30	-50.00
Prevalence of schistosomiasis	0	0	0.00	0	0	0
Prevalence of malaria	0.30	0	-100.00	0	0	0

## 4. DISCUSSION

Coliforms cultures were used to classify all four well systems into a couple of balanced categories, with tanks 1 and 2 labeled as the intervention group and the remaining two as controls.

To explain the “unacceptable level of contamination” (i.e.,  $\geq 4$  colonies/100 ml) reported in the first tank, extensive investigations were done and attributed to a modified return system unique for that well. It acts as a radiator by transferring hot water coming out from the lister directly into the tank for heat exchange Figure 2.

Contamination of well 4 with only 1 colony/100 ml was inconsistent with the surrounding poor hygiene and stagnant water.

Table 5 | Portion of diagnosed water diseases in Um-Baddah Nevachah Health Center from total referrals during the study period [22]

	Before intervention	After intervention	Change (%)
	N (%)	N (%)	
Nonspecific gastrointestinal symptoms	57 (9.677)	13 (5.394)	-44.260
Diarrhea	32 (5.433)	5 (2.075)	-61.807
Dysentery	21 (3.565)	0	-100.000
Giardiasis	15 (2.547)	0	-100.000
Schistosomiasis	2 (0.340)	0	-100.000
Malaria	4 (0.679)	1 (0.415)	-38.881
Total referrals/duration	589	241	



Figure 2 | Tank of well 1 with the modified radiator (red arrow).

This could be due to the use of electricity as a pure source of energy to supply the pump. Samples collected after the intervention were free of contamination in the sample wells, indicating the efficacy of the intervention, whereas those of the control endured status quo.

Presence of diarrhea in 100% of respondents complaining of HCG makes it the most important HCG criterion. Disinfection of sample wells only resulted in a significant reduction in cases of diarrhea among the sample compared with the static levels among the control group. Control cases of water-associated diseases outweighed their peers. Perhaps, the heavier level of well 1 contamination as compared with others is something to attribute to and it suggests the presence of specific pathogens restricted to the sample zone. During May, two of the sample respondents were infected with typhoid and a third one by malaria; although these diseases were not reported among control respondents during the same period.

The drop in the frequency of water-related conditions originating from our sample zones has contributed to the overall declivity in cases diagnosed in Um-Baddah Nevachah Health Center in the whole area. This reported decrease in the sample area was felt by the majority of respondents living in that area (21%), whereas the static situation of the control was obvious for the most of them (19%). This may be a result of their high sensitivity against diarrhea developed by experience.

The study was simply randomized. It was successfully blinded because only 7.9% of the respondents correctly guessed to which group they belonged on being informed the experiment and being asked. The estimated prevalence of HCG among the sample at the start of the study was 17.63% and 3.04% at the end-point, totaling a remarkable 82.8% reduction, far behind the rates of other diseases have been trailed. This could be a result of the simplicity of HCG that is self-determined as compared with the others that require diagnosis in a health center. Besides, the small portion of respondents who complained of symptoms of water-associated diseases and referred to the health center as compared with those who did not.

## 5. CONCLUSION

Water-associated diseases constitute a major problem in Um-Baddah Nevachah. The unsealed locally developed system that pumps ground water into tanks to be stored and later distributed to public through a common tap provides access for pathogens at different points. Chlorination has been proven to provide an efficient and a timely decontamination of the supplied water.

Periodic chlorination of tanks using chlorine tablets and establishing an enclosed distribution network for the drinking water are strongly encouraged. Recommendations for short-term are: replace the currently used means of water transportation “Karrowhat” with more sealed ones, improve hygiene of “Karrowhat” owners, advise them to avoid direct contact with water and to regularly wash their “Karrowhat” with disinfectants, and to support health education and promotional activities.

Another less-related observation raised during field preparation of this research is the concept of assisting health cadre about the

“watery diarrhea.” Considering it a hazard or epidemic caused only by cholera infection, contrarily, it could be sporadic resulting from less pathogenic species such as enteropathogenic *E. coli*. Workup to change this idea is recommended.

## CONFLICTS OF INTEREST

Researchers declared no conflicts of interest associated with either the study or subsequent publications.

## AUTHOR CONTRIBUTIONS

A.S. and D.A. study conceptualization and writing (original draft). A.S. data curation, formal analysis and project management. D.A. supervised the project and revised methodology. Both authors have read and approved final manuscript.

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