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ARSENIC REMOVAL MONITORING FROM GROUNDWATER IN A VILLAGE IN BANGLADESH WITH GUAVA METHOD

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Arsenic removal monitoring method, Guava Method, was developed using guava leaves and transparency meter as an appropriate technology. Field surveys were carried out in arsenic affected rural area in Bangladesh to identify the present situation of arsenic contamination which causes health problems. Groundwater quality was analyzed to identify the relationship between arsenic concentration and depth of tube wells. Sociological survey was also carried out to identify villagers' recognitions on arsenic contamination, willingness-to-pay for arsenic removal equipments. Demonstration of Guava Method to villagers showed their willingness-to-pay increase because of the visible change in the water color.

Key Words *: arsenic contamination in drinking water, Bangladesh, Guava Method, tube-well groundwater, willingness to pay (WTP)*

1. INTRODUCTION

In Bangladesh, arsenic contamination in drinking water is one of the environmental problems to be solved (Smith et al., 2000; Adeel, 2001). When we consider the economic level of the country and affordability of the utilities by households, appropriate technologies and systems should be important to be developed for sustainable development of villages in Bangladesh. Arsenic removal with appropriate technologies and simple monitoring methods should be necessary for villagers to obtain safe drinking water continuously. Pitcher Filter (PF) is one of the arsenic removal methods applied in villages in Bangladesh. PF is less costly and affordable by the villagers. Guava leaves contain tannin which react with iron to show black color. We have developed an arsenic removal monitoring methods, Guava Method, which can be considered to be an appropriate technology to monitor arsenic removal with arsenic removal plants because of its features applicable with materials available in rural area of Bangladesh (Wang et al., 2007a,b). Iron concentration is estimated from the color or turbidity of liquid after reaction with Guava leaves which include tannin. Arsenic and iron have characteristics of co-sedimentation. We use these function of tannin, iron and arsenic to monitor removal of arsenic in drinking water.

We have investigated arsenic pollution situations in a ordinary village, and surveyed people's thoughts on economic and social conditions of the village lives including awareness on arsenic pollution (Wang et al., 2007a,b). We have selected the village because the village is in a highly arsenic affected zone and no NGO or no other suitable organizations has activity in the village.

This paper is mainly based on Wang et al. (2007a,b) with some minor modification including the explanation of PF and water sources in the village. We have developed Guava Method to monitor arsenic removal (1) to estimate directly iron concentrations before and after arsenic removal plant treatment and to estimate indirectly arsenic removal rate, and (2) to find arsenic contamination situations in an ordinary village in Bangladesh. Moreover, we have surveyed alternation of people's recognition on willingness to pay (WTP) for arsenic removal plants and on drinking water arsenic contamination by introducing Guava Method to the villagers.

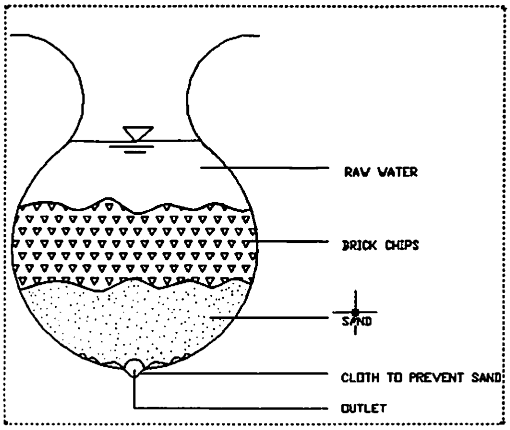

Fig. 1 Cross section of a pitcher filter

2. GUAVA METHOD

(1) Theory of Guava Method and arsenic removal with arsenic and iron removal plants (AIRP)

Guava Method uses a reaction of tannin and iron which shows black color (Kitawaki, 2005). Tannin is a general term for chemicals which are contained in plants as soluble materials, combine strongly with proteins, alkaloids and metal ions and form insoluble salts. In an excess tannin condition, iron reacts with tannin to form suspended materials. The iron concentration is measurable with transparency.

In arsenic and iron removal plants (AIRP), which are generally used in Bangladesh, arsenic is trapped to hydro oxidized iron floc and removed with sand filtration. The desirable features of AIRP are simple method to obtain lower arsenic concentration drinking water, and simple maintenance and operation. PF is more simple method to remove arsenic with ceramics which can be obtained in rural area (**Fig. 1**). Arsenic and iron are removed simultaneously. Arsenic removal can be monitored by monitoring iron concentration reduction with Guava Method. The arsenic removal estimation formulas were found by Ahmed and Rahman (2000) and Ahmed and Ahmed (2002) as shown in eqs. (1) and (2).

$$y = 0.8718\,x + 0.4547 \quad (1)$$

$$Asr = 87.18\,(Fe_i - Fe_0) / Fei + 0.4547 \quad (2)$$

where x: iron removal rate (%), y: arsenic removal rate (%), Asr: arsenic removal rate (%), Fe_i: iron content in raw water (mg l^{-1}) and Fe_0: iron content in treated water (mg l^{-1}).

(2) Measurement of tannin in Guava leaves

In the literatures, such data can be found as tannin contents in the leaves are twice in Spring, poly-phenol contents changed quantitatively and qualitatively by seasons. The results of tannin measurement with Lowenthal-Proctor-Method (Yamanishi, 1969) (**Fig. 2**) showed tannin contents in 2.5 g of Guava leaves change slightly by seasons. We have considered the results as almost constant in a year in this study.

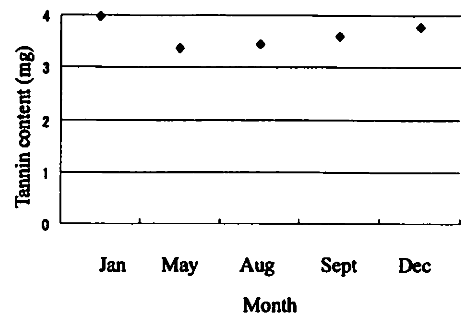

Fig. 2 Tannin content in 2.5 g Guava leave (Nakatani and Kitawaki, 2003)

(3) Arsenic and iron removal

Iron concentration is larger as well as arsenic concentration in Bangladesh. Iron concentration of groundwater is more than 2 mg l^{-1} in 65% tube-well samples in Bangladesh and largest ones are more than 15 mg l^{-1} (Ahmed and Ahmed, 2002). The relationships between iron and arsenic concentrations in tube-well samples are arsenic concentrations are below the drinking water standard (0.05 mg l^{-1}) in almost all samples under 1 mg l^{-1} iron concentration, arsenic concentrations of 50% samples are below the drinking water standard in tube-well samples in 1-5 mg l^{-1} iron concentration, and arsenic concentrations of 75% samples are over the drinking water standard in tube-well samples above 5 mg l^{-1} iron concentration. Iron sediment, $Fe(OH)_3$, which is formed by oxidation of iron solution, $Fe(OH)_2$, shows affinity of absorption of arsenic. PF and AIRP were developed applying these characteristics of iron and arsenic. Meng et al. (2001) found more than 40 ratio of iron and arsenic concentration in pre-treatment drinking water is necessary to remove arsenic to the concentration below 0.05 mg l^{-1} considering interference reaction under the existence of bicarbonate, silica, phosphorus and sulfate ions. The study results by Sugimura et al. (2001) found that the ratio of iron and arsenic concentrations in pre-treatment tube-well groundwater was below 40 when arsenic concentration in treated water with AIRP was above 0.4 mg l^{-1}. They estimated a reason for large arsenic concentration as absorption of arsenic to iron was

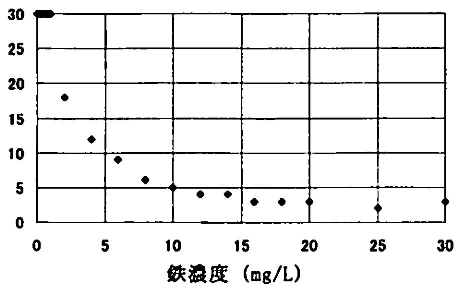

Fig. 3 Iron concentration and transparency (Nakatani et al., 2001)

not enough derived from lower iron concentration in pre-treatment water.

Eqs. (1) and (2) shown above show that iron concentration difference between pre-treatment and after-treatment drinking water leads to estimate iron removal ratio.

(4) Preparation of Guava leaves extraction

Guava leave extraction method was as the followings. Guava leaves powder are prepared first and boiled in water to make weight measurement easy, to keep tannin concentration in reaction liquid to certain level, and to make measurement conditions to be the same.

(i) Dry Guava leaves at 100 °C for 30 minutes. Remove leafstalks and leafveins and refine the leaves with a mortar into powder.

(ii) Boil 2.5 g Guava leave powder prepared in (i) with 40 ml of water for 30 minutes, add water up to 50 ml. Filtrate leaves.

(5) Reaction of iron and Guava leaves

5 ml of Guava leaves extraction was added to 250 ml of groundwater samples, and transparency was measured with a transparency meter (**Fig. 3**). Transparency decrease was observed with iron concentration increase.

(6) Guava Method procedures

Guava method procedures based on the above theory and experimental results in this study are as the followings:

(i) Preparation of Guava leave extraction

Guava leave extraction powder is prepared as described in "(4) Preparation of Guava leaves extraction". The extraction can be preserved for one to several weeks in pet bottles at room temperature.

(ii) Sample volume

Sample volume is 250 ml, which is suitable for measurement with a transparency meter of 30 cm height.

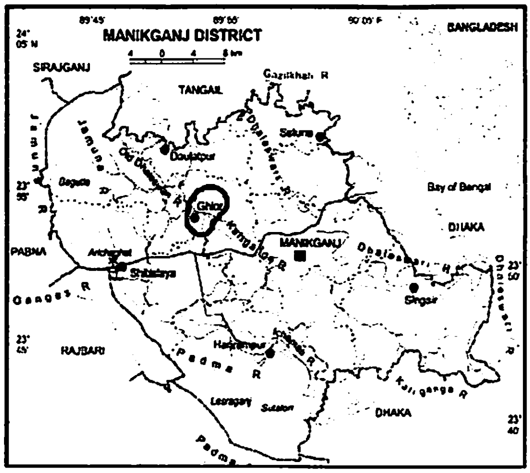

Fig. 4 Study site (Wang et al., 2007b)

(iii)Reaction of samples with Guava leave extraction

Add 5 ml of Guava leave extraction to 250 ml of sample and stir slightly.

(iv)Measurement of transparency

Transparency is measured with a transparency meter immediately after reaction.

(v) Estimation of iron and arsenic removal rate

Iron concentration is estimated from a measured transparency and the relationships shown in **Fig. 2.** Arsenic removal ratio is estimated from both iron concentrations in pre-treatment and after-treatment water samples applying eqs. (2).

(7) Guava Method features

Only materials which can be obtained in a village in Bangladesh are used in Guava method. The color reaction is apparent for ordinary people, and effects of people's awareness and WTP increase can be anticipated by introducing demonstrations of Guava method in a village. Other merits of Guava method includes smaller cost, available anytime and easily operated by ordinary people. Even poorer people in a village can operate Guava method. Transparency measurement can be conducted with glass cups and newspaper when a transparency meter is not available.

3. ARSENIC POLLUTION SITUATIONS IN AN ORDINARY VILLAGE AND APPLICATION OF GUAVA METHODS

(1) Study site

Field surveys were conducted in September and December in 2005, August in 2006 and January in 2007 to find arsenic contamination situations and

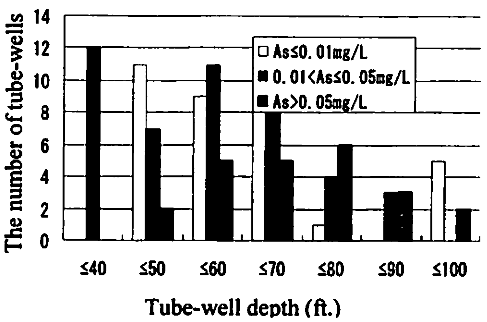

Fig. 5 Arsenic concentration distribution by depth of tube-wells (Wang et al., 2007a)

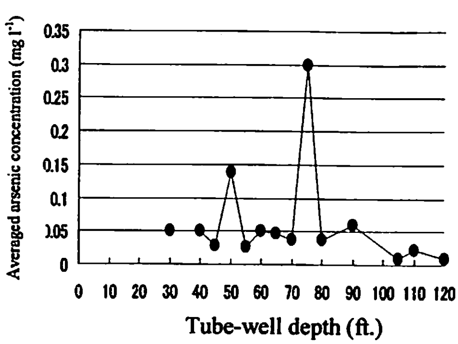

Fig. 6 Tube-well depth and averaged arsenic concentration (Wang et al., 2007a)

effects of Guava Method demonstration on people's recognition on drinking water arsenic pollution and WTP in a rural area village in Bangladesh, Baikuthapur village, Ghior county (thana), Manikganj District (**Fig. 4**). The population of the village was about 800 person. Occupation of 64% of villagers was farmer. Illiteracy rate was 47%, people with elementary education was 33%, the number of tube-wells was 103, the number of toilets was 78, and the number of Bari, larger family system, was 96. PO_4-P, Mn and pH were monitored for all the tube-wells in the village during the field survey with Pack Tests ® (Kyoritsu Chemical Laboratory), and arsenic and iron concentrations were monitored with an arsenic and iron measurement kit (HACK co. ltd.). The arsenic concentration of the tube-well drinking water was monitored in rainy season, August in 2006. Tube-well distribution map was prepared using GPS measurement data.

(2) Arsenic contamination in the village

Arsenic concentration by the depth of tube-wells showed that the ratio of tube-wells with more than 0.05 mg l^{-1} arsenic concentration was larger for the tube-wells with 70~80 ft. (21~24 m) depth (**Fig. 5**). The ratio with less than 0.01 mg l^{-1} arsenic concentration, drinking water standards of WHO and Japan, was larger for the tube-wells with more than 100 ft. (30 m) depth. Most of arsenic concentrations of the shallow tube-wells with less than 50 ft. (15 m) were found to be less than the Bangladesh standards, 0.05 mg l^{-1}, all the arsenic concentrations of the tube-wells less than 40 ft. (12 m) depth were found to be less than the Bangladesh drinking water standards. The relationship between the tube-well depth and arsenic concentration did not show clear correlation (**Fig. 6**).

(3) Water supply sources in the village

The Kaliganga River flows 2 km north of the village. Brief communication with villagers suggested some portions of cooking water were obtained from the river because of their taste. River water and pond water in the village were applied for bathing and washing clothes. There was one simple digging well, which was not used for the drinking water purpose. Drinking water source is only the tube-wells.

(4) Distribution of wells and arsenic concentration

Arsenic concentration distribution in the tube-wells (**Fig. 7**) shows 35% (36 tube-wells) of arsenic concentrations of the tube-wells was below 0.01 mg l^{-1}, 37% (38 tube-wells) was 0.01~0.05 mg l^{-1}, 24% (25 tube-wells) was 0.05~0.1 mg l^{-1} and 4% (4 tube-wells). The ratio of tube-wells satisfying the Bangladesh standards was 68%, whereas that above the standards was 32%. The geographic distribution of arsenic concentration in the tube-well groundwater showed that severer arsenic contamination in District C. Tube-wells in District A and B were lesser contaminated and those in District C and D were moderately contaminated. Lesser arsenic contamination in District B implied the effect of the river water. Total number of the tube-wells with more than the Bangladesh standards and that with less than the standards were almost the same. Arsenic concentration depends on the groundwater depth, geological conditions, geographic areas, seasons and year (Ueno, 2003).

(5) Water quality alternation with pitcher filter (PF)

Pitcher filter (PF) was found to be operated for arsenic removal from drinking water in Baikuthapur village. The number of PF has increased during the field survey: three in December, 2005, five in August, 2006, and eight in January, 2007. There are three types of PF, i.e. one-stage type, two-stage type and three-stage type. Water quality of influent and effluent of each one of the three types of PF was

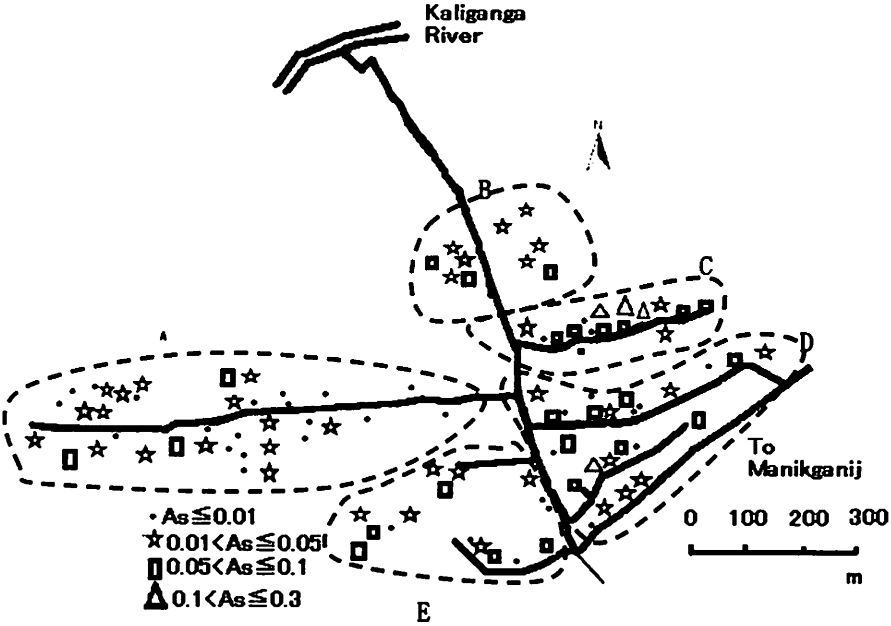

Fig. 7 Tube-well distribution and arsenic concentration in Baikunthapur village, Bangladesh (Wang et al., 2007b)

monitored in this study. Water quality parameters monitored in this study were pH, iron (Fe), arsenic (As), manganese (Mn), phosphate (PO_4-P), transparency of Guava Method and water temperature. Fe and As were monitored with the arsenic and iron measurement kit.

The measurement results of pH, Fe, As and transparency of Guava Method were shown in **Figs. 8-11**. pH and transparency increased, and Fe and As decreased with the treatment with PF. Fe removal rate was 67% for one-stage PF, 83% for two-stage PF and 90% for three-stage PF, respectively. As removal rate of one-stage PF was 38%, that of two-stage PF was 54%, and that of three-stage PF was 96%, respectively. The alternation patterns of Fe, As and transparency of Guava Method had similarity, which suggested the appropriateness of applying Guava Method to monitor iron and arsenic removal with the method.

(6) Arsenic and iron removal with PF

Soluble iron concentration is known to decrease when groundwater is kept in oxidation environment, i.e. in air. We have monitored Fe, As and transparency alternation of groundwater in the oxidation environment (**Fig. 12**). Fe concentration decreased with time whereas As concentration increase at first and decreased with time. Transparency of Guava Method increased with time. Groundwater is recommended to drink immediately after drawing from tub-wells (e.g. UNICEF) to prevent bacterial contamination, however, to keep a few hours in the oxidation environment was considered to be appropriate from the point of view of arsenic removal when arsenic removal plants are not available.

Relationship between iron and arsenic removal rates was analyzed based on the monitored data in rainy season, August, 2006, and in dry season, January, 2007 (**Fig. 13**). The ratio of iron and arsenic removals was about 40:1, which was similar to the results in Sugimura et al. (2002). They suggested the ratio with more than 40:1 in raw groundwater is necessary for after-treatment drinking water to satisfy the Bangladesh arsenic standard of drinking water, 0.05 mg l^{-1}.

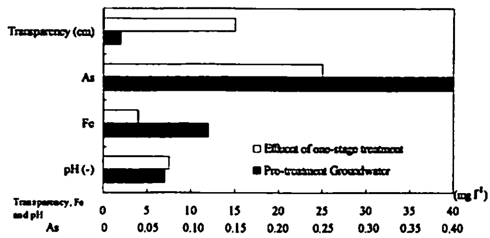

Fig. 8 Water quality changes in one-stage PF (Wang et al., 2007b)

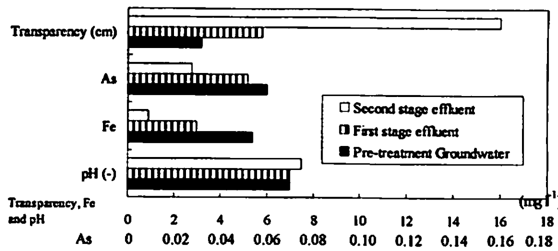

Fig. 9 Water quality changes in two-stage PF (Wang et al., 2007b)

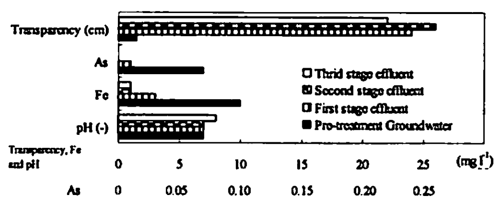

Fig. 10 Water quality changes in three-stage PF (Wang et al., 2007b)

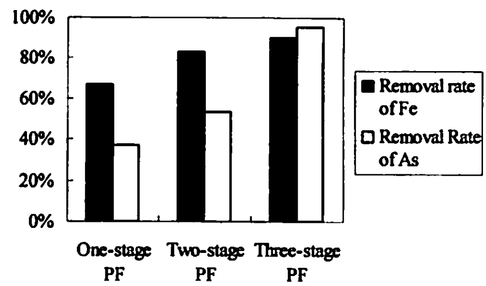

Fig. 11 Fe and As removal with PF (Wang et al., 2007)

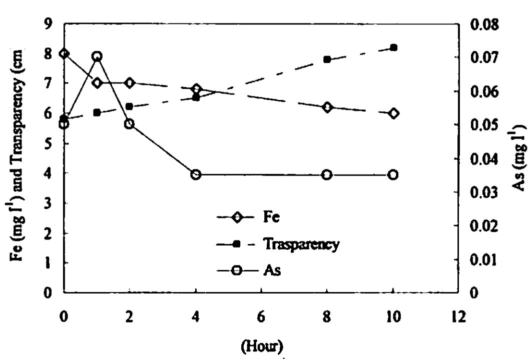

Fig. 12 Hourly change of Fe, As and transparency of Guava Method of raw groundwater in oxidation environment (Wang et al., 2007b)

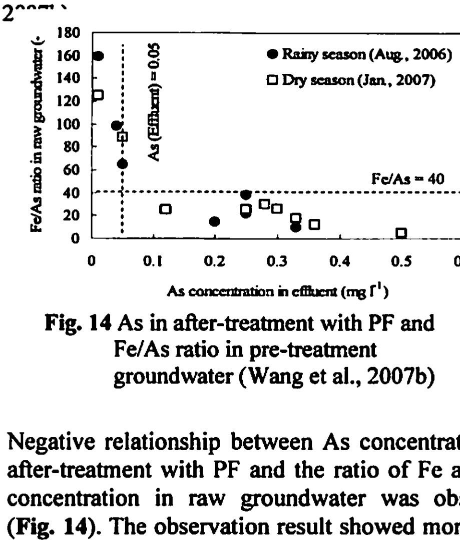

Fig. 14 As in after-treatment with PF and Fe/As ratio in pre-treatment groundwater (Wang et al., 2007b)

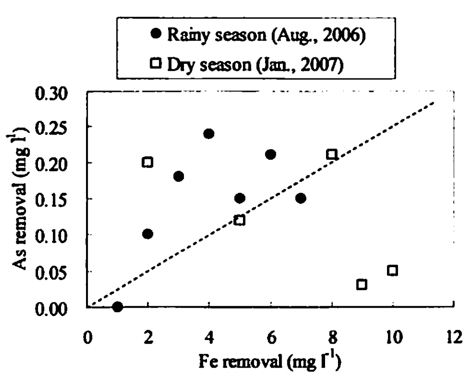

Fig. 13 Relationship between Fe and As removals (Wang et al., 2007b)

Negative relationship between As concentration in after-treatment with PF and the ratio of Fe and As concentration in raw groundwater was observed (**Fig. 14**). The observation result showed more than 40:1 is required to decrease As concentration below the Bangladesh standard. The result corresponded to Sugimura et al. (2002).

4. EFFECTS OF GUAVA METHODS IN THE VILLAGE ON THE PEOPLE'S THOUGHTS

(1) Study method of social survey

Guava method which shows visibly ordinary people change of color might psychologically

Table 1 Attributes of targeted people of the questionnaire survey in the village (Wang et al., 2007b)

Age \ Sex	Male	Female	Total
Under 20	16	24	40
20 - 40	33	42	75
40 - 60	13	36	49
Over 60	7	5	12
Total	69	107	176

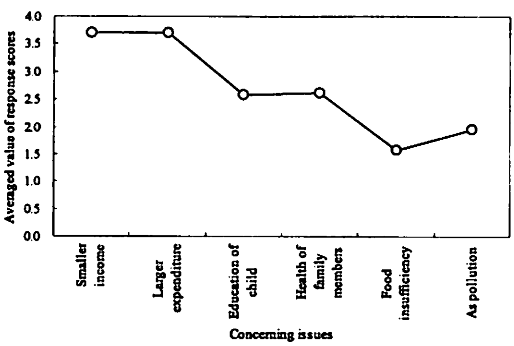

Fig. 15 Concerning issues of the villagers (Wang et al., 2007b)

impact the recognition of arsenic pollution problem in drinking water. The impact might increase people's awareness to the arsenic problem and WTP to arsenic removal plants. Questionnaire survey was conducted to monitor recognitions by the villagers on arsenic pollution. Attributes of the targeted people in the village is shown in **Table 1**. The number of participants in the questionnaire survey was 176 persons.

(2) People's awareness on arsenic contamination

The villagers were interested in (1) small amount of income, (2) large expenditures, (3) education of children, (4) hygiene health of family members, (5) insufficient food, and (6) arsenic pollution, in the order (**Fig. 15**). The averaged points of seven-glade answers for each item were compared in **Fig. 15**.

(3) Alternation of people's awareness on arsenic pollution by Guava Method demonstrations

Almost all villagers were found to have some knowledge on arsenic pollution, however, their recognition of the arsenic pollution was not so severe. The reasons for the lower recognition were considered to be (1) arsenic is no-taste and no-smell and hard to recognize in daily lives, (2) arsenic diseases are chronic and hard to recognize in a short period. We surveyed people's thoughts on arsenic contamination by demonstrating Guava Method with

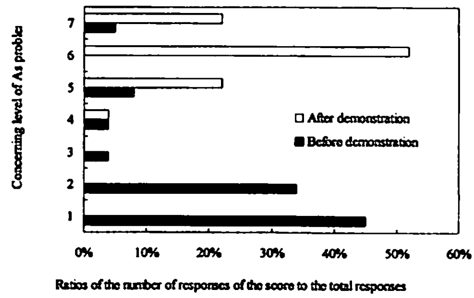

Fig. 16 Recognition change by demonstration of Guava Method with PF (Wang et al., 2007b)

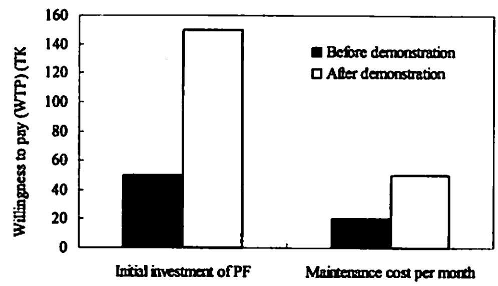

Fig. 17 WTP change by demonstration of Guava Method with PF (Wang et al., 2007b)

PF treatment of groundwater. The people's recognitions were found to be changed from points 1-2 to points 5-7 by the demonstration (**Fig. 16**). The result showed that demonstration of Guava Method change the people's recognition on arsenic pollution.

(4) Alternation of willingness to pay (WTP) by Guava Method demonstrations

We have monitored WTP change for PF by the demonstration of Guava Method (**Fig. 17**). WTP for an initial investment cost of arsenic removal plants increased from 50 TK to 150 TK (1TK was almost equal to 2 JPY). The actual initial cost of PF was 150~250 TK. WTP for maintenance cost of arsenic removal plants increased from 10 TK month^{-1} to 50 TK month^{-1}. People's WTP was found to be increased by introducing Guava Method demonstration.

5. CONCLUSIONS

We have developed an appropriate technology for arsenic contamination problem on drinking water, Guava Method to monitor arsenic removal from drinking water. Field surveys and questionnaire survey with demonstration of Guava Method in a ordinary village found the following conclusions:

(1) Arsenic concentration in groundwater depended on tube-well depth, averaged arsenic concentration by the depth of tube-wells ranged 0.01-0.3 mg l^{-1}, and largest concentration was observed for the tube-wells with 70-80 ft. (21-24 m).

(2) Horizontal distribution of arsenic concentration in the village was monitored and illustrated in a map;

(3) PF was found to be effective to remove arsenic from drinking water. More than two-stage PF was found to be necessary to have appropriate drinking water quality of arsenic in the village; and

(4) Guava method demonstration was found to change villagers' recognition on arsenic contamination problem in drinking water and to increase villagers' WTP for initial investment and maintenance costs of arsenic removal plants.

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REFERENCES

1) Adeel Z. (2001) Policy Dimensions of the Arsenic Problem in Bangladesh, Bangladesh University of Engineering & Technology, pp.270-277.
2) Ahmed, M.F. and Ahmed, C.M. (2002) Arsenic mitigation in Bangladesh, An outcome of the International Workshop on Arsenic Mitigation in Bangladesh Dhaka, Local Government Division Ministry of LGRD &Co-operatives Government of the People's Republic of Bangladesh, pp.14-16, 2002.
3) Ahmed, M. Feroze and Rahman, Md. Mujibur (2000) Rural Supply & Sanitation, ITN-Bangladesh, June 2000.
4) Kitawaki, H. (2005) Arsenic removal monitoring manual with Guava Method, Bulletin of Regional Development Studies, Toyo University.
5) Meng X.G., Klrfiatis G., Christodoulatos C. and Bang S. (2001) Treatment of arsenic in Bangladesh well water using a household co-precipitation and filtration system, Water Research, Vol.35, No.12, pp.2805-2810, 2001.
6) Nakatani, T. and Kitawaki, H. (2003) Groundwater arsenic contamination in Bangladesh, Master thesis at Toyo University, pp.55-56. (in Japanese)
7) Nakatani, T., Kitawaki, H., Yamamoto, K. and Sugimura, N. (2001) Development of arsenic removal method from groundwater with Guava leaves, Proceedings of 29th Annual Meeting of Environment System Research, pp.101-104. (in Japanese with English abstract)
8) Smith A.H., Lingas E.O., Rahman M. (2000) Contamination of drinking-water by arsenic in Bangladesh: a public health emergency, Bulletin of the World Health Organization, pp.78-79.
9) Sugimura, M., Fukushi, K. and Yamamoto, K. (2002) Arsenic removal plants for arsenic contaminated groundwater in Bangladesh, 57th Annual Meeting of Japan Society of Civil Engineers, pp.27-27. (in Japanese)
10) Ueno, N. (2003) Broaden arsenic contamination in Asia, Asia Arsenic Network, pp.37-40. (in Japanese)
11) Yamanishi, T. (1969) Domestic science experiment series No.3, *Sangyo Tosyo*, pp.215-216. (in Japanese)
12) Wang, B., Kitawaki, H. and Rahman, M.M. (2007a) Water supply and arsenic contamination in rural area of Bangladesh, Proceedings of 8th annual Spring Meeting of International Development Society, 105-108. (in Japanese)
13) Wang, B., Kitawaki, H. and Rahman, M.M. (2007b) A study of arsenic remocal monitoring from groundwater in Bangladesh using "Guava Method", Environmental Engineering Research, Vol.44, 407-416. (in Japanese with English abstract)

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