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Survey of trace metals in drinking water supply options in coastal areas of Bangladesh

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To ascertain the water quality for human consumption, chemical parameters such as pH, conductivity and the concentrations of calcium, magnesium, iron, manganese, copper, zinc, lead, chromium, cadmium, nickel and arsenic were evaluated in the drinking water supply options employed in the southwest coastal areas of Bangladesh. The mean iron and manganese concentrations for pond and pond sand filter (PSF) water were much higher than harvested rainwater. The iron concentrations for 41% of the pond water samples were higher than the Bangladesh guideline value. However, iron and manganese removal by PSFs were found 74% and 51%, respectively. Furthermore, scarcity of calcium and magnesium were found in harvested rainwater. One pond water sample showed arsenic concentration above the 10 µg/l WHO drinking water guideline. The presence of an elevated iron and manganese and low calcium and magnesium concentrations in the drinking water could be a matter of public health concern.

Keywords*: drinking water, water quality, metals, coastal areas, Bangladesh*

Introduction

In Bangladesh, 73% of the population lives in rural areas, and tubewell water is the primary source of drinking water for the majority of the rural population. However, in the coastal areas, drinking water is very scarce because suitable fresh water aquifers at reasonable depths are not available and the surface water is highly saline and turbid (Ahmed and Rahman, 2000). There are certain areas in the coastal districts where shallow and deep tubewells are not useful due to high salinity in groundwater. In many places in these areas, rainwater is preserved in natural reservoir ponds and collection of rainwater is the only source of drinking water (Kamruzzaman and Ahmed, 2006). Moreover, the presence of excessive arsenic in shallow tubewell water has been reported in 59 out of 64 districts in Bangladesh, and it is estimated that 35–77 million people are at risk of drinking arsenic-contaminated tubewell water (GOB, 2000). Accordingly, it is necessary to supply safe water to protect the health and well being of the rural population living in the coastal and arsenic affected areas of Bangladesh. In the coastal and arsenic affected areas of Bangladesh, the government is currently promoting alternative water supply options such as rainwater harvesting, pond-sand filters (PSFs) since these are considered to be the safe options for drinking water. The currently used water supply options in rural southwest coastal areas of Bangladesh are: household based rainwater harvesting systems (RWHSs), community based rainwater harvesting systems (CRWHSs), PSFs, and rain-fed pond water. PSF is a manually operated treatment unit, based on the principle of slow sand filtration. Water is pumped up from the rain-fed pond by a hand pump and is poured into filter chamber filled with the sand. So, the treated water quality depends on the efficiency of filtration system and also on the raw water quality of the pond. Thus water supply is mainly dependent on rainwater.

It is well known that dissolved metals are more readily absorbed from drinking water than from most foodstuffs, and therefore metal toxicity may be higher through drinking water intake. Bio-available metals present in drinking water may induce the development of several diseases in humans. In the rural areas of Bangladesh, corrugated galvanized iron sheet roofs are commonly used for collection of rainwater. Use of metal roofs for collection of rainwater has been shown to be a source of zinc (Handia, 2005; Simmons et al., 2001; Gromaire et al., 2002). Elevated zinc intakes can cause demyelinating diseases in humans (Zatta et al., 2003). Lead was observed in harvested rainwater collected from galvanized iron roof (Simmons et al., 2001). Several studies (Mostafa and Shafiuzzaman, 2008; Uba and Aghogho, 2000) have shown that rain water has the possible chemical scarcity of some bio-essential elements such as calcium and magnesium. The scarcity of calcium and magnesium in drinking water has been associated with cardiovascular diseases (Kousa et al., 2006; Yang et al., 2006). The risk of drinking pond water is greatly concerned because runoff from the surrounding environment with rainfall contaminates the pond water serving as drinking water. In addition, arsenic has been detected from pond and PSF water in Bangladesh (Yokota et al., 2001; Howard et al., 2006).

Previous studies of alternative water supply options in Bangladesh have primarily focused on microbiological quality (Howard et al., 2006; Kamruzzaman and Ahmed, 2006). There is little information on trace metal concentrations in these alternative drinking water options. Thus, the objective of the present paper was to evaluate some chemical parameters such as pH and conductivity and the concentrations of calcium, magnesium, iron, manganese, copper, zinc, lead, chromium, cadmium, nickel and arsenic in alternative drinking water options employed in the southwest coastal areas of Bangladesh, as a way to ascertain the water quality for human consumption.

Methodology

Water samples were collected from the Dacope and Mongla Upazilas (sub-district) of the Khulna and Bagerhat districts located in the southwest coastal areas of Bangladesh. Samples were collected from RWHSs, CRWHSs, PSFs and ponds. We collected water from both PSFs and PSF ponds to examine the removal efficiency of trace metals by PSFs. For RWHSs, plastic and ferrocement tanks were considered in the present study. Since the government and NGOs are now promoting plastic and ferrocement tanks for rainwater harvesting. CRWHS tanks were made of reinforced cement concrete (RCC) or ferrocement. A total of 90 water samples were collected (Table 1) during March 2009.

Table 1. Number of samples taken from each drinking water option

Sampling sources	Number of sample
RWHSs	20
CRWHSs	14
PSFs	17
Ponds	39
Total	90

Water from different water supply options was collected following the standard procedures (APHA, 1998). For trace metal analysis, 500-ml water samples were collected using polyethylene bottles. After collection of the samples nitric acid (0.1% v/v) was added as a preservative. The temperature of all stored samples was maintained at 0°C to 4°C until immediately before analysis. Samples were allowed to warm up to room temperature before analysis.

The pH and conductivity of the samples were measured on site. An inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Perkin Elmer Optima 3300DV) was used for determination of trace metal concentrations. Samples were digested with concentrated HNO_3 and concentrated at 80^oC until the solution becomes transparent (APHA 1998). The concentrated samples were filtered through 0.45 µm membrane filters. Instrument start-up and optimization were carried out as detailed in the operating manual. For each sample, the machine measures the concentration three times and calculated the average value. Arsenic concentrations were determined using Atomic Absorption/Flame Emission Spectrophotometer (Shimadzu AA-660GPC). A five-point calibration curve was established by linear regression analysis of emission intensity versus standard concentration. In addition, samples blanks were analyzed after 7–10 samples. All reagents were of analytical grade. All parameters were measured using standard method (APHA, 1998).

Statistical analyses were conducted using Statistical Package for Social Sciences (SPSS) version 16.0. Mean, standard deviation, minimum and maximum values were used to describe trace metal concentrations for each option. The Mann Whitney U test was used to analyze the differences in trace metal concentrations between PSF ponds and PSFs.

Results and discussion

Data for the pH, conductivity and the concentrations of calcium, magnesium, iron, manganese, copper, zinc, lead, chromium, cadmium, nickel and arsenic in the drinking water options assessed are shown in Table 2. This table contains the minimum and maximum values found as well as the mean concentrations and the standard deviations for the parameters considered. Similarly, Table 2 compares the values proposed in guidelines of quality criteria for drinking water established by the World Health Organization (WHO, 2008) and the Government of Bangladesh (BD) (GOB, 1997).

pH and conductivity

The mean pH for CRWHSs was higher than the other drinking water options (Table 2). The highest pH of 10.5 was recorded in the CRWHSs. We considered pH levels >8.5 for the calculation of the percentage of samples above WHO guideline value. About 79% (11/14) of the CRWHS samples had a pH above 8.5. For RWHSs, the highest pH for the plastic and ferrocement tank was 8.5 and 9.9, respectively. The possible reason of high pH in CRWHSs and ferrocement tanks of RWHSs was leaching of calcium oxide from cement used for the construction of rainwater storage tank. Handia (2005) also found high pH in harvested rainwater stored in the ferrocement tanks. The average conductivity value for ponds and PSFs were found to be more than 1000 µS/cm. High conductivity is a symbol of high ionic load and indicates that organic and inorganic matter has washed into the water.

Calcium and magnesium

The mean Ca and Mg concentrations for all options were much lower than the BD guideline values. However, the mean concentrations for PSFs and ponds were comparatively higher than RWHSs and CRWHSs (Table 2). Conversely, CRWHSs and PSFs showed high Ca concentrations compare to RWHSs and ponds, respectively. The possible reason of high Ca in CRWHSs and PSFs was leaching of Ca from ferrocement tank.

The mean Ca and Mg concentrations in RWHSs showed the scarcity of these bio-essential base cations in harvested rain water. The principal constituents of water hardness (calcium and magnesium) have been closely associated with cardiovascular diseases. This scarcity of Ca and Mg can produce several diseases in populations which use this water for drinking and cooking purposes. The mean concentrations of Mg for RWHSs and CRWHSs were extremely low. Epidemiologic study in Taiwan (Yang et al., 2006) has shown a protective effect of Mg from drinking water on the risk of death from cardiovascular diseases. In the general population, the major proportion of Mg intake is through food, and a smaller proportion is through drinking water. However, for individuals with borderline Mg deficiency, waterborne Mg can make an important contribution to their total intake. The recommended dietary amount for Mg is 6 mg/kg/day (Durlach, 1989). Assuming a mean water ingestion of 2 L per person per day, the estimated daily intakes of Mg from RWHSs and CRWHSs in population living in the southwest coastal Bangladesh were 0.98 and 0.88 mg, respectively, which constitute little contribution to the intake recommended levels. In addition, the loss of magnesium from food is higher when the food is cooked in magnesium-poor water (Haring and Delft, 1981).

Iron

The mean concentration of Fe for pond water was much higher than the other drinking water options. As shown in Table 2, the highest Fe concentration was found in pond water, it was about 5 times higher than the BD guideline value. About 41% (16/39) of the pond water were above the BD guideline value. Shallow aquifer in the southwest coastal area contains elevated iron concentrations (Ahmed and Rahman, 2000). Thus high iron concentrations in pond water originate primarily from the dissolution of naturally occurring iron present in the soil. The highest Fe concentrations for RWHSs and CRWHSs were about 5 times lower than the BD limit. The high Fe levels in pond water assigned for human consumption can represent a risk for human health since excess accumulation of Fe is correlated with the oxygen-free radical formation, which may be carcinogenic (Stevens, 1990).

Table 2. Minimum, maximum and mean values of pH, conductivity, arsenic and metals concentrations present in the drinking water sources, and comparison against the levels allowed by WHO (WHO 2008) and Government of Bangladesh (BD) (GOB 1997). ND and N/A indicates not detected and no published WHO and BD guideline, respectively.

Parameters	Sampling sources	Mean (SD)	Min	Max	% above WHO Guideline value	% above BD Guideline value	WHO Guideline value	BD Guideline value
pH	RWHSs	7.9 (1.1)	5.7	9.9	22	-	6.5–8.5	N/A
	CRWHSs	8.9 (0.8)	7.6	10.5	79	-		
	PSFs	7.6 (0.5)	6.8	8.5	0	-		
	Ponds	7.8 (0.4)	6.9	8.8	5	-		
Conductivity (µS/cm)	RWHSs	140 (120)	24	470	-	-	N/A	N/A
	CRWHSs	170 (70)	94	340	-	-		
	PSFs	1300 (840)	340	3400	-	-		
	Ponds	1200 (820)	350	3900	-	-		
Ca (mg/l)	RWHSs	6.2 (5.5)	0.4	19	-	0	N/A	75
	CRWHSs	13 (3.1)	9.4	19	-	0		
	PSFs	29 (5.5)	15	38	-	0		
	Ponds	17 (5.1)	11	27	-	0		
Mg (mg/l)	RWHSs	0.49 (0.5)	0.003	2.5	-	0	N/A	30–35
	CRWHSs	0.44 (0.5)	0.05	1.9	-	0		
	PSFs	2.7 (0.5)	1.8	3.2	-	0		
	Ponds	2.5 (1.0)	1.9	4.1	-	0		
Fe (µg/l)	RWHSs	29 (43)	0.3	190	-	0	N/A	1000
	CRWHSs	66 (59)	22	210	-	0		
	PSFs	240 (260)	2.1	800	-	0		
	Ponds	3200 (1100)	44	4800	-	41		
Mn (µg/l)	RWHSs	8.7 (18)	3.4	66	0	0	400	100
	CRWHSs	3.2 (3.9)	0.5	15	0	0		
	PSFs	160 (220)	1.0	700	12	52		
	Ponds	180 (180)	1.0	850	10	45		

Cu (µg/l)	RWHSs	3.7 (8.5)	0.3	28	0	0	2000	1000
	CRWHSs	5.6 (5.3)	0.2	21	0	0		
	PSFs	24 (44)	0.3	190	0	0		
	Ponds	12 (13)	0.5	54	0	0		
Zn (µg/l)	RWHSs	310 (440)	9.5	1700	0	0	N/A	5000
	CRWHSs	86 (95)	9.6	350	0	0		
	PSFs	37 (87)	1.4	360	0	0		
	Ponds	6.2 (7.8)	1.3	40	0	0		
Pb (µg/l)	RWHSs	3.7 (15)	0.8	69	4	4	10	50
	CRWHSs	0.6 (1.3)	0.08	4.8	0	0		
	PSFs	ND	ND	ND	0	0		
	Ponds	0.1 (0.5)	0.008	2.9	0	0		
Cr (µg/l)	RWHSs	1.2 (2.9)	0.02	13	0	0	50	50
	CRWHSs	0.05 (0.1)	0.03	0.5	0	0		
	PSFs	ND	ND	ND	0	0		
	Ponds	1.6 (1.2)	1.3	3.8	0	0		
Cd (µg/l)	RWHSs	0.2 (0.2)	0.03	0.6	0	0	3	5
	CRWHSs	ND	ND	ND	0	0		
	PSFs	0.3 (0.2)	0.05	0.8	0	0		
	Ponds	0.1 (0.2)	0.003	1	0	0		
Ni (µg/l)	RWHSs	0.3 (0.3)	0.1	1.2	0	0	70	100
	CRWHSs	0.2 (0.5)	0.1	0.2	0	0		
	PSFs	0.04 (0.1)	0.1	0.4	0	0		
	Ponds	0.9 (3.9)	0.1	18	0	0		
As (µg/l)	RWHSs	1.1 (1.6)	0.2	6.8	0	0	10	50
	CRWHSs	0.6 (0.8)	0.2	3.1	0	0		
	PSFs	3.4 (2.8)	0.6	9.4	0	0		
	Ponds	3.8 (3.4)	0.5	18	3	0		

Manganese

The mean Mn concentrations for PSFs and ponds were higher than the BD guideline value. The highest Mn concentration 850 µg/l was found in pond water sample. The primary sources of Mn in pond and PSF water may have been leaching of Mn from the soil and surface runoff from the surrounding areas. In the present study, 52% (9/17) of the PSF and 45% (18/39) of the pond water samples showed Mn concentrations higher than the BD guideline value. The accumulation of Mn in blood may cause hepatic encephalopathy

(Layrarguse et al., 1998). High manganese concentrations in drinking water have also been shown to affect intellectual functions in 10-year-old children in Araihazar, Bangladesh (Wasserman et al., 2006).

Copper

The highest Cu concentration (190 µg/l) was found in PSF water; however the concentration was about 11 and 5 times lower than the WHO and BD guideline values, respectively. Even though Cu concentrations in the drinking water options assessed in our study were lower than the values recommended by WHO and BD, the mean Cu concentrations for RWHSs and CRWHSs were extremely low. This Cu scarcity in drinking water could cause deficiency, since Cu is considered as bio-essential metal.

Zinc

The mean Zn concentrations for all options were very low compare to the BD guideline value. However, the concentrations in RWHSs and CRWHSs were higher than PFSs and ponds. RWHSs showed the highest Zn concentration of 1700 µg/l. The possible source of Zn in harvested rain water was roof catchments. High zinc concentrations were measured from zinc-covered roof (Förster, 1996; Gromaire et al., 2002) due to erosion of zinc roof.

Lead

The mean Pb concentrations for all drinking water options were much lower than the WHO guideline value. However, one RWHS sample showed Pd concentration about 7 times higher than the WHO guideline value. High Pb concentrations were also observed in runoff from galvanized iron roof (Simmons et al., 2001). Lead is a "possible human carcinogen" because of inconclusive evidence of human and sufficient evidence of animal carcinogenicity. In addition, the 10 µg/l WHO drinking water guideline for Pb was calculated using the lowest measurable retention of Pb in the blood and tissues of human infants (WHO, 1996).

Chromium, cadmium and nickel

The mean concentrations of Cr, Cd and Ni for all options were much lower than the guideline values. The highest concentrations of Cd and Ni were found in pond water, while RWHSs showed the highest Cd concentration.

Arsenic

All the drinking water options showed mean As concentrations below the WHO and BD guideline values. However, one pond water sample showed As concentration above the 10 µg/l WHO guideline value. Previous studies (Yokota et al., 2001; Howard et al., 2006) from arsenic affected areas of Bangladesh have shown that pond and PSF water may contain arsenic higher than WHO guideline value. The arsenic in the pond water was probably due to surface drainage from an arsenic polluted tube well.

Removal of iron and manganese by PSFs

Table 3 shows the mean Fe and Mn concentrations for PSF water and the relevant PSF pond water. The PSFs reduced Fe concentrations significantly. However, the removal of Mn by PSFs was not found statistically significant. We also examined the removal efficiency of Fe and Mn by PSFs. The removal efficiency of Fe and Mn by PSFs is shown in Table 3. In the present study, Fe and Mn removal by the PSFs was about 74% and 51%, respectively. Si-min et al. (2010) found higher Fe and Mn removal by bio-sand filter than were observed in the present study. Thus consumption of PSF water instead of pond water may reduce the health risk from Fe and Mn exposure. The removal of other metals by PSFs was negligible and some metals showed little increases of the concentrations after filtration by PSFs. The pipelines between PSFs and PSF ponds, and other fittings used for PSFs may have contributed to increased metal concentrations.

Table 3. Removal efficiencies of Fe and Mn by PSFs

Trace metal	PSF ponds (mean)	PSFs (mean)	Average % removal by PSFs
Fe (μg/l)	1300	240	74 %
Mn (μg/l)	220	160	51 %

Conclusions

The mean concentrations of the metals under consideration complied with international guidelines of quality criteria for drinking water. However, the mean Fe and Mn concentrations for pond water and the mean Mn concentration for PSF water were higher than the Bangladesh guideline value. The scarcity of Ca and Mg in harvested rainwater is of importance to the health of populations in the study area. We recommend Ca and Mg supplementation as a possible way of reducing the risk of heart and other diseases for populations entirely dependent on harvested rainwater. Methods of supplementary Ca and Mg can include fortification of foods, and public education to change dietary habits. Furthermore, this study reveals unsafe concentrations of Fe and Mn in pond water. Conversely, Fe and Mn removal by PSFs were found 74% and 51%, respectively. Thus consumption of PSFs water instead of pond water will reduce associated health risk. In addition, ponds should be well protected to ensure sufficient protection from surface run off and for efficient filter operation.

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