# Bacteriological assessment of dug well water in rural areas of Bangladesh

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## ABSTRACT

This study assessed the bacteriological quality of dug well waters from Jashore district – an arsenic affected area of Bangladesh. A total of 58 dug wells (42 installed by a government organization (GO) and 16 installed by a non-government organization (NGO)) were sampled in the dry and wet seasons. The samples were evaluated for total coliform (TC), faecal coliform (FC) and *Escherichia coli* (*E. coli*). Sanitary inspections of the surroundings of the GO-installed dug wells identified the sources of faecal contamination. Both the GO-installed and NGO-installed dug wells had bacterial contamination. The median concentrations of *E. coli* among the GO-installed and NGO-installed dug wells were, respectively, 41 and 21 cfu/100 ml in the wet season, and respectively 2 and <1 cfu/100 ml in the dry season. In the wet season, 24 and 31%, respectively, of the GO-installed and NGO-installed dug wells were in the high-risk category. All of the dug wells had higher disease burden in the wet season compared to the dry season. The findings suggest that drinking water from the dug wells is likely to pose health risks to the rural communities.

**Key words** | drinking water, dug well, indicator bacteria, risk assessment, water quality

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## HIGHLIGHTS

- Examined bacterial contamination of dug well waters of an arsenic affected area of Bangladesh.
- Contamination and disease burden of the dug wells installed by a government organization were relatively higher than those installed by a non-government organization.
- Contamination and disease burden increased in the wet season.



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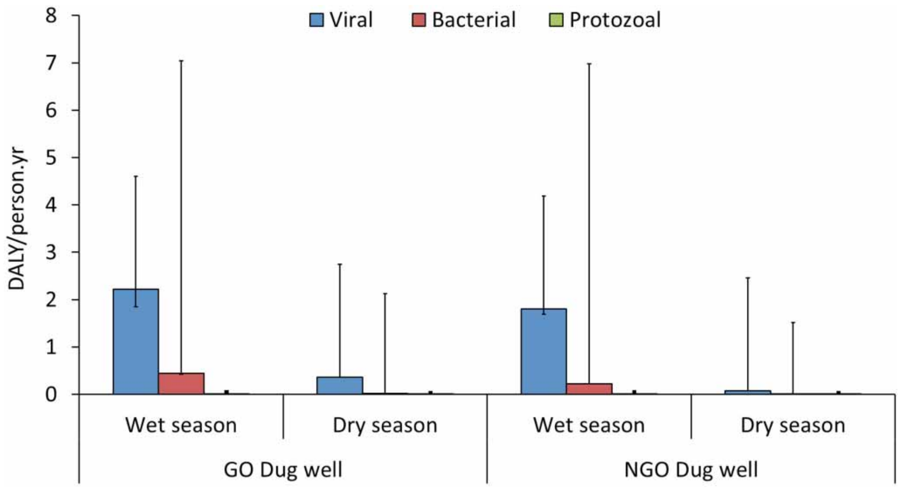
## GRAPHICAL ABSTRACT




## INTRODUCTION

Groundwater is one of the major sources of drinking water in Bangladesh (Chakraborti *et al.* 2015). The availability of shallow aquifers and less possibility of microbial contamination are the two prime reasons for preferring groundwater over available surface water sources. As a result, low-cost tube wells have become widespread in the country (Chakraborti *et al.* 2015), particularly in rural areas. However, high levels of arsenic in the groundwater of Bangladesh (Nickson *et al.* 1998; Harvey *et al.* 2002) has greatly affected the success of shallow tube wells (Ahmed *et al.* 2004). Arsenic contamination in the groundwater of Bangladesh was first confirmed by the Department of Public Health Engineering (DPHE – a government organization of Bangladesh responsible for building water supply infrastructure in rural and urban areas) in 1993 (Chakraborti *et al.* 2015). This serious natural calamity and public health hazard soon turned into one of the greatest environmental disasters in the country (Chowdhury *et al.* 2000; Ahmed *et al.* 2004).

To reduce the exposure of arsenic through water, the Government of Bangladesh has been promoting alternative water supply options including low-cost sanitary dug wells (Caldwell *et al.* 2006; Hoque *et al.* 2006; Howard *et al.* 2006, 2007; Mink *et al.* 2019). In fact, sanitary dug wells are one of the prioritized interventions of the Government of Bangladesh to mitigate arsenic-related health problems in the rural areas of the country (Caldwell *et al.* 2006). The dug well is a traditional method of withdrawing groundwater from the upper layer of a water table by constructing a well of large diameter, typically lined by concrete rings and enclosed by a concrete slab or metal sheet with ventilation (Howard *et al.* 2006; Bain *et al.* 2014). In the case of a protective dug well, the well-lining or casing is raised above the ground level and provided with a platform that can draw away spilled water to avoid contamination of surface runoff. This also includes an enclosure of a concrete slab or metal sheet with ventilation to protect the water from bird droppings and animals. Generally, a hand pump is connected to a protective dug well for withdrawing water.

A dug well is typically installed at a shallow depth (1–20 m) which is above the arsenic-contaminated aquifer. However, there is a high risk of bacterial contamination (APSU 2005; Howard *et al.* 2006, 2007) because of the unregulated disposal of sanitary wastes, which is a common problem in developing countries (Sadler *et al.* 2016) like Bangladesh. Several studies from Bangladesh have reported the high sanitary risk of dug well water (Hoque *et al.* 2006; Howard *et al.* 2006). Previous studies regarding the water quality of dug well water conducted in Bangladesh mainly indicated arsenic contamination and the microbial quality of dug well water (Ahmed *et al.* 2006; Howard *et al.* 2006, 2007; Ohno *et al.* 2007; Akber *et al.* 2020). The quality of the product water might vary between the dug wells installed by GO and non-government organizations (NGOs) because of differences in installation and maintenance. Currently, there is little information on the product water quality of GO-installed and NGO-installed dug wells located in the arsenic affected rural areas of Bangladesh. The present study was conducted to evaluate the bacterial quality of product water from existing dug wells and to determine potential human health risks due to the consumption of dug well water. It is expected that the outcomes of this study will be useful to develop effective strategies to improve the water quality of dug wells installed in the rural areas of Bangladesh.

## METHODOLOGY

### Study area and dug well

The present study was conducted in Chowgacha sub-district under Jashore district in Bangladesh. Chowgacha sub-district is located within latitudes 23°10′ N to 23°22′ N and longitudes 88°54′ E to 89°08′ E, covering an area of 269.31 km$^2$. The location of selected unions under Chowgacha sub-district is shown in Figure 1. To select the dug wells, we first spoke with relevant officials from GO and NGOs to obtain an overview of the distribution of dug wells in Jashore district. According to the DPHE and NGO officials, most of the dug wells are present in Chowgacha sub-district. We considered seven out of 11 unions of the sub-district for water sampling because the majority of the dug wells were installed in those seven unions (Singhajhuli, Pashapole, Phulsara, Arardha, Narayanpur, Dhuliani and Swarupdaha). The selected unions have a total population of 231,370.

There are differences in the installation and maintenance of the dug wells installed by the GO and NGO. According to DPHE and NGO officials, the average depth of GO-installed and NGO-installed dug wells are 20–35 ft and 30–45 ft, respectively. In both cases, a concrete ring is used and the well is lined (cased) with sand to prevent collapse. The top of GO-installed dug wells are generally sealed with a concrete slab and water is withdrawn by a hand pump. NGO-installed dug wells typically have a curb about 1 foot above the ground and another 2/3 feet surrounded by a net, along with the top of the well being covered by a metal sheet with ventilation. NGO-installed dug wells also include a slow sand filter (SSF) to filter the dug well water and a caretaker regularly adds disinfectant (bleaching powder) in the well water by a dropout system. The GO-installed dug wells have a sealed top (Figure 2), and eventually no maintenance is carried out.

### Water sampling

Water samples were collected only from the active dug wells from the selected seven unions of Chowgacha sub-district. Dug wells installed by the NGO include SSF to treat the water before consumption. In this way, the water from a dug well first goes into a SSF when the water is pumped manually. After filtration, the water is collected from the outlet tap of the SSF. As the GO-installed dug wells do not have any filtration or treatment system included, the product water is collected from the hand pump that is connected with the dug well. Therefore, the samples were collected from hand pumps of the GO-installed dug wells and from the outlet of the SSF of NGO-installed dug wells. Since the dug wells are enclosed by a concrete slab or metal sheet, it was not possible to collect water directly from the dug well. Moreover, the NGO-installed dug well has a hand pump directly connected with the inlet of the SSF thereby stopping the collection of water from the hand pump. As a result, it was not possible to collect water before and after filtration to compare the efficiency of the SSF. Consequently, only product water from the NGO-installed dug wells was collected. Photographs of typical GO and NGO dug wells are shown in Figure 2. Sterilized nalgene plastic bottles were used to collect water samples. The sampling procedure described by APHA (2005) was strictly followed to avoid any contamination during the collection and storage of samples. The outlet of the water source was disinfected before taking the sample in disinfected bottles collected from the laboratory. The disinfection procedure included wiping the outlet using clean tissue paper, flushing the water for 1–2 minutes, heating the outlet with an alcohol burner and flushing again for

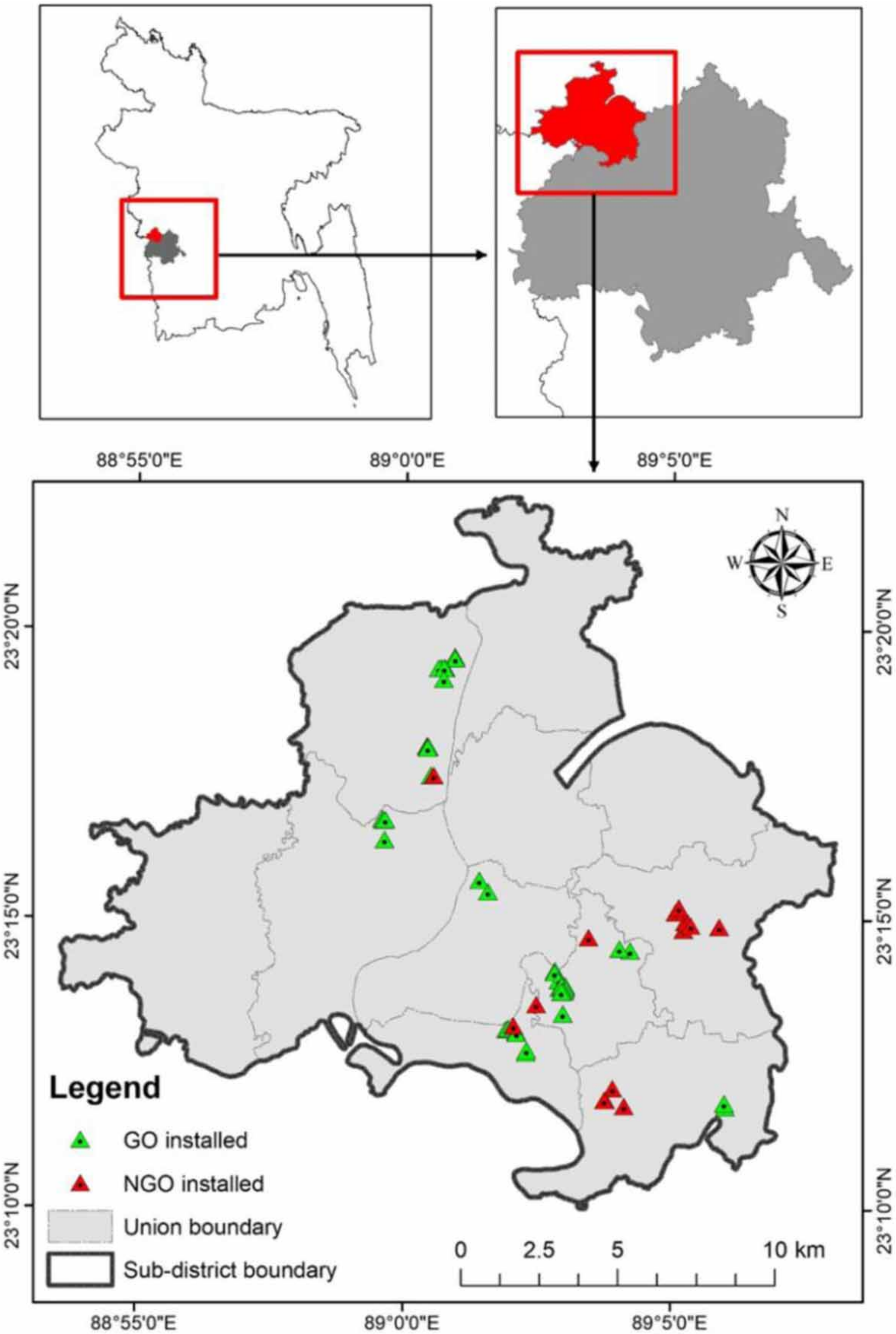



**Figure 1** | Map of the study area and sampling locations.


**Figure 2** | Photographs of typical dug wells in the study area: (a) GO-installed dug well with hand tube well and (b) NGO-installed dug well with a slow sand filtration system.

1–2 minutes before collecting the water in the disinfected bottle. Then, the bottles were adequately labelled by dug well location, date, time, GPS coordinates to recognize the exact sampling point. The sample bottles were tightly capped to avoid leakage and contamination during handling and transportation. All the samples were stored in an insulated box filled with ice packs (Johnny Plastic Ice; Pelton Sheperd, Stockton, CA, USA) immediately after collection, and were transported to the Environmental Microbiology Laboratory of Khulna University for bacteriological analysis. To ensure quality control of sample analysis, duplicate samples were used to correct the analytical values. DPHE under the Government of Bangladesh is responsible for installing and maintenance of dug wells. The only NGO working on the installation and maintenance of dug wells in the study area is Asia Arsenic Network (AAN). Samples were collected from 58 dug wells (of which 42 were GO-installed and 16 were NGO-installed) in both the wet (July 2018) and dry (January 2019) seasons. Water samples were collected from all the NGO-installed dug wells available in the Chowgacha sub-district. However, three of the GO-installed dug wells were located in very remote areas with inaccessible road conditions. The reason for not collecting water samples from these dug wells was the transportation of water samples to our laboratory maintaining the time-bound to perform microbiological analysis.

## Detection of indicator bacteria

Bacteriological analysis was carried out by the membrane filtration (MF) method. Standard procedure (APHA 2005) was followed to conduct the analysis. Several dilutions of samples were considered. We considered triplicate plates for each dilution to determine the number of bacteria. Filtration devices were treated by using a burner to ensure proper sterilization and to prevent cross-contamination among samples. To determine the concentration of total coliform (TC), faecal coliform (FC) and *Escherichia coli* (*E. coli*), water samples were filtered through different 0.45 μm pore-size membrane filters (Millipore Corp., Bedford, MA, USA), which were then placed on m-Endo, mFC and mTEC agar plates, respectively. The m-Endo and mFC plates were incubated at $35 \pm 0.5$ °C for 24 h and 44 °C for 18 to 24 h to determine the TC and FC, respectively. Characteristic pink and blue colonies were noted as TC and FC, respectively. To determine the concentration of *E. coli*, the mTEC agar plates were incubated at $35 \pm 0.5$ °C for 2 h followed by further incubation at $44.5 \pm 0.2$ °C for 22–24 h. Then, the filters were transferred to a pad saturated with urea substrate for 15–20 min. After incubation on the urea substrate at room temperature, yellow, yellow-green or yellow-brown colonies were counted as *E. coli*. The bacterial counts were expressed as colony forming units (cfu) per 100 ml.

## Health risk assessment

Disease risk of drinking the dug well water was determined using a quantitative health risk assessment (QHRA) model (Islam *et al.* 2011). This model was introduced by the Arsenic Policy Support Unit of the Government of Bangladesh. It gives an estimation of the microbial disability-adjusted life years (DALYs) for three reference pathogens (rotavirus, cryptosporidium and *E. coli*) for viral, protozoal and bacterial diseases, respectively. Thus, it determines the total disease risk in μDALY/person-yr. Further details of the model assumptions about pathogen and indicator organisms and the dose–response relationship are available in previous literature (Ahmed *et al.* 2005; Howard *et al.* 2006, 2007). DALYs is a WHO (2004) recommended matrix to compare various disorders and diseases with various health outcomes. In this study, we calculate DALYs using the results of *E. coli* concentration to estimate the likely disease risk associated with drinking dug well water.

### Sanitary inspection

A sanitary inspection (SI) form was prepared following the WHO dug well SI form (WHO 1997). The form is designed to note the risk factors based on potential sources of pollution at the site of a dug well. A draft SI form was prepared and tested in the study area, which was further modified according to the findings from the field. The sanitary inspection was conducted at each of the sampling sites of GO-installed dug well during the sample collection in the wet season. We did not consider NGO-installed dug wells for sanitary inspection since product waters were filtered by SSF and may not represent the actual relation between sanitary risk factors and faecal contamination of the dug well water. For each of the sampled GO-installed dug wells, the height of dug well casing above ground level and the distance of the well from any sanitary structure (pit latrines or septic tanks) were determined using a measuring tape. Other characteristics of the dug wells were determined by visual inspection. Sanitary risk factors were noted in the form of binomial data. The concentration of *E. coli* obtained from the sample analysis was transformed into a categorical variable to determine the association between the risk factors and faecal contamination.

### Statistical analysis

Nonparametric tests were used for the data analysis. The Wilcoxon signed-rank t-test was used to compare the seasonal variation of indicator bacterial contamination of the GO-installed and NGO-installed dug wells. The Chi-square test was used to examine the relation between sanitary risk factors and faecal contamination. Statistical analyses were done by Statistical Package for Social Sciences (SPSS) software version 22.0.

## RESULTS

### Indicator bacterial contamination

The mean, median, minimum and maximum concentrations of TC, FC and *E. coli* of GO-installed and NGO-installed dug wells product water are presented in Table 1 according to the seasons. The distribution of the concentrations of *E. coli* is shown in Figure 3.

The summary of the findings of Table 1 and Figure 3 are as follows:

- The median concentrations of TC, FC and *E. coli* among the product waters of the GO-installed dug wells were high in both the wet and dry seasons compared to those installed by NGO (Table 1). The mean concentrations of TC and FC of GO-installed dug wells were also high compared to the NGO-installed dug wells. The mean *E. coli* concentrations of GO-installed dug wells' product water in the wet season were lower than that of NGO-installed dug wells.
- Both GO-installed and NGO-installed dug wells had the widest interquartile range of *E. coli* concentrations in the wet season, with 25th and 75th quartiles of 9.7 and 103 cfu/100 ml, and 0 and 181 cfu/100 ml, respectively (Figure 3).
- Product water from GO-installed and NGO-installed dug wells had significant differences in the mean concentrations of TC and *E. coli* between the dry and wet seasons ($p < 0.05$). The concentration of FC differed significantly between the wet and dry seasons for GO-installed dug wells, although it did not vary significantly for NGO-installed dug wells.
- The minimum concentrations of *E. coli* and FC were less than 1 cfu/100 ml for both GO-installed and NGO-installed dug wells' product water in both seasons. Concentrations of TC were higher in all the dug wells' product water during both seasons; however, the greatest

**Table 1** | Indicator bacterial concentration in the product water of GO-installed and NGO-installed dug well in different seasons

| | | Wet season | | | | Dry season | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Indicator bacteria (cfu/100 ml)** | **Sampling sources** | **Mean ± SD** | **Med** | **Min** | **Max** | **Mean ± SD** | **Med** | **Min** | **Max** |
| TC | GO dug well | 16,750 ± 14,130[a] | 12,000 | 900 | 48,800 | 8,719 ± 948[b] | 4,650 | 300 | 35,000 |
| | NGO dug well | 13,418± 13,730[a] | 8,700 | 500 | 48,000 | 3,387 ± 2,235[b] | 2,100 | 700 | 9,000 |
| FC | GO dug well | 101 ± 116[a] | 35 | <1 | 420 | 33 ± 61[b] | 3 | <1 | 240 |
| | NGO dug well | 42 ± 32 | 27 | <1 | 190 | 22 ± 43 | 0.5 | <1 | 140 |
| *E. coli* | GO dug well | 59 ± 62[a] | 41 | <1 | 236 | 21 ± 39[b] | 2 | <1 | 180 |
| | NGO dug well | 78 ± 102[a] | 21 | <1 | 280 | 14 ± 29[b] | <1 | <1 | 100 |

SD, standard deviation; Med, median; Min, minimum; Max, maximum; FC, faecal coliform; TC, total coliform.
[a,b]Significantly different between wet and dry seasons at $p < 0.05$ by Wilcoxon signed rank t-test.

median concentration of TC was observed among the GO-installed dug wells product water.

## Risk category

Based on the concentration of *E. coli*, the product water from GO-installed and NGO-installed dug wells was categorized according to the WHO prescribed risk categories (WHO 1997): (i) no risk (*E. coli* concentration <1 cfu/100 ml), (ii) low risk (*E. coli* concentration 1–10 cfu/100 ml), (iii) intermediate-risk (*E. coli* concentration 11–100 cfu/100 ml), (iv) high risk (*E. coli* concentration 101–1,000 cfu/100 ml) and (v) very high risk (*E. coli* concentration >1,000 cfu/100 ml). There was no sample in the very high-risk category. Among the product water from GO-installed dug wells, 47 and 24% of the samples collected in the wet season were in the intermediate and high-risk category, respectively (Figure 4). However, the percentages of product water samples in these categories

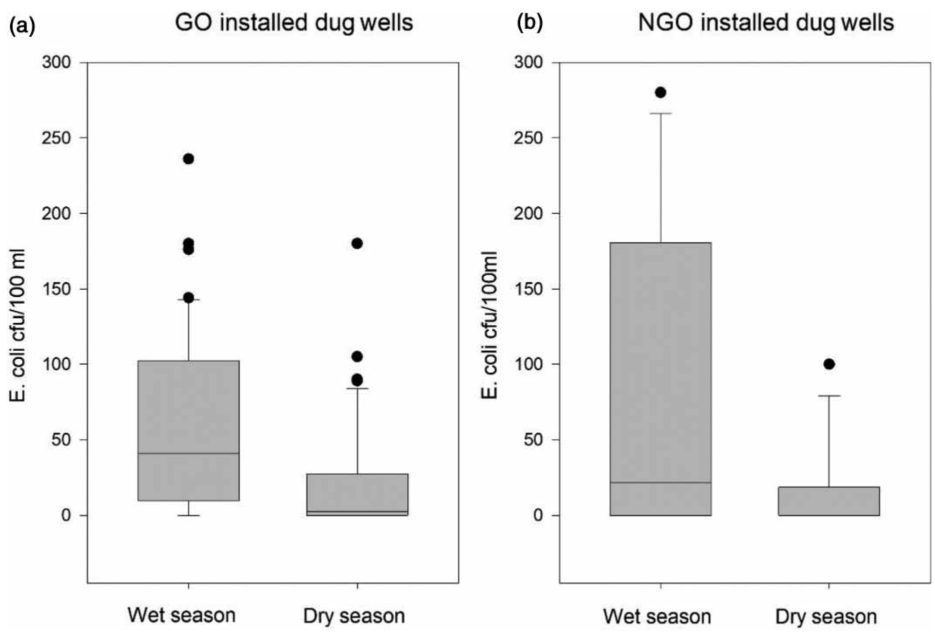



**Figure 3** | Box and whisker plot showing the range of concentrations of *E. coli* in GO-installed and NGO-installed dug well product water during the wet and dry seasons. For each box, the line within the box represents the median, while the top and bottom of the box represent the 75th and 25th percentiles, respectively, and the top and bottom whisker extends to the 90th and 10th percentiles, respectively. Observations beyond the 10th and 90th percentiles are shown as outliers.

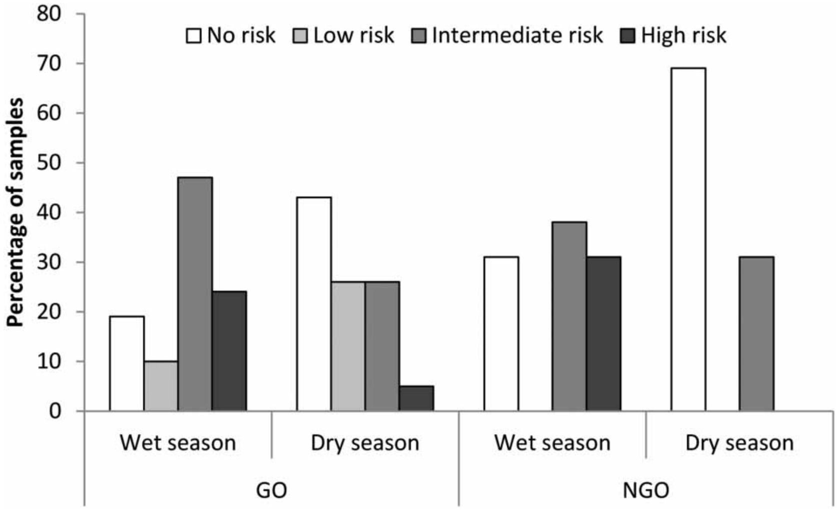



**Figure 4** | Comparison of health risk from *E. coli* contamination of GO-installed and NGO-installed dug well product water in different seasons.

during the dry season decreased to 26 and 5%, respectively. NGO-installed wells' product water also exhibited a similar pattern. In the wet season, 31 and 19% of the samples, respectively, from NGO-installed and GO-installed dug wells were within the WHO guideline values for drinking water ('no risk' category). However, in the dry season, 69 and 43% of the samples, respectively, from NGO-installed and GO-installed dug wells complied with the WHO guidelines value. This means that the number of product water samples that ensure WHO drinking water standard increased in the dry season.

## Health risk assessment

The lower (5th percentile), median and upper (95th percentile) disease burden estimates for GO-installed and NGO-installed dug wells product water according to the seasons are presented in Figure 5. The median disease burden estimates indicate that the disease burden for drinking water from both GO-installed and NGO-installed wells was higher compared to the WHO recommended reference level of disease burden ($1 \times 10^{-3}$ DALYs/1,000 person-yr) during the wet season.

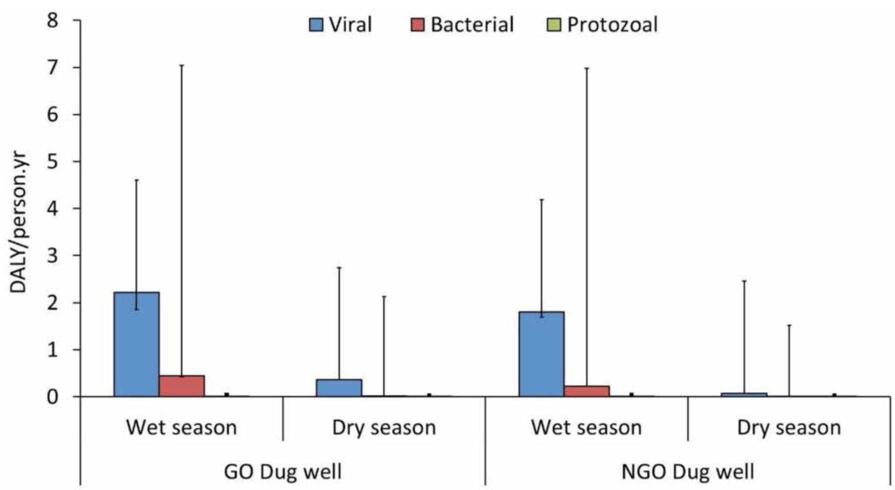



**Figure 5** | Health risks of consuming GO-installed and NGO-installed dug well water in wet and dry seasons. The bars represents median health risks, and the upper and lower bound of the middle lines on the bars represent upper (95th percentile) and lower (5th percentile) health risks, respectively.

However, GO-installed wells exhibited comparatively higher disease burden in both the wet and dry seasons. The burden of viral disease was greater than the bacterial and protozoal disease. The disease burden estimates were dominated by the viral and bacterial pathogen concentrations, whereas the contribution of protozoal pathogens to the total microbial DALY was negligible. At the lower estimation of disease burden, the viral risk was the major contributor in water from both GO-installed and NGO-installed wells. However, the contribution of bacterial and protozoal burden was almost nil. Conversely, at higher risk estimation (95th percentile), disease risk of consuming water from both GO-installed and NGO-installed dug wells was high and that was dominated by viral and bacterial disease risks. The WHO guidelines of drinking water quality (WHO 2004) recommended the reference level of risk per contaminant is $10^{-3}$ DALYs/1,000 person-yr. The viral and bacterial disease burden for both GO-installed and NGO-installed wells was much higher than the reference level, in both wet and dry seasons. Only the lower estimates of protozoal burden in the dry seasons for the GO-installed and NGO-installed dug wells were lower than the recommended reference level of risk.

### Effects of sanitary risk factors

Results of the health risk assessment indicate microbial risk of drinking water from both GO-installed and NGO-installed dug wells, and the risk was higher in the wet season. We used the data from the sanitary inspection of GO dug wells to identify the sources of microbial contamination. The relevance between individual risk factors and the presence of *E. coli* is indicated by the odds ratio (OR) (Table 2). An OR greater than 1 indicates that the corresponding factor might influence the *E. coli* concentration. We considered *E. coli* <1 cfu/100 ml as the threshold according to the WHO guidelines for drinking water quality. Three risk factors significantly contributed to the *E. coli* concentration: (1) age of the well, (2) presence of sanitary structure within 10 m of the dug well and (3) presence of animal excreta or rubbish within 10 m of the dug well.

**Table 2** | Contingency table analysis of sanitary risk factors and *E. coli* presence in the water of dug wells to determine sources of faecal contamination

| | ***E. coli*** **> 0 cfu/ml** | |
|---|---|---|
| **Variables** | **OR** | ***p*** |
| 1. Age of the well | 4.2 | 0.021* |
| 2. Well elevation above ground (in metres) | 0.501 | 0.227 |
| 3. Condition of well casing (covered or not) | 0.595 | 0.456 |
| 4. Is there a faulty drainage channel? Is it broken, permitting ponding? | 0.99 | 0.567 |
| 5. Is there a sanitary structure (pit latrine/septic tank/animal husbandry) within 10 m of the well and hand pump? | 9.50 | 0.012* |
| 6. Is there any other source of pollution (e.g., animal excreta, rubbish) within 10 m of the well? | 5.98 | 0.021* |

OR, odds ratio; $p =$ chi-square value; *significant at the 0.05 level.

## DISCUSSION

Product water of dug wells installed by both GO and NGO had bacterial contamination that can pose a potential health risk for inhabitants consuming drinking water from these wells. Previous studies conducted from arsenic affected areas of Bangladesh also reported bacterial contamination in dug well water (APSU 2005; Howard *et al.* 2006, 2007). APSU (2005) reported median *E. coli* counts of 0 and 445 cfu/100 ml in the dry and wet seasons, respectively. Howard *et al.* (2006) found median thermotolerant coliform counts of 47 and 820 cfu/100 ml in dry and wet seasons, respectively. Howard *et al.* (2007) estimated the disease burden of consuming dug well water from arsenic affected areas of Bangladesh and found high disease burden due to frequent microbial contamination. Median TC, FC and *E. coli* contamination of the GO-installed dug wells was relatively higher compared to those installed by NGO. However, mean *E. coli* contamination of the NGO-installed dug wells was higher compared to GO-installed dug wells in the dry season, which indicates very high *E. coli* contamination in some NGO-installed dug wells. Although NGO dug wells had caretakers, in most of the cases after one year of the construction activity, caretakers were not visible due to the end of the funding period of NGO. All the dug wells were more than one year old and during field visit and sampling, we did not find any activity of caretakers.

NGO-installed dug wells include a SSF for treatment of the water before collection. However, the performance of the SSF depends on its regular maintenance. A previous study conducted in southwest coastal Bangladesh also found poor operation and maintenance of pond-sand filters (Islam *et al.* 2013). To improve the water quality, it is important to properly follow the instructions for construction, operation and maintenance of dug wells.

In the case of GO dug wells, sanitary structure and presence of animal excreta or rubbish within 10 m of the well were found significantly related with *E. coli* contamination, which suggests that sanitary structure and unsanitary condition surrounding the dug well are the sources of pollution for GO-installed dug wells. A decline in bacterial quality of the GO-installed dug wells' water is observed in the wet season. This could be explained by the findings of the sanitary inspection. In the wet season, the possibilities of seepage and runoff from the surrounding areas are higher. Therefore, the presence of the poor sanitary condition and sanitary latrine might have contributed to high contamination due to seepage and runoff from the surrounding areas in the wet season. Several studies from Bangladesh (Howard *et al.* 2006; Mahmud *et al.* 2007) and other developing countries (Akoachere *et al.* 2013; Lutterodt *et al.* 2018; Ali *et al.* 2019; Salifu *et al.* 2019) have reported that the poor sanitary condition surrounding dug wells are widely responsible for microbial contamination in the water. The presence of cattle-shade or stall-feeding near the well may also contribute to similar contamination from seepage and runoff. Consequently, sanitary structures and keeping livestock near the dug well should be avoided.

Both GO-installed and NGO-installed dug wells' product water showed higher disease burden compared to the WHO recommended reference level of disease burden ($1 \times 10^{-3}$ DALYs/1,000 person-yr) (WHO 2004). The WHO reference level of disease burden indicates the risk of disease per contaminants. As the water contains different contaminants, the disease burden would be more than $1 \times 10^{-3}$ DALYs/1,000 person-yr. The lower disease estimates indicate that dug wells installed by both GO and NGO have a risk of disease only in the wet season. In the dry season, the disease risk was close to the reference level of the WHO. Consequently, both GO-installed and NGO-installed well product water could potentially comply with the reference level of risk if the dug wells are properly installed and maintained. The median disease burden shows the general tendency of disease risk related to the drinking water. It should be noted that the median disease burden of arsenic contamination in groundwater of Bangladesh is 0.185 DALYs /1,000 person-yr (Howard *et al.* 2007), while the standard value used for the country is 50 μg/l. For the GO-installed dug wells' product water, we compared median disease burden (arsenic risk at 50 μg/l) from arsenic-contaminated water with median disease burden of microbial risk from dug well water and found that the disease burden of microbial risk from dug well water was about 14 and four times higher in the wet and dry seasons, respectively. Conversely, for NGO-installed wells, it was 11 times higher in the wet season. In the dry season, the disease burden was nearly half of arsenic risk at 50 μg/l. The upper bound of the disease burden for GO-installed and NGO-installed dug wells' product water in the wet season was 9 and 9.15 DALYs/1,000 person-yr, respectively, which is lower than the disease burden estimated by Howard *et al.* (2006) (about 16 DALYs/1,000 person-yr). NGO-installed wells exhibited relatively lower disease burden in the dry season, while the upper bound of the disease burden became high in the wet season. Thus, higher disease burden for product water from both GO-installed and NGO-installed dug wells in the wet season indicates the lack of proper maintenance and the sanitary risk from the surrounding environment.

The WHO (2008) Water Safety Plan (WSP) states the methods of complete risk assessment and risk management of a water supply system at different levels from the catchment to the end-users. According to Mahmud *et al.* (2007), promoting WSP could be effective to improve the water quality of dug wells in Bangladesh. According to the sanitary inspection results, pit latrines were available within 10 m of the dug well. Hence, relocation of sanitary latrines are very important for the improvement of water safety. In Bangladesh, there is a lack of maintaining a minimum safe distance of latrines from water supply sources (Mahmud *et al.* 2007). Therefore, WSP also needs to incorporate a mandatory minimum safe distance of the latrine from the dug well. In addition, awareness-raising activity for the communities concerning the operation and maintenance, and personal hygiene practices, are essential to ensure drinking water quality for rural areas of Bangladesh (Islam *et al.* 2011, 2013). The DPHE of Bangladesh works to ensure reliable water for rural areas of the country through implementing WSP. This can be facilitated by involving the local community and NGO. Although WSP can significantly improve the water quality, chlorination is still required to ensure safety of the dug well water (Mahmud *et al.* 2007). Monitoring the system and follow-up with the communities on a periodic basis could be an effective approach of verifying the WSP. It is very difficult to achieve complete removal of faecal contamination for small community water supplies, particularly in rural conditions (Howard *et al.* 2003; Islam *et al.* 2011). In that context, taking initiatives to gradually improve the quality of water could be more practical.

This study has some limitations that are essential to consider in interpreting the results. This study was conducted in a remote rural area of Bangladesh and within the limited resources of the research project. Although this study used a small sample size, we tried to best represent the area by collecting water samples from all the dug wells available in the study area except for those having poor transportation facilities. We were not able to collect source water due to inaccessibility to the dug wells and failed to compare the product water with the source water quality. Particularly for NGO wells, the impacts of additional SSF on the bacteriological quality of the dug wells are not identified. To minimize any sampling error, we trained the sample collectors and provided a detailed instruction sheet detailing the techniques of water sampling and the sanitary inspection. This study conducted sanitary inspections of GO-installed dug wells and only in the wet season. To obtain a more reliable insight into the association between sanitary risk factors and bacterial contamination, further research is necessary to investigate both GO and NGO dug wells using a larger sample size and considering the seasonal variation.

## CONCLUSIONS

This study examined the bacterial contamination of product water of dug wells in an arsenic affected area of Bangladesh. Water of dug wells installed by both GO and NGO had a prevalence of indicator bacteria. However, the median TC, FC and *E. coli* concentrations of GO-installed dug wells were relatively higher compared to NGO-installed dug wells, both in the wet and dry seasons. The median *E. coli* concentrations of GO-installed dug wells' product water in the wet and dry seasons were 41 and 21 cfu/100 ml, respectively, and 2 and <1 cfu/100 ml for the NGO-installed dug wells, respectively. In the wet season, only 31 and 19% of the samples from NGO-installed and GO-installed dug wells, respectively, were within the WHO guidelines value for drinking water ('no risk' category). Disease burden of drinking water from the dug wells expressed in DALYs showed a high disease burden for GO-installed dug wells compared to the NGO-installed dug wells in both seasons, and an increased disease burden in the wet season. The results of this study indicate that using water from dug wells as drinking water in the arsenic-affected areas of Bangladesh could result in substantial health risk. There are also risk factors involved in the *E. coli* contamination of the GO-installed dug wells, such as the age of the well, presence of sanitary structure within 10 m of the well, and presence of animal excreta or rubbish within 10 m of the well. Sanitary structures and cattle-shade should not be allowed within a minimum safe distance of a dug well. A better assessment considering a larger sample size and covering the seasonal variation is required to achieve a more representative insight of the sources of faecal contamination.

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## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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