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A STUDY ON ARSENIC CONTAMINATION OF GROUNDWATER IN SAMTA VILLAGE, BANGLADESH

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Abstract

90% of the tube wells in the residential area in Samta village, where we have been investigating the causes of the arsenic pollution in groundwater and developing arsenic-free water supply systems since March 1997, had arsenic concentration above the Bangladesh standard of 0.05mg/l. The tube wells with higher arsenic concentration of over 0.50mg/l were distributed in the south of residential area with a belt-like shape from east to west, and the distribution of arsenic concentration showed gradual decreasing pattern towards the north of the residential area. In order to examine the characteristics of the arsenic distribution in Samta village, many investigations have been done. And, recently the followings were investigated: 1) the arsenic concentration of trivalence and pentavalence of the tube wells water in the residential area, 2) the geological profiles in the rice field on the north of the residential area, and 3) hydrological data for numerical analysis of groundwater flow. This paper shows results of these investigations and examines the mechanism of the above-mentioned characteristics of arsenic contamination in the residential area of Samta village.

KEYWORDS: *arsenic, groundwater, contamination, mechanism, Bangladesh*

1. Introduction

Arsenic polluted groundwater has been found in 59 districts (as of January 1999) out of a total of 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). In early 1990s Prof. D. Chakraborti, who had revealed the arsenic calamity in West Bengal, India, often emphasized that the groundwater in the Ganges basin in Bangladesh, too, is to be contaminated with arsenic.

In Bangladesh, arsenic polluted water was first detected at Chapai Nawabganj, which is in a region adjacent to West Bengal, in 1993 by the Department of Public Health Engineering in Bangladesh (DPHE). In 1994 the National Institute of Preventative and Social Medicine (NIPSOM) identified eight chronic arsenicosis patients at Chapai Nawabganj.

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The arsenic pollution of groundwater in Bangladesh was worldwide recognized at the International Conference on Arsenic in Groundwater, held by School of Environmental Studies (SOES), Jadavpuir University at Culcutta 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 (DCHT), NIPSOM and Asian Arsenic Network (AAN).

Miyazaki University and AAN first visited Bangladesh in February 1996 and have been making detailed surveys in Samta village, Jessore district, from March 1997 in collaboration with NIPSOM and Research Group for Applied Geology (RGAG). The village is located in southwest of Bangladesh near the State of West Bengal, India (see Fig.1). It was found that more than 90% of tube wells in the residential area in Samta village had arsenic concentration above 0.05mg/l (Bangladesh standard). And 15% of tube wells which showed higher concentration above 0.50mg/l was distributed in the south of residential area with a belt-like shape from east to west, and the arsenic concentration was decreasing towards the north of the residential area in Samta village (Yokota et al., 1997).

In 1997, Bangladesh University of Engineering & Technology (BUET) tested more than 2000 samples of groundwater covering six districts in northeast Bangladesh and showed that the range of arsenic concentration above 0.05mg/l in the districts was 27-61% and 10-17% for concentration above 0.10mg/l (Badruzzaman et al., 1997). During 1998, British Geological Survey (BGS) together with DPHE, undertook a new survey of 41 out of the 64 districts of Bangladesh, showing that groundwater was contaminated with arsenic over 70% of national land in Bangladesh (British Geological Survey and Motto MacDonald Ltd, 1999).

After the survey of arsenic pollution of groundwater in Samta village in March 1997, we examined the followings in order to get the solution for the above-mentioned characteristics of arsenic distribution in Samta village. Namely, 1) the characteristics of groundwater flow, 2) the increasing tendency of arsenic concentration with passing time, 3) the geological structure of ground and arsenic concentration in ground, and 4) the mechanism of arsenic leach to groundwater. Recently, we measured the arsenic concentration of trivalence and pentavalence for the tube wells water in the residential area in Samta village. Moreover, we examined the geological profiles in the rice field on the north of the residential area by boring tests, measured the arsenic concentration of groundwater at the boring sites, and obtained the hydrological data for numerical analysis of groundwater flow.

In this paper, the data from March 1997 are shown, and the characteristics of arsenic concentration in Samta village, "The high arsenic concentration in the south of the residential area and the gradual decrease of the concentration towards the north", is discussed by examining the above data. Lastly, the introduction of future research is mentioned.

2. Arsenic concentration in groundwater and ground

2.1 Characteristics of arsenic concentration of groundwater

Fig.2 shows the distribution of arsenic concentration of groundwater in dry season, March 1997, which was obtained by measuring water of all tube wells in the residential area in Samta village where about 3,600 people (680 of household) are now living. The water was used for drinking and cooking purposes then. 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 0.01mg/l in the north to over 0.5mg/l in the south of the residential 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 Fig.2 occurred in the Samta village, which is considered as a dot compared with area of the Ganges basin.

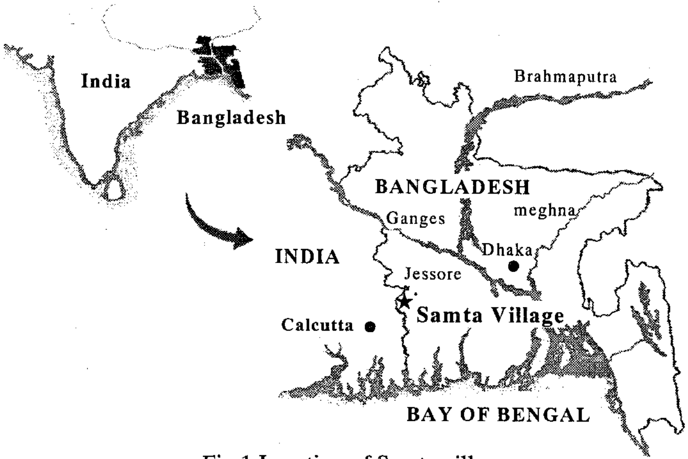

Fig.1 Location of Samta village

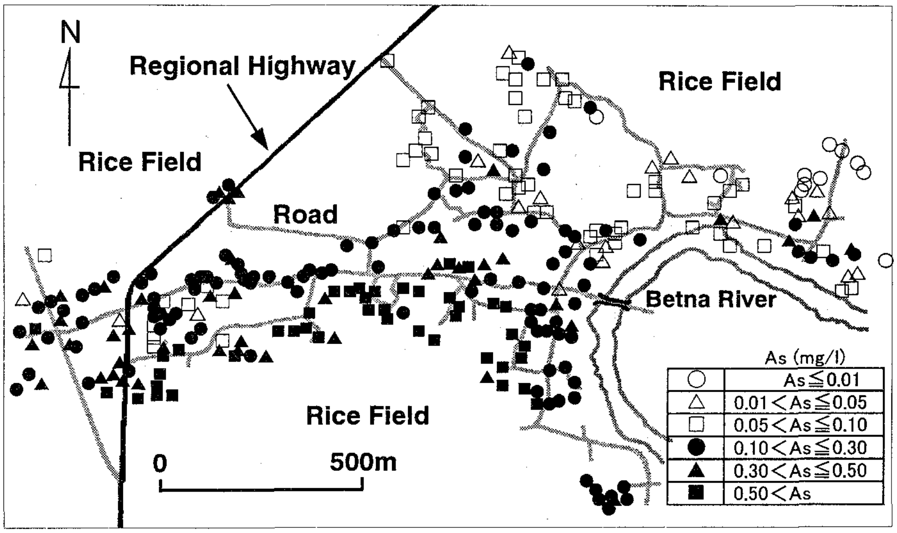

Fig.2 Distribution of arsenic concentration of groundwater in the residential area in Samta village (March 1997)

2.2 Geological profile and arsenic in muddy layer

The strata in the residential area, consists of; from the surface, upper most muddy layer (***umm***), upper most sandy layer (***ums***), upper muddy layer (***um***), upper sand layer (***us***), lower muddy layer (***lm***) and lower sandy layer (***ls***) as shown in Table 1 (RGAG et al., 2000). The ***us*** and ***ls*** are first and second aquifer, respectively.

Table 1 Stratigraphy in the residential area in Samta village (modified data from RGAG et al., 2000)

layer		depth (m)	thickness (m)	facies	aquifer
Embankment		0~1.5	0~1.5	silt and clay	
Upper most muddy layer	***umm***	0~5	0~3	silt and clay	
Upper most sandy layer	***ums***	1~6	0~3	very fine sand	unconfined aquifer
Upper muddy layer	***um***	1~15	0.8~12	silt and clay with organic materials	aquiclude
Upper sandy layer	***us***	10~120	80~110	fine to medium sand	first confined aquifer
Lower muddy layer	***lm***	90~170	0~60	sandy silt to very fine sand	aquiclude
Lower sandy layer	***ls***	100+	100+	fine to coarse sand with silt and granule layer	second confined aquifer

Arsenic is detected in the ***um***, especially in peat bed distributing partially in the ***um***, as shown in Fig.3 (Ishiga, et al., 1999; Rahman et al., 1999; Yamazaki et al., 2000). The locations of the boring samples, B-20, 9, 7, 1, 3, 4 are shown in Fig.4, in which the residential area of Fig.2 is located inside the dotted lines and the boring points in the rice field on the north of the residential area expressed as B-21~B33 (B-25, 26:excluded), too. Fig.3(a) expresses the arsenic concentration in a boring sample which mainly belongs to the ***um***. It was measured by the fluorescence X-ray analysis (□mark in the figure) and the chemical quantitative analysis by resolving with hydrochloric acid (○mark). Fig.3(a) shows that the values of arsenic concentration from the former analyses appears rather larger than the latter which generally gives more accurate value than the former. The distribution of arsenic concentration is, however, similar to each other, and the depth from the ground surface which gives the peak value of arsenic is almost same in the both analyses. Hereafter, the vertical distribution of arsenic concentration is to be analyzed by the former as shown in Fig.3(b).

Fig.3(b) shows the results for six samples measured by the fluorescence X-ray analysis. The high arsenic concentration is recognized at the peat in ***um*** from Fig.3(a). The depth of peat beds are different for the boring points in Fig.3(b). The peat beds are located at the peak points of arsenic concentration in the figure.

Fig.5 shows the thickness of ***um*** in the rice fields on the north of the residential area, which was measured in May 2000, together with that in the residential areas which had been obtained from the surveys in 1998-1999 (Bando et al., 1999; RGAG et al., 2000). The thickness is zero or less than 1 meter in the rice field on the north of the residential area, though it is thicker in the residential area: about 10 meters and several meters in the north and the south, respectively. The thickness of ***um*** in the rice field on the south of the residential area is several meters, too.

Fig.6 shows the concentration of arsenic in the rice fields on the north of the residential area, measured in May 2000, together with those in the residential area. In the rice fields on the north of the residential area, the arsenic concentration is all less than 0.05mg/l. This may be caused by the above-mentioned ***um*** thickness of zero or less than 1 meter in the rice fields on the north of the residential area.

Comparing Figs.6 and 2 with Fig.5, it is understood that the lower zone of arsenic concentration (As≦0.05mg/l) in the residential area in Figs.6 and 2 belongs to the thinner zone of ***um*** thickness in Fig.5. The thinner zone distributes from the northwest to the southeast on the north of the residential

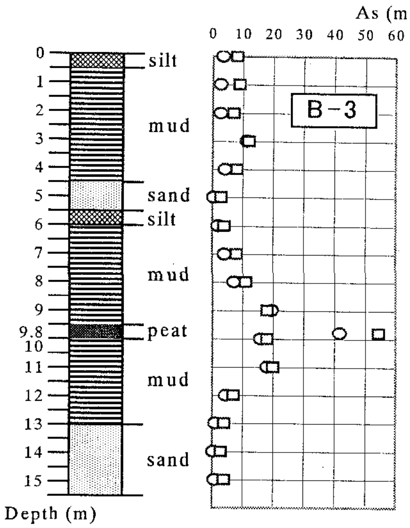

Fig.3 (a) Arsenic concentration for a boring sample by measuring the fluorescence X-ray analysis (□) and the chemical quantitative analysis (○)

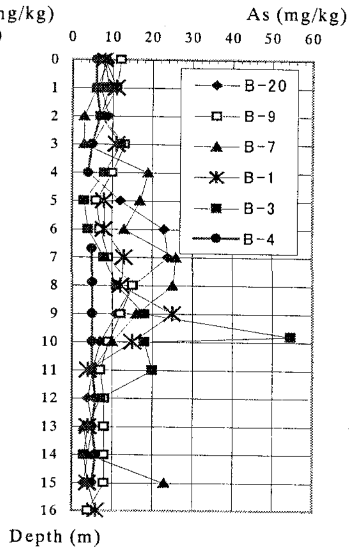

Fig.3 (b) Distribution of arsenic concentration at six boring points

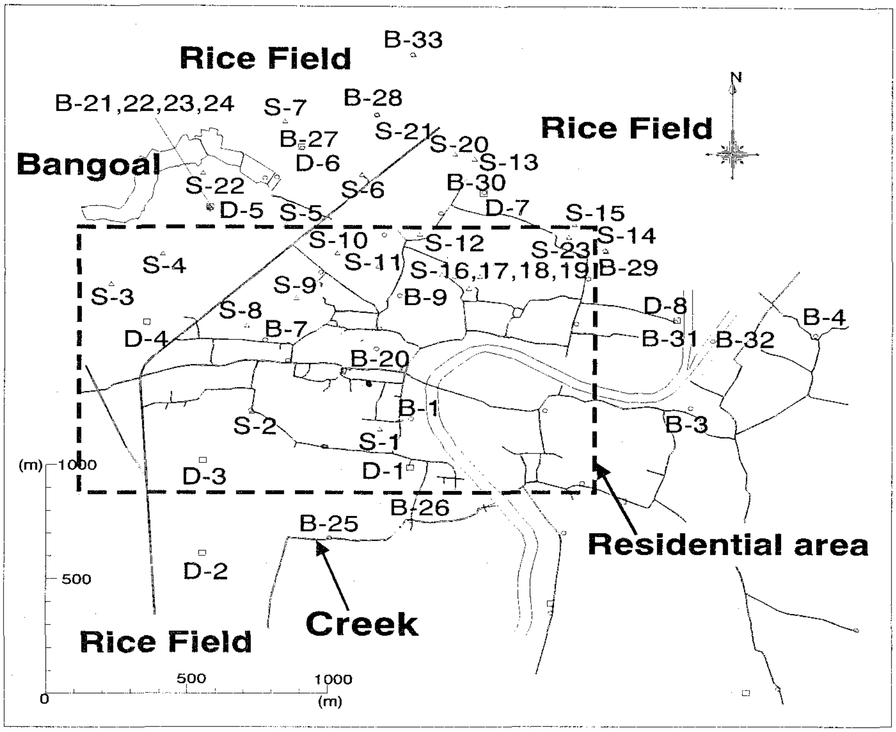

Fig.4 Locations of boring points, wells and residential area

area including the lake "Bangoal". And, it may be considered that the lower zone of arsenic concentration (As≦0.05mg/l) in Fig.6 distributes from the northwest to the southeast, too. The reason why the arsenic concentration was low at the north in the residential area in Fig.2 may be explained as above.

On the other hand, the higher zone of arsenic concentration in the south of the residential area in Fig.2 almost agrees with the zone of thicker ***um***. Accordingly, the first question why the arsenic concentration increases gradually from north to south is roughly explained by the thickness distribution of the ***um*** which often includes arsenic. The additional examination of the higher zone of arsenic concentration will be mentioned later in 2.4.

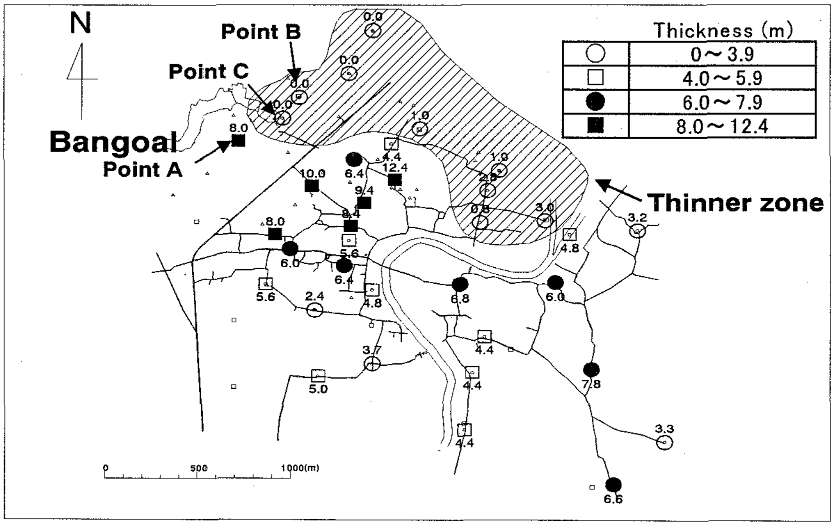

Fig.5 Distribution of thickness of upper muddy layer

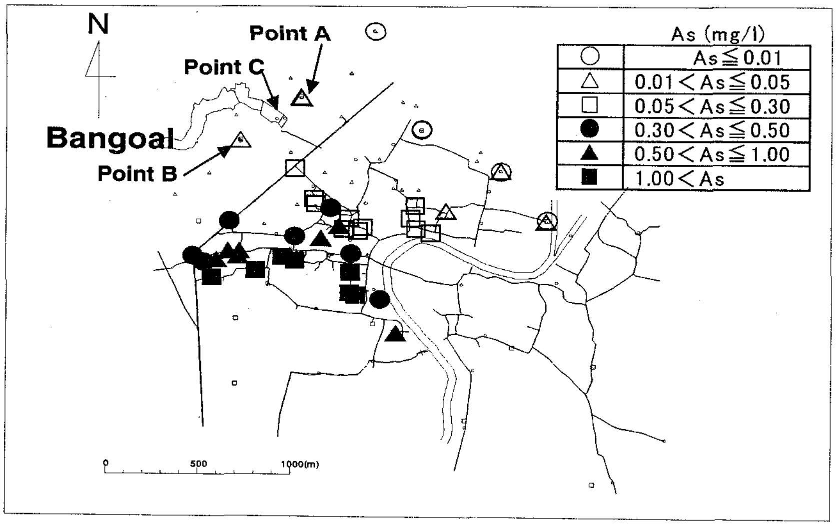

Fig.6 Distribution of arsenic concentration

2.3 Groundwater flow in Samta village

Fig.7 shows the contour lines of groundwater levels obtained by measuring the water level of 38 sample tube wells in the residential area in the dry season May 1998 (Yokota et al., 1999). From the contour lines it can be seen that groundwater flows from north to south, drifts at the low water table at the south in the residential area, and flows into the Betna river on the east.

On the other hand, from Fig.5 it is considered that the first aquifer, which is laid under ***um***, inclines down from north towards south. The reasons are considered as follows: 1) There is no existence of ***ums*** and ***umm,*** which lie on the ***um*** in the residential area, in the rice fields on the north of the residential area and the first aquifer is almost revealed at the ground surface. And 2) the depth to the surface of aquifer is a few meters in the north, more than 10 meters in the center and several meters in the south of the residential area (RGAG et al., 2000).

It may be said, therefore, the groundwater flow in Fig.7 is in harmony with the geological profile mentioned at 2.2. And, the drifting of groundwater in the south of the residential area, mentioned above, may be caused by the characteristics of distribution of ***um*** thickness, that is, the thickness is deeper in the center than in the south of the residential area.

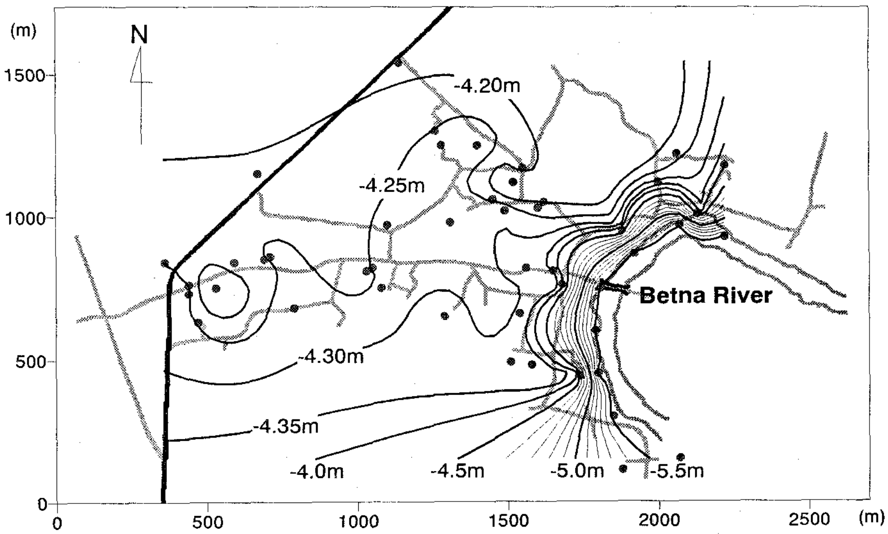

Fig.7 Contour lines of groundwater levels in dry season in Samta village (May 1998)

2.4 Distribution of trivalent and pentavalent arsenic concentration in the residential area

Fig.8 shows the distribution of trivalent and pentavalent arsenic concentration in the residential area measured in May 2000. The values, put down on left side of measuring points in the figure, show trivalent arsenic and the right ones pentavalent. These were measured by HPLC-ICP/MS. The boundary line, PQ, between the zone of the pentavalent arsenic and one of the trivalent arsenic is roughly drawn in Fig.8. It is characteristic of the arsenic distribution that arsenic exists in pentavalency at the north in the residential area, trivalent arsenic at the south. This means that groundwater is under oxidation condition at the north, under reduction at the center and south in the residential area.

It may be said that Fig.8 is in harmony with the distribution of depth of first aquifer, namely the downward inclination from north to south in Samta village. In the north, groundwater is under the condition of oxidation, because the aquifer is close to the ground surface. It may be, therefore, considered that the arsenic in the muddy layer is dissolved by oxidation of pyrite in the north as Prof. D. Chakraborti's theory (Das et al., 1995; 1996; Chowdhury et al., 1998), though the arsenic concentration is not so high.

On the other hand, towards the south from the border line, PQ, in the center and the south of the residential area, the condition of reduction may be considered as aquifer lies under the thick ***um*** at deeper level from ground surface as mentioned in 2.2. The flow of groundwater in the south of the residential area may express the state of reduction, too, because the aquifer is generally in the state of reduction when the flow of groundwater is under the condition of drifting as mentioned in 2.3. Under the state of reduction the pentavalent arsenic, which had precipitated with hydrous ferric oxide ($5Fe_2O_39H_2O$), could be reduced to the trivalent arsenic and released into groundwater (Nickson et al. 1998; 2000; Akai et al., 1999; Niigata University, As-contamination Research Group, 1999; 2000). The trivalent arsenic at the center and the south of Fig.8 shows the arsenic is released to groundwater under the state of reduction.

Comparing the distribution of arsenic concentration of Fig.2 with that of Fig.8, it could be seen that the higher arsenic zone (As$\geqq$0.3mg/l) in Fig.2 almost agrees with the trivalent arsenic zone of Fig.8. As the arsenic concentration is higher with trivalency at the major part (at the center and south) in the residential area, and lower with pentavalent at the minor part (at the north), it may be said that arsenic is dissolved mainly in the condition of reduction in Samta village. This is another explanation for the question with respect to the distribution of arsenic concentration in Fig.2.

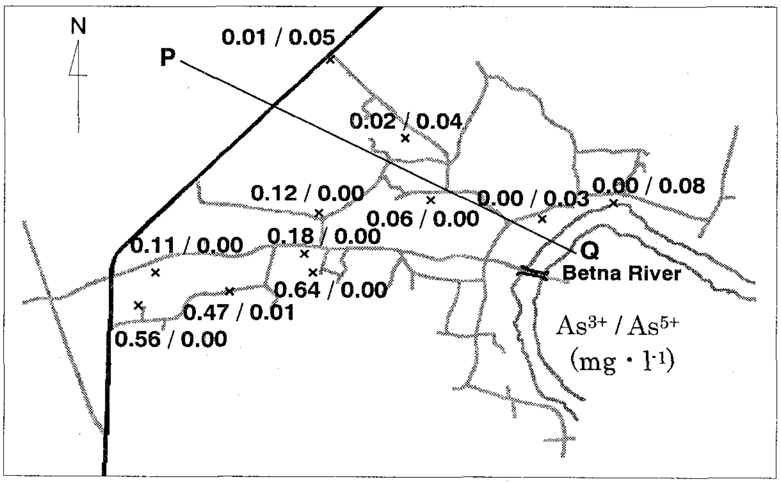

Fig.8 Distribution of trivalent and pentavalent arsenic concentration in the residential area in Samta village (May 2000)

3. Introduction to analysis of groundwater flow

Fig.9 shows the increasing of arsenic concentration in groundwater during pumping test at point A in Fig.5, which was obtained from a pumping well, D-5 and two observation wells, B-22, 24 (see Fig.4). D-5 is a deep irrigation well with depth of 85m used as the pumping well and B-22, 24 were installed as the observation wells after the boring tests with depth of 9.95m and 3.37m, respectively. From Fig.9 it is seen the concentration increases two times as large as the concentration before the pumping test. The arsenic concentration in groundwater is influenced by the flow of groundwater. The increase of arsenic concentration may be caused by advection and diffusion of arsenic through groundwater flow.

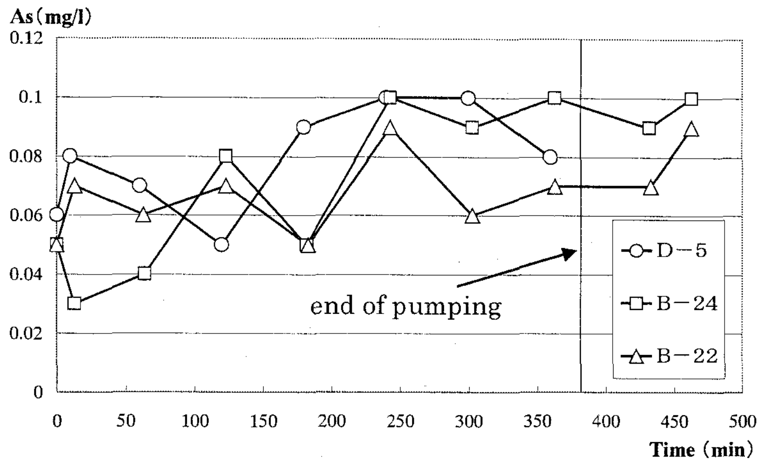

Fig.9 Increasing of arsenic concentration in groundwater during pumping test

The distribution of arsenic concentration of Fig.2 should be examined from the point of the advection and diffusion of arsenic through groundwater flow. It becomes, therefore, necessary to analyze numerically the groundwater flow through the advection and diffusion equation. Especially, the groundwater flow, caused by pumping the irrigation wells in dry season, may largely affect the arsenic concentration in groundwater, because the usual flow of groundwater is not so large in dry season as shown in Fig.7.

There are many irrigation wells in Samta village as shown in Fig.4: 8 deep tube wells (D-1~D-8) and 23 shallow tube wells (S-1~S-23). The capacity of pumping is large with 4tf/min of the deep tube well and 1tf/min of the shallow one. And, the large volume of groundwater has been pumped for 4 months a year during 10 or more years. It is considered the pumping of groundwater affects the distribution of arsenic concentration in Samta village.

We obtained the values of permeability coefficient, k and storativity, S, from the pumping test as shown in Table 2. Moreover, we measured the decreasing velocity of irrigation water in rice fields at the points A and B (see Fig.5), and obtained the values of the decreasing velocity caused by vertical infiltration from the bottom of rice field to groundwater. They are expressed as C1 and C2 for the points A and B, respectively, in Table 2, too. The hydrogeological data will be used for the numerical analyses of groundwater flow in our next research.

Table 2 Hydrogeological data for analysis of groundwater flow

permeability coefficient	storativity	decreasing velocity of irrigation water in rice field	
k (cm/sec)	S	C1	C2
0.05	0.002	0mm/h	10mm/h

At the area of thin ***um***, the major part of water in rice fields infiltrates vertically to the underground and the other part of water flows horizontally to "Bangoal" through the gradient of ground surface. At just north side of "Bangoal", point C in Fig.5, where the thickness of ***um*** was zero and the depth to the first aquifer was about 1 meter, the water seemed to go down to underground to recharge groundwater. The vertical circulation of water between groundwater and water in rice fields should be numerically analyzed with the data of Table 2 to obtain the more accurate mechanism for the arsenic contamination of groundwater in Bangladesh.

4. 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 followings were obtained as the results.

1) The new findings about arsenic concentration of groundwater in Samta village:
- a)Arsenic is highly included at peat bed in upper muddy layer which lies on the first aquifer in the residential area.
- b)The thickness of upper muddy layer is zero or less than 1 meter in the rice fields on the north of the residential area. In the residential area the thickness is a few meters in the north, about 10 meters in the center and several meters in the south.
- c) The arsenic concentration of groundwater is less than 0.05mg/l in the rice fields on the north of the residential area.
- d) The pentavalent arsenic is more detected compared with trivalent arsenic in the north of the residential area. Conversely in the south, the trivalent arsenic was more detected.

2) Examination about the characteristics of arsenic distribution in Samta village:
- a) The distribution of the upper muddy layer, mentioned in the conclusion 1.b), may support well the characteristics of arsenic concentration, that is, the high arsenic concentration in the south and the decrease of the concentration towards the north of the residential area. Especially, the low concentration in the north of the residential area, is verified by the conclusion 1.c).
- b) As the arsenic concentration is higher with trivalency for the major part in the residential area (at the center and south) and lower with pentavalent at the minor part (at the north), it may be said that arsenic is dissolved mainly in the condition of reduction in Samta village.

3) Analysis of groundwater flow

It was determineded that arsenic concentration of groundwater increased up to 2 times during the pumping test. It is, therefore, necessary to analyze numerically the advection and diffusion of arsenic in the groundwater, and some hydrogeological data were obtained for the analyses.

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