Arsenic contamination in groundwater of Samta, Bangladesh


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Abstract In March 1997, we analyzed the water of all tubewells used for drinking in Samta village in the Jessore district, Bangladesh. It has been confirmed from the survey that the arsenic contamination in Samta was one of the worst in the Ganges basin including West Bengal, India. 90% of the tubewells had arsenic concentrations above the Bangladesh standard of 0.05 mg/l. Tubewells with higher arsenic concentrations of over 0.50 mg/l were distributed in the southern area with a belt-like shape from east to west, and the distribution of arsenic concentration showed gradual decreasing toward northern area of the village. In order to examine the characteristics of the arsenic distribution in Samta, we have performed investigations such as: 1) the characteristics of groundwater flow, 2) the distribution of arsenic in the ground, 3) the concentration of arsenic and the other dissolved materials in groundwater, and 4) the distribution of arsenic concentration of trivalence and pentavalence. This paper examines the mechanism of arsenic release to groundwater and explains the above-mentioned characteristics of the arsenic contamination in Samta through the investigations of the survey results for these years.

Keywords Arsenic; Bangladesh; contamination; groundwater; elution mechanism

Introduction
Arsenic contaminated groundwater has been found in 59 districts out of a total 64 districts in Bangladesh, where almost all drinking water is supplied from groundwater. The causes of arsenic contamination of groundwater are not clear yet, and it is estimated that about 40 million people are at risk of arsenic poisoning (Ahmad et al., 1998). The arsenic contamination of groundwater in Bangladesh was recognized worldwide at the International Conference on Arsenic in Groundwater, held by the School of Environmental Studies, Jadavpur University at Calcutta in 1995. The arsenic problems were reported at the conference by Bangladesh researchers and the extensive surveys for the arsenic problems have been carried out since the conference, for example, by Dhaka Community Hospital Trust, the National Institute of Preventative and Social Medicine (NIPSOM) and the Asia Arsenic Network (AAN).

Miyazaki University and AAN first visited Bangladesh in February 1996 and have been making detailed surveys in Samta village, Jessore, from March 1997 in collaboration with NIPSOM and the Research Group for Applied Geology (RGAG). The village is located southwest of Bangladesh near to the State of West Bengal, India. It was found that more than 90% of tubewells in Samta were above 0.05 mg/l (Bangladesh standard). And 15% of tubewells showed higher concentration above 0.50 mg/l which distributed in the southern area with a belt-like shape from east to west, and the arsenic concentration was decreasing toward northern area of the village (Yokota et al., 1997).
After the survey of arsenic contamination of groundwater in Samta village in March 1997, we have examined the following in order to obtain the solution for the above-mentioned characteristics of arsenic distribution: 1) the characteristics of groundwater flow, 2) the vertical and horizontal distribution of arsenic in the ground, 3) the concentration of arsenic and the other dissolved materials in groundwater, and 4) the distribution of arsenic concentration of trivalence and pentavalence.

This paper discusses that the causes for the arsenic distribution of groundwater in Samta is mainly dependent on the distribution of muddy layer including the arsenic. Moreover, the mechanism of arsenic release to groundwater is discussed by examining the relation between arsenic concentration and such water quality as Fe$^{2+}$, HCO$_3^-$, NH$_4^+$ and EC (electric conductivity), ORP (oxidation-reduction potential) in groundwater.

**Characteristics of arsenic contamination in Samta**

**Characteristics of arsenic concentration in groundwater**

Figure 1 shows the distribution of arsenic concentration of groundwater in dry season, March. The arsenic was measured by using AAN field kit developed by Hironaka (Tanabe et al., 1998). It was very interesting why the arsenic concentration changes gradually from 0.01 mg/l in the northern area to 0.5 mg/l in the southern area (Yokota et al., 1997). It might be considered that arsenic had been transported through distributary of the Ganges several thousands years ago and had precipitated to the river bottom with muddy soil, though the river was already buried and is now in the underground. It is a question why the arsenic distribution shown in Figure 1 was caused in the Samta village, which is considered as a dot compared with area of the Ganges basin.

**Geological profile and arsenic in the muddy layer**

The strata, from ground surface to the depth of 200 m, consists of: from the surface, uppermost sandy layer (ums, thickness: 0–5 m), upper muddy layer (um, thickness: 0.5–12 m), upper sand layer (us, thickness: 90–100 m), lower muddy layer (lm, thickness: 25–35 m) and lower sandy layer (ls, thickness: 90+ m) (Bando et al., 1999). The us and ls are first and second aquifer, respectively. Arsenic is detected in the um, specially in peat bed distributing partially in the um, as shown in Figure 2 (Ishiga et al., 1999). Figure 2 expresses the arsenic concentration in a boring sample including the um, which was measured by the fluorescence X-ray analysis (○ mark in the figure) and the chemical quantitative analysis by resolving with hydrochloric acid (□ mark).

The contour lines of the um depth are shown in Figure 3 together with the distribution of arsenic concentration. The region of Samta map in Figure 3 is larger than Figure 1 being...
extended in the northern area. The um depth at the northern area, which was measured May 2000, is zero or less than 1 metre, and in the centre and the southern areas about 8 metres and several metres, respectively (Bando et al., 1999). The concentrations of arsenic in the most northern area, measured May 2000, are all less than 0.05 mg/l. This may be caused from the above-mentioned um thickness of zero or less than 1 metre in this area. Comparing Figure 3 with Figure 1, the lower zone of arsenic concentration at the northern area in Figure 1 almost coincides with the zone of thinner um in Figure 3 and the higher zone in the southern area almost agrees with the zone of thicker um. Accordingly, the question why the arsenic concentration increases gradually from north to south may be explained by the thickness distribution of the um including arsenic.

**Water quality and arsenic release into groundwater in Samta**

**Water quality and arsenic in groundwater**

The results of water quality analyses are shown in Table 1 (Tanabe et al., 2001). Some of the special features are that concentrations of HCO$_3^-$ and iron were 179–432 mg/l and 3.9–10.5 mg/l respectively, greatly higher than those of normal groundwater. The values of pH were between 7.1 and 7.6 showing alkalescence and ORP were minus values showing reduction state. Figures 4 to 6 with Table 2 illustrate the distribution of Fe$^{2+}$, HCO$_3^-$, and EC, respectively. When comparing Figures 4 to 6 with Figure 1, it can be observed that the well water with high arsenic concentrations contains high amounts of Fe$^{2+}$, HCO$_3^-$ and EC, while in the wells with low arsenic concentrations their amounts were small.

Most of the iron is present in the bivalent form as shown in Table 1. It is, therefore, considered that the arsenic is released to groundwater from the co-precipitated arsenic with iron under reduction circumstances. The minus values of ORP will support the reductionism. With regard to the high amounts of HCO$_3^-$, it can be interpreted that it was formed by the reduction of SO$_4^{2-}$ and NO$_3^-$. The contour lines of groundwater level are shown together with the distribution of EC in Figure 6. From Figure 6, it is considered that groundwater

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**Figure 2** Vertical distribution of arsenic concentration in upper muddy layer

**Figure 3** Distribution of thickness of upper muddy layer and arsenic concentration in Samta village

**Table 1** Water quality of groundwater in Samta (shallow tubewell for drinking: May 1998)

<table>
<thead>
<tr>
<th>EC (µS/cm)</th>
<th>pH</th>
<th>ORP (mV)</th>
<th>As (mg/l)</th>
<th>Fe$^{2+}$ (mg/l)</th>
<th>Fe$^{3+}$ (mg/l)</th>
<th>HCO$_3^-$ (mg/l)</th>
<th>HNO$_3^-$ (mg/l)</th>
<th>NH$_4^+$ (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>574–1192</td>
<td>7.1–7.6</td>
<td>-(88–6)</td>
<td>0.03–1.20</td>
<td>3.9–10.5</td>
<td>0–1.0</td>
<td>179–432</td>
<td>0.1–8.4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>K$^+$ (mg/l)</th>
<th>Mg$^{2+}$ (mg/l)</th>
<th>Ca$^{2+}$ (mg/l)</th>
<th>F$^-$ (mg/l)</th>
<th>Cl$^-$ (mg/l)</th>
<th>Br$^-$ (mg/l)</th>
<th>NO$_2^-$ (mg/l)</th>
<th>SO$_4^{2-}$ (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1–14.7</td>
<td>13–48</td>
<td>51–100</td>
<td>0–4.4</td>
<td>0–58.3</td>
<td>0–0.1</td>
<td>0–0.40</td>
<td>0–7</td>
</tr>
</tbody>
</table>
flows from the northern part towards the southern part of the village, and then into the river to the east after drifting at the low table of the south (Yokota et al., 1999). Since the EC value is high in the south where arsenic concentration is also high, it is assumed that the amount of dissolved ion is large and groundwater temporarily stays in the south.

Other dissolved components such as \( \text{NH}_4^+ \) (0.1–8.4 mg/l), \( \text{K}^+ \) (2–15 mg/l), \( \text{Cl}^- \) (0–60.0 mg/l), \( \text{Br}^- \) (0–0.1 mg/l), \( \text{F}^- \) (0–4.5 mg/l) and \( \text{NO}_3^- \) (0–0.4 mg/l) were also detected in groundwater. Iron and \( \text{F}^- \) were above the limits set for drinking water in Japan. As seen in Table 1, iron exceeded the limit (below 0.3 mg/l), and \( \text{F}^- \) was above the limit (below 0.8 mg/l) in the 74% of the examined tubewells. The high content of \( \text{NH}_4^+ \) may indicate the direct inflow of excreta to well water. It is necessary, therefore, to assess the whole water quality including other dissolved components and bacteria for the supply of safe drinking water.

**The distribution of trivalent and pentavalent arsenic concentration**

Figure 7 shows the distribution of trivalent and pentavalent arsenic concentration measured in May 2000. The values, put down at left side of measuring points in the figure, show trivalent arsenic and the right ones pentavalent. These were measured by ICP/MS (inductively coupled plasma). It is characteristic that arsenic exists in pentavalency at the northern area, trivalent arsenic at the southern area. This means that groundwater is under oxidation condition at the northern area, under reduction at the southern area.

![Figure 4](image1.png)

**Figure 4** Distribution of \( \text{Fe}^{2+} \) of groundwater in Samta village (May 1998)

![Figure 5](image2.png)

**Figure 5** Distribution of \( \text{HCO}_3^- \) of groundwater in Samta village (May 1998)

![Figure 6](image3.png)

**Figure 6** Distribution of electric conductivity of groundwater in Samta village (May 1998). The contour lines show depth (m) of the groundwater level

![Figure 7](image4.png)

**Figure 7** Distribution of \( \text{As}^{3+} \) and \( \text{As}^{5+} \) concentration of groundwater in Samta village (June 2000)

**Table 2** Values of \( \text{Fe}^{2+} \) (mg/l), \( \text{HCO}_3^- \) (mg/l) and EC (\( \mu \)s/cm) in Figures 4, 5 and 6

<table>
<thead>
<tr>
<th>( \text{Fe}^{2+} ) (mg/l)</th>
<th>( \text{HCO}_3^- ) (mg/l)</th>
<th>EC (( \mu )s/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>△</td>
<td>HCO_3^- &lt; 200</td>
<td></td>
</tr>
<tr>
<td>○</td>
<td>( \text{Fe}^{2+} &lt; 5.0 )</td>
<td>200 ≤ HCO_3^- &lt; 300</td>
</tr>
<tr>
<td>▲</td>
<td>5.0 ≤ ( \text{Fe}^{2+} &lt; 7.0 )</td>
<td>300 ≤ HCO_3^- &lt; 350</td>
</tr>
<tr>
<td>■</td>
<td>7.0 ≤ ( \text{Fe}^{2+} &lt; 9.0 )</td>
<td>350 ≤ HCO_3^- &lt; 400</td>
</tr>
<tr>
<td>●</td>
<td>9.0 ≤ ( \text{Fe}^{2+} )</td>
<td>400 ≤ HCO_3^-</td>
</tr>
</tbody>
</table>

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It may be said that Figure 7 is consistent with the distribution of depth of first aquifer, namely the downward inclination from northern area to southern area. At the northern area groundwater is under the condition of oxidation as the aquifer exists near the ground surface. The arsenic in the muddy layer, therefore, may be dissolved by oxidation of pyrite in the northern area as Prof. D. Chakraborti’s theory (Das et al., 1995) suggested.

On the other hand, at the center or southern area, the condition of reduction may be explained from the strata structure that aquifer lies under the thick mud at deeper level from ground surface. The groundwater flow in the southern area in Figure 6, too, may explain the state of reduction, because the aquifer generally is in the state of reduction when the flow of groundwater is under the condition of drifting. Under the state of reduction the pentavalent arsenic, which had precipitated with hydrous ferric oxide ($5\text{Fe}_2\text{O}_3\cdot9\text{H}_2\text{O}$), could be reduced to the trivalent arsenic and released into groundwater (Nickson et al. 1998; Akai et al., 1999). Comparing the distribution of arsenic concentrations of Figure 1, it could be seen that the higher arsenic zone ($\text{As} > 0.5 \text{mg/l}$) almost agrees with the trivalent arsenic zone. It means that the arsenic of high concentration in the area is more toxic trivalency, and may express that arsenic is dissolved in the condition of reduction. This is another explanation for the question with respect to the distribution of arsenic concentration in Figure 1.

**Conclusions**

In this paper the characteristics of arsenic contamination of groundwater in Samta village was shown, and the mechanism of contamination was discussed by using the data measured until now. The following were obtained as a result.

1. The new findings about arsenic concentration of groundwater in Samta.
   a) Arsenic is heavily present in the peat bed in upper muddy layer which lies on first aquifer.
   b) The thickness of upper muddy layer is zero or less than 1 metre in the most north area, a few metres in the northern area, about 8 metres in the central area and several metres in the southern area.
   c) The arsenic concentrations of groundwater are less than 0.05 mg/l in the most northerly area.
   d) The pentavalent arsenic is more detected compared with trivalency in the northern area. Conversely in southern area, the trivalent arsenic was more detected.

2. Examination about arsenic distribution in Samta: “the high arsenic concentration in the southern area and decrease of the concentration toward north from south”.
   a) The distribution of the upper muddy layer including the arsenic, mentioned in the above conclusion of 1(b), may explain the characteristic of arsenic concentration, especially the low arsenic concentration in the northern area.
   b) The higher values of trivalent arsenic in the southern area, the conclusion 1(d), means that the arsenic of high concentration in the area is more toxic trivalency, and may express that arsenic is dissolved in the condition of reduction. It is in harmony with the distribution of thicker upper muddy layer, namely deeper groundwater level from ground surface, in the center and southern part mentioned in the conclusion of 1(b).

3. Consideration of arsenic release to groundwater:
   It was characteristic that $\text{HCO}_3^-$ and $\text{Fe}^{2+}$ contents of groundwater were high and their distribution was in accordance with that of arsenic contamination. Although it was not possible to identify the mechanism of arsenic elution from the water analyses, the distribution of dissolved components well explains the reduction theory.
Acknowledgement
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