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Evaluation of Dug-Well as a Safe Water Alternative Option in Case of Arsenic Contamination in Groundwater

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ABSTRACT

The investigation aims to evaluate dug-well as a safe water alternative option in case of arsenic contamination in groundwater. The study was carried out with 129 dug-wells in both Rajshahi and Chapai Nawabganj districts of Bangladesh. Total arsenic concentration (As_T) was measured by HG-AAS. 98% of total dug-well water contain arsenic below Bangladesh standard and 54% below WHO standard**.** Roughly, arsenic concentration decreased with increasing depth of dug-well. 60.5% of dug-well water was safe in terms of fecal coliform (FC) bacteria. Average disinfection period was found to be 30 days. In Simple Bleaching Treatment method, for 3-6, >6-10 and >10 ft depth of water 0.10, 0.15 and 0.25 kg of bleaching powder (having 32% chlorine) was required respectively. Both As_T and FC of dug-well water varies seasonally. Measurement of pH, turbidity and odor showed that the overall physical condition of the dug-well water was very good**.** On an average, 17 families of members 85 were used water from a single dug-well, one-third of which were fully satisfied with the water.

Key words: Arsenic, Fecal Coliform, pH, Turbidity, Dug-well, Hand pump, Safe water.

INTRODUCTION

Another name of safe water is life. But the groundwater in 59 districts out of 64 in Bangladesh becomes polluted with the deadly poison arsenic[1]. An estimated 24 million people are directly exposed to this contamination and another 75 million are at risk[2]. Nearly 7,600 patients have been identified and a few deaths due to arsenic-related diseases have also been reported[2-4]. Evidently, Bangladesh is facing probably the largest mass poisoning in history.

Arsenic has long been associated with toxic effects, producing marked impacts on health ranging from acute lethality to chronic effects. Chronic arsenic exposure includes vascular diseases[5], hypertension[6], cancer[7], genotoxicity[8], diabetes mellitus[9], etc.

In response to the nationwide crisis caused by arsenic in drinking water in Bangladesh, several international and local agencies and NGOs has launched a number of programs. This was implemented by introducing different types of arsenic removal units (Shapla, 3-Pitcher filter, ALCAN filter, Bucket Treatment Unit, SIDKO, etc.) and alternative sources of drinking water (Dug-well, Rain Water Harvesting, etc.). Dug-well is a community based simple and affordable technology especially for rural people. It may have different water withdrawal mode, namely, hand pump, rope pump and, rope and bucket. Dug-well has been used from long time in Bangladesh and many countries of the world[10] based upon the assumption that its water is arsenic free and safe.

After implementation of dug-well no significant study has been carried out in Bangladesh to evaluate whether dug-well water is really safe or not. But it is an urgent need in case of severe arsenic contamination in groundwater in Bangladesh. To address the need and the safety of human health led us to conduct this investigation. The present study was carried out with 129 dug-wells of different water withdrawal systems in both Rajshahi and Chapai Nawabganj districts of Bangladesh.

MATERIAL AND METHODS

Materials

The chemicals used in this investigation were of high purity analytical grade. Distilled de-ionized water (DDW), obtained through the deionization plant (TYP-2500, Deng Yuan, China), was used throughout. Perkin Elmer pure atomic spectroscopy standard solution (Perkin Elmer, USA) of arsenic (CAS # 7440-38-2) was used for calibration of arsenic. A number of standard solutions, reducing solutions, buffer solutions, and other solutions were prepared according to respective standard procedures[11-12]. The other reagents were from Merck (Germany), Fluka (Switzerland) or Sigma Aldrich (Germany) and were used without further purification. For the detection of fecal coliform, M-FC Agar (Hi-Media, India) was used.

Site and Dug-well Selection

The study area is situated at the northwestern part of Bangladesh, namely, Rajshahi and Chapainawabganj district. The study area located roughly between 24.40° N to 24.73° N and 88.20° E to 88.50° E that covers an area of about 4,109 sq. kilometer (Fig. 1).

Among the studied 129 dug-wells, 57 were located in Chapai Nawabgonj district and 72 were in Rajshahi districts. The dug-wells were implemented by Swiss Development and Cooperation (SDC) during 2000-2004 addressing the community need in arsenic affected areas. Out of the studied 129 dug-wells, 100 are renovated (i.e., re-excavated and reconstructed) and 29 are excavated (i.e., newly constructed). Among all the studied dug-wells, 104 are with hand pump and 15 with rope pump and 10 with rope and bucket. Different studies were performed with different sets of dug-wells

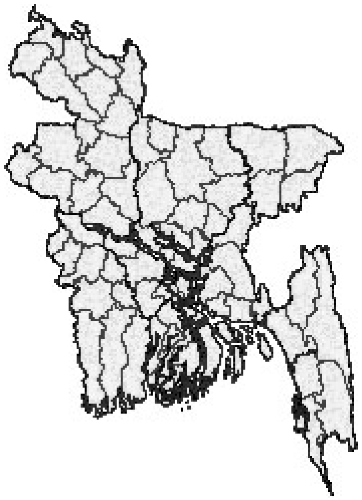

Fig. 1: Study areas (shaded)

Methods

Characterization of dug-well water

The dug-well water was characterized by measuring the physical parameters of pH and Turbidity, the chemicals parameters of Total Arsenic Concentration (As_T) and Total Iron Concentration (Fe_T) and the microbiological parameter of Fecal Coliform (FC). All the parameters were measured using standard procedures and properly calibrated instruments.

Extraction

Prior to analysis of water samples for total arsenic (As_T) and total iron (Fe_T), the aqueous samples were subjected to mild digestion with HNO_3[11]. 100 mL of well-mixed, acid-preserved water sample was taken in an Erlenmeyer flask, 5 mL of 68% HNO_3 was added and evaporated on a hot plate to make a volume of 15-20 mL. Additional HNO_3 was added and heating was continued until the digestion was completed as shown by a clear solution. It was transferred to a 100 mL volumetric flask with two rinsings, pH was adjusted to 4.0 with 1.0 M NaOH solutions and diluted with DDW up to the mark.

Analysis for total arsenic and iron concentrations

The digestates obtained after further dilution were analyzed for As_T by Hydride Generation-Atomic Absorption Spectroscopy (HG-AAS) and for Fe_T by Flame-AAS using a Shimadzu-AA 6800 (Shimadzu Corporation, Kyoto, Japan) atomic absorption spectrophotometer[12]. Prior to analysis by hydride generation, 1.5 mL of 37% (v/v) HCl, 1.0 mL of 3% (w/v) KI (containing 3.0 g KI and 5.0 g L(+)-ascorbic acid in 100 mL water) and 5.0 mL of DDW were added to 10.0 mL of the digestates and allowed to stand for 30 minutes to reduce As(V) to As(III).

Microbiological examination

The water samples were tested for fecal coliform within 6 hours of collection. Membrane filter (MF) method[11] was used to count total and fecal coliform bacteria. A volume of 100 ml water was filtered through gridded nontoxic Nitrocellulose membrane filter (Millipore, USA), 47 mm in diameter having pore size of 0.45 µm, under manual vacuum condition. It was placed in a glass Petri dish, with support of absorbing pad, containing 4 ml of the specific cultural media and incubated in a B-28 incubator (Binder, Germany) for 24 h at 44.5ºC for fecal coliform. Finally the produced colonies were counted with aid of a microscope.

Instrumentation

The Atomic Absorption Spectrophotometer used in the investigation was Shimadzu-AA 6800 (Shimadzu Corporation, Kyoto, Japan) that can run with AA WizAArd software in both graphite furnace and flame mode. The system was equipped with an autosampler ASC-6100 (Shimadzu, Japan) and a hydride vapor generation system HVG-1 (Shimadzu, Japan). The HVG-1 comprises the peristalsistic pump that is used to send the sample, 5M HCl and 0.4% $NaBH_4$ solution to the reaction coil. The instrumental conditions used for As_T determination by HG-AAS were the following: wavelength, 193.7 nm; slit width, 1.0 nm; lamp mode, BGC-D_2; lamp current, 12 mA; flame type, Air-C_2H_2; fuel gas flow rate, 2.0 L min^{-1}; carrier gas, argon; reducing agent, 0.4% (w/v) $NaBH_4$ in 0.5% (w/v) NaOH solution, $NaBH_4$ flow rate, 6 mL min^{-1}; and cell temperature, 2200-2300ºC.

Statistical Analyses

All results were expressed as an average of triplicates. The datasets were treated separately for analyzing basic statistical parameters and making cross tabulations and cross plots. The statistical software used in the data analyses includes SPSS (release 13.0) statistical software package (SPSS Inc., Chicago, Illinois, 2004). Mathematical models were established based upon simple and multiple regression analysis using SPSS and Microsoft Excel (release 12.0.4518.1014, 2006). The models were cross-checked by analyzing ANOVA, *P* value, r value (Pearson correlation coefficient) and Durbin–Watson statistics.

Quality Control

All glassware were treated with 10% (v/v) HNO_3 for 24 h and then rinsed three times with DDW followed by drying in an oven. Arsenic analysis was carried out following USEPA approved Quality Assurance/Quality Control (QA/QC) plan with a reagent blank, a duplicate and a spike for every 20 samples. The recoveries of arsenic from the environmental samples were 87.05–91.41%. Moreover, after analyzing every 10 samples, readings of standard solutions were recorded to check the instrument.

RESULTS AND DISCUSSION

Physical condition of the dug-well water

Physical condition of the dug-well water was measured in terms of pH, turbidity and odor of the water. It was found that all the 129 dug-well water are very good from the point of acidity/alkalinity, since pH of all the dug-well water lies within the range of 7.1-7.8, averaging 7.38. All the values remain within WHO and Bangladesh standard[13].

It was observed that out of studied 39 dug-well water for turbidity, 34 were transparent (0-10 NTU), 3 was slightly turbid (10-30 NTU) and the remaining 2 very turbid (>30 NTU). The reasons identified for turbidity include seepage through the junction of the rings of slabs from surrounding contaminated tanks and improper baseline support of the dug-well. The odor of studies 20 dug-well water was judged by human noses. It was also found that 17 dug-well water had no bad smell, 1 had slight bad smell and 2 intense bad smell.

Concentration of arsenic and iron in dug-well water

The average total arsenic concentration (As_T) ranges of the renovated and excavated dug-wells (n = 129) are shown in Table 1.

It was observed that out of the 129 dug-well water, 127 contained arsenic below Bangladesh standard of 50 µg L^{-1}, whereas 70 below WHO standard of 10 µg L^{-1}. Obviously, 64.0% of renovated and 20.7% of excavated covered dug-well water have arsenic concentration below WHO standard, whereas 99.0% of renovated and 96.9% of excavated covered dug-well water contains arsenic below Bangladesh standard. This reflects that water of renovated covered dug-wells is more stable than that of excavated covered dug-wells in terms of arsenic concentration. The obtained maximum and minimum arsenic concentrations were found as 296.07 and 0.50 µg L^{-1} respectively, with an average value of 16.02 µg L^{-1}.

A total of 35 samples were measured for total iron concentration (Fe_T). It was found that 17 covered dug-wells (i.e., 48.6% of the measured dug-wells) contained Fe_T below Bangladesh standard, whereas 18 (i.e., 51.4 %) above the standard. With a view to WHO standard, 3 covered dug-wells (i.e., 8.6%) contain Fe_T below the standard, whereas 32 (i.e., 91.4%) above the standard (Table 2).

Table 1: Average total arsenic concentration ranges in the dug-wells.

Type of	Average Arsenic Concentration (µg L^{-1})				
Dug-wells	0 – 10	>10 – 50	>50 – 100	> 100	Total
Renovated	64	35	01	00	100
Excavated	06	22	00	01	29
Total	70	57	01	01	129

Table 2: Average total iron concentration in covered dug-well water

	Average total iron concentration			
	Below WHO Std. ≤ 0.3 mg/L)	Above WHO Std. > 0.3 mg/L	Below Bd. Std. ≤ 1.0 mg/L	Above Bd. Std. > 1.0 mg/L
Number of Dug-wells	03	32	17	18
Percentage ofDug-wells	8.6 %	91.4 %	48.6 %	51.4 %

Table 3: Fecal Coliform in the studied dug-wells

Type of	Fecal Coliform (CFU / 100 ml)				
Dug-wells	Nil	01 – 10	11 – 200	> 200	Total
Renovated	57	03	35	05	100
Excavated	21	00	05	03	29
Total	78	03	40	08	129

Microbiological condition

Microbiological examination (Table 3) showed that most (60.5% cases) of the dug-well water are safe from the view of fecal bacteria. The presence of fecal bacteria in the remaining dug-well water (39.5% cases) is due to a combination of one or more factors: i) closeness of sources of microbiological pollution (e.g., latrine, deposited waste, cow-dung, contaminated tank, etc.), ii) not application of disinfectant (e.g., bleaching powder) to the water and iii) seepage through the junction of the rings of slabs.

It was observed that in most cases, the nearest source of microbiological pollution was contaminated tank, most of which lied within 10 ft (i.e., 3.05 m) radius around the dug-well. Latrine was frequently occurring second source and deposited used dug-well water was the next source. On an average, there was a single source within 30 ft (i.e., 9.14 m) radius and 3-4 sources within 100 ft (i.e., 30.48 m) radius around the dug-well. This reveals that the covered dug-wells are very close to the sources of microbiological pollution. This is why, disinfection is required after short intervals and effectiveness of disinfection does not persist for long period.

Seasonal variation of arsenic concentration in dug-well water

It was found that arsenic content in dug-well water varied seasonally. In most cases, the arsenic content in dug-well water becomes higher during rainy season, i.e., in May to July. This is shown for dug-wells of low or moderate arsenic content in Fig. 2.

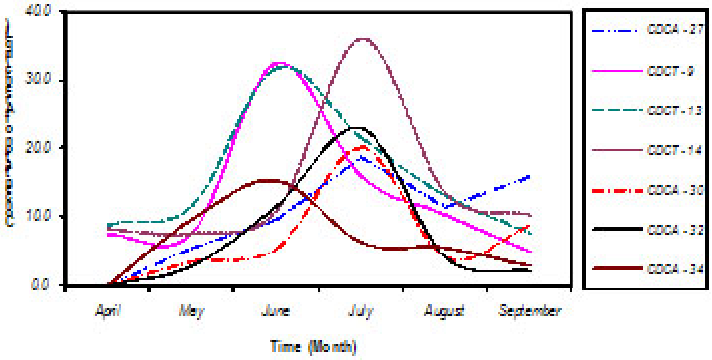

Fig. 2: Seasonal variation of arsenic content in dug-well water of low or moderate arsenic content

The probable reasons for high arsenic content in covered dug-well water are due to high water table and compactness of soil caused by raining. This high water table reduces oxygen content in water and compactness of soil impede the entrance of oxygen into the aquifer, thus leads to reducing condition of groundwater. Under this condition, insoluble arsenic goes to water through dissolution[1]. When water is withdrawn from dug-well, the more arsenic containing water comes into the dug-well and thus creating arsenic pollution.

Seasonal variation of fecal coliform in dug-well water

It was found that Fecal Coliform in dug-well water also varied seasonally. In general, bacterial contamination decreases or becomes nil after disinfection, but increases slowly (during summer) which then increases further reaching a maximum (during rainy season) and finally falls down (during winter), creating a peak as in Fig. 3.

Since bleaching powder, Ca(OCl)Cl, kills the pathogens especially fecal *E. Coli* and fecal *Streptococci* bacteria effectively[14], it is used for disinfection of dug-well water for long period**.** Fecal coliform was found as nil or almost nil in February due to application of bleaching powder. But as time goes on, the growth of bacteria was accelerated due to hot weather and gradual diminishing effect of bleaching powder**.** Further growth of bacteria was probably due to leaching of water after rainfall (in

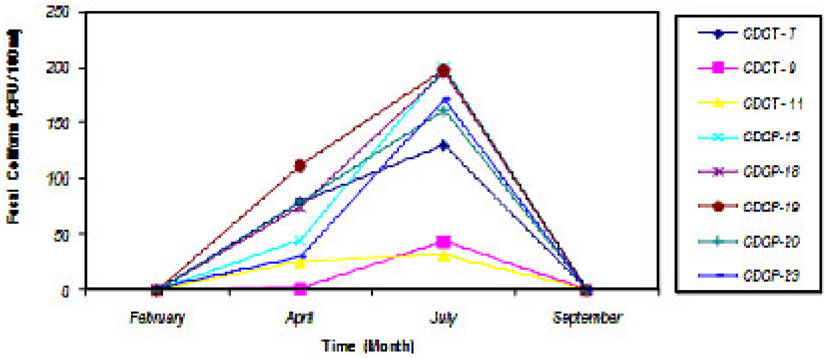

Fig. 3: Seasonal variation of fecal coliform in dug-well water.

May-July) that was enriched in organic matter (which contained nutrients for bacteria) as well as hot weather**.** The decrease in fecal coliform was attributed to lack of nutrients for the bacteria afterwards**.**

Disinfection of dug-well water

It was found that, on an average, the studied covered dug-well becomes microbiologically polluted after one month of disinfection. Several methods are available to disinfect the dug-well water, namely, Simple Bleaching Treatment Method, Single Pot Chlorination and Double Pot Chlorination[14], of which the former was found as the most effective, easiest and cost effective over the other two methods.

In Simple Bleaching Treatment method, in a small bucket, the desired amount of bleaching powder is mixed well with water to prepare a homogeneous concentrated solution. After filtration the bucket containing the solution is placed into the dug-well water with a rope. The bucket is shaken well so that bleaching powder is mixed with water slowly. After few minutes the remaining solution in the bucket is poured into the water. It was found that if the bleaching powder (e.g., LOBA, India) contained 32% of chlorine, then the amounts of bleaching powder required for 3-6, >6-10 and >10 ft depth of water were 0.10, 0.15 and 0.25 kg respectively. It is to be noted that the dug-well water should not pump out or use before 24 hours of disinfection.

Users' number and their attitude towards dug-well water

To understand the users' attitude towards dug-well water, a study was conducted with users of 20 dug-wells in both Rajshahi and Chapai Nawabganj districts. It was found hat in 2004, about 350 families of total population of 1,703 from the studied 20 covered dug-wells were used the water. On an average, 17 families of members 85 are using water from a single covered dug-well in 2004. Upon comparison those in 2002, it was found that 6 families of member 28 are additionally using water from a single covered dug-well from 2002 to 2004. Approximately two-thirds of the users were satisfied with the quality of the covered dug-wells. Their attitude is reflected in Fig. 4.

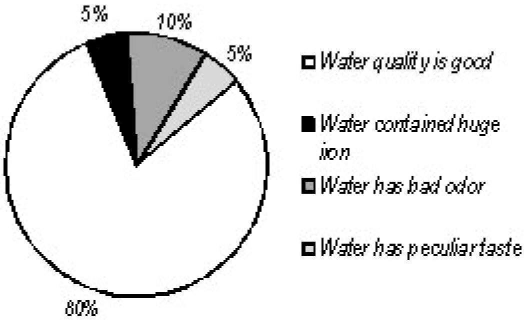

Fig. 4: Water quality of covered dug-wells according to the users

Variation of arsenic concentration with depth of dug-well

The depth of the studied dug-wells ranged 19-93 ft with an average of 34 ft. It was found roughly that the arsenic concentrations of shallow dug-well water were higher than those of deep dug-well water. The regression equation of the fitted model was $y = -0.165x + 21.59$ (where y was arsenic

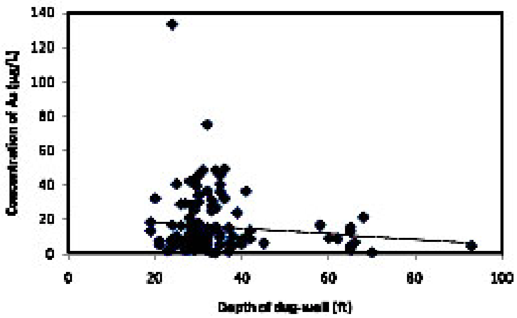

Fig. 5: Relation between arsenic concentration with depth of dug-well

concentration of dug-well water in μg L^{-1} and x was depth of dug-well in feet) with r=0.110 (Fig. 5).

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