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# Performance Evaluation of Existing Community Level Arsenic Removal Plants for Arsenic Free Drinking Water Supply in Jessore and Jhenidah Districts of Bangladesh

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**Abstract:** The use of groundwater as drinking water in Bangladesh is favoured by its easy availability, microbial safety and absence of proper infrastructure for treatment and distribution of surface water. As a result, millions of people are affected by widespread arsenic poisoning through drinking water drawn from underground sources containing arsenic at concentrations well above the permissible limit of 50µg/L. Since 2000, hundreds of community level arsenic removal plants have been installed in the south-west region of Bangladesh. However, the performance of the plants over time is hindered by lack of information due to the absence of long term water quality monitoring information. The objective of this study is to evaluate the performance of existing community level arsenic removal plants. In this study, we selected five arsenic removal plants (four plants were Arsenic Iron Removal Plant, namely AIRP; and one Granular Ferric Hydroxide Based Arsenic Removal Unit, namely SIDKO) located in Jessore and Jhenidah district. All AIRPs and SIDKO achieved the Bangladesh standard for arsenic in drinking water of 50µg/L. The AIRPs removed 64% of influent arsenic on average. However, the SIDKO removed 80 % of influent arsenic. Treated water quality parameter (such as pH, EC, TDS, $PO_4^{3-}$, As, $NO_3^-$) of the plants were within the WHO standards, except $NH_3$ (0.01-1.89 mg/L) and $Fe^{++}$ (1.0 – 1.21 mg/L) for long term uses.

**Keywords:** Arsenic Contamination, Arsenic Removal Plants, Drinking Water

## 1. Introduction

Arsenic is a toxic, poisonous and cancer-causing metalloid, which is ubiquitous in rock, soil and water [1]. High concentrations of arsenic in groundwater have been found in many environmental conditions originating from natural processes and from anthropogenic sources. Natural occurring arsenic in ground waters associated with geothermal activity is recognized to be significant [2]. In Bangladesh alone, 57 million people are exposed to arsenic levels of up to 3200µg/L [3], well in excess of the maximum contaminant level (MCL) recommended by the World Health Organization of 10µg/L [4]. Recent measurements show that in many parts of the Ganges and Brahmaputra basin more than 60% of the shallow and deep tube well water contains arsenic above the WHO guideline value of 10µg/L and more than 30% of the tube wells contains arsenic above the Bangladesh standard of 50µg/L [5, 6]. Long term exposure to low concentrations of arsenic has been reported to cause cancer of bladder, skin and other internal organs [7]. The health hazard caused by drinking arsenic affected water can be prevented by drinking arsenic free water because the biological half-life of arsenic appears to be between ten hours and four days [8].

Drinking As-free water is the best option for health hazard protection and this options are, surface water treatment by low-cost methods, drinking water from deep aquifers, rainwater harvesting, and treatment of As contaminated tube-well water etc. All these options require major technological innovation in water supply except the latter one, through which huge number of tube-wells likely abandoned can easily be revitalized. Methods for removal of As from water have been highlighted in a number of papers [9, 10, 11, 12, 13]. The arsenic removal technologies can be grouped into the following four categories: Coagulation and filtration, Sportive filtration, Oxidation and sedimentation, Membrane filtration [9, 10, 11]. In the process of coagulation and flocculation, arsenic is removed from solution through three mechanisms: Precipitation: The formation of insoluble compounds, Co-precipitation: The incorporation of soluble arsenic species into a growing metal, hydroxide phase, Adsorption: The electrostatic binding of soluble arsenic to external surfaces of the insoluble metal hydroxide [14].

During the last few years a number of low-cost household As removal technologies in context of Bangladesh have been developed [15, 16, 17, 18, 19] and some field based evaluation have also been done and some evaluation has already done [20, 21, 22, 23]. In this study, evaluate the performance of two indigenous Arsenic removal plants namely Arsenic Iron Removal Plant (AIRP), and SIDKO arsenic removal plant. The evaluation method was conducted by measuring water chemistry parameters such as pH, Nitrate ($NO_3^-$), Iron (Fe++), Phosphate ($PO_4^{3-}$), Ammonia ($NH_3$), Total Dissolved Solid (TDS), Arsenic (As), and Electrical Conductivity (EC), finally these parameters were compared with WHO drinking water standard.

# 2. Materials and Methods

## *2.1. Overview of the Investigated Plants*

### *2.1.1. Arsenic Iron Removal Plants (AIRPs)*

The conventional small-community type iron removal plants [Fig. 1], which operate on the principles of aeration of ferrous iron to convert them to ferric iron to co-precipitate arsenic. Groundwater has drawn by hand tube -well drops into storage (aeration/ sedimentation) chamber for oxidation of iron and arsenic with air to co-precipitate. Water from storage chamber passes through filtration chamber due to the pressure head of aeration/ sedimentation chamber and subsequently collected into a storage tank for public uses. Filtration media comprises of brick chips, charcoal and sands. Filtration media is periodically (3 to 4 times a year) back washed, and sludge is collected in a holding pond [24].

### *2.1.2. SIDKO Arsenic Removal Plant*

Granular ferric hydroxide (AdsorpAs®) is a highly effective adsorbent used for the adsorptive removal of arsenate, arsenite, and phosphate from natural water. It has an adsorption capacity of 45g/kg for arsenic and 16 g/ kg for phosphorus on a dry weight basis. M/S Pal Trockner (P) Ltd, India, and SIDKO Limited, Bangladesh, have installed several granular ferric hydroxide-based arsenic removal units in India and Bangladesh. The proponents of the unit claim that AdsorpAs® has very high arsenic removal capacity, and produces relatively small amounts of residual spent media. The typical residual mass of spent AdsorpAs® is in the range of 5–25 $g/m^3$ of treated water. The typical arrangement of the SIDKO/Pal Trockner unit [Fig. 2] requires aeration for oxidation of water and pre-filtration for removal of iron flocs before filtration through active media. Chemi-Con and Associates has developed and marketed an arsenic removal plant based on adsorption technology in which crystalline ferric oxide is used as an adsorbent. The unit has a pre-filtration unit containing manganese oxide for oxidation of As (III) to As (V) and retention of iron precipitates [25].

***Figure 1.*** *Arsenic Iron Removal Plant (AIRP).*

***Figure 2.*** *SIDKO arsenic removal plant.*

## *2.2. Sample Collection, Preparation and Analysis for Arsenic and Other Parameters Estimation*

### *2.2.1. Sample Collection*

Water samples were collected from randomly selected Arsenic Iron removal Plant (AIRP), and SIDKO Arsenic removal plants installed at Jhenidah and Jessore District (Detail in Table -1).

### *2.2.2. Sample Preparation*

For the arsenic and iron test 2 ml conc. $HNO_3$ acid was mixed with 100ml sample water and the rest samples water (400 ml) was kept for testing other parameters.

### *2.2.3. Sample Analysis*

Arsenic was estimated by Atomic Absorption Spectrophotometer [(Shimadzu (Japan) Model: - AA-6200 Range: - 0.01 to 10 ppb (As)]. Nitrate ($NO_3$) was estimated by Cadmium reduction Method from HACH DR/2010 spectrophotometer, USA, Range: 0 – 4.5 mg/L ($NO_3$). Phosphate ($PO_4^{3-}$) and Ammonia ($NH_3$) was estimated by the Powder pillows method no: 8048, and Powder pillows method no: 8038 from HACH DR/2700 spectrophotometer, USA. Range: 0.02-2.50 mg/L. Iron ($Fe^{++}$) was estimated by Atomic Absorption Spectrophotometer, Shimadzu (Japan) Model:- AA-6200 Range:- 0.01 to 05.00 ppm ($Fe^{++}$). Total Dissolve Solids (TDS) and Electrical Conductivity (EC) were estimated by Electrode method from HACH Sension -156 multi parameter. USA Model: 156. Electrode Model: 51975. Electrode type: Conductivity probe combination with temp. pH (Hydrogen Ion Concentration) was estimated by MARTINI instruments, pH 56 $p^H$WP.

***Table 1.*** *Sample collection system and location in the study area.*

| Sampling location | | | Sampling point | Selected plants name |
|---|---|---|---|---|
| **District** | **Upazilla** | **Union** | **Village** | |
| Jhenidah | Kaligonj | Barabazar | Majdhia village | AIRP1, AIRP2, AIRP3 |
| Jessore | Jessore sadar | Churamonkati | Shymnagor village | SIDKO |
| Jessore | Chugacha | Phulsara | Phulsara village | AIRP4 |

District= Districts are the first tier of the administrative unit of local government in Bangladesh.
Upazilla= Upazilas are the second lowest tier of the administrative unit of local government in Bangladesh.
Union= Union is the third lowest tier of an official administrative unit of local government in Bangladesh.
Village= Village is the lowest tier of an official administrative unit of local government in Bangladesh.

#### *2.2.4. Qualitative Filed Survey*

A defined questionnaire was used among 80 users for knowing about plants and drinking water related information.

## 3. Results and Discussion

### *3.1. Performance of Two Arsenic Removal Plants*

The Arsenic removal efficiency of SIDKO was better (80%) than AIRP1 and AIRP2 (70.50%) and (78.62%) but in case of Iron removal AIRP1 (86.16%) and AIPR2 (85.25%) is comparatively good then SIDKO (17.14%) because iron removal process was occurred due to oxidation process Fe (II) to Fe (III) by bacteria and dissolved oxygen in the water. In SIDKO raw water iron concentration was very low than AIRP1 and AIRP2 for these reasons its removal efficiency was low. In case of arsenic removal AIPR3 (61.82%) and AIRP4 (44.44%) is lower than other plants due to lower operation and maintenance and poor performance of plants media. For total dissolved solid and electric conductivity removal, the performance of SIDKO (28.73%) was higher than other AIRP plants (18.93%, 6.67%, 1.93%, and 14.39%) because the concentration of total dissolved solid and electric conductivity in raw water was low. Based on examination of raw water in laboratory, known that the concentration of total solid in raw water in these installations already meet the requirement of drinking water quality standard. In case of pH all plants were removed negatively because the pH of the treated water increased by one unit, possibly a result of decarbonation. This is also evident from the decrease in bicarbonate concentration. Except AIRP2 (13.30%) plant, other plants AIPR1 (76.38%), AIRP3 (97.87%), AIRP4 (95.23%) and SIDKO (93.75%) performance was good for Ammonia removal and in case of Nitrate removal AIRP1 (66.44%), AIRP3 (99.56%) and SIDKO (89.47%) was good because the Nitrate elimination process is carried out by microorganisms through nitrification process but AIRP2 (-66.11%) was negatively removed due to irregular cleaning of plants media increase ammonia aeration as a results nitrate concentration are increased in treated water.

For phosphate removal SIDKO (84.11%) was good, but the other AIRP plants performance was very low. Irregular cleaning of plant media, lower operation and maintenances is responsible for these performances. As per recommendation, AIRP and SIDKO must be subjected to thorough washing after every one month, but the field observation result represent that most of the AIRP user clean their plant after 6 months sometime it occurred after one year on the other hands SIDKO plant user clean it after 3 month and sometime after 6 months. So washing more or less frequently than the recommended intervals may hamper the efficiency of the plants. The observed removal efficiency of these plants cannot be sustained with erratic maintenance and the users must be made aware of it.

### *3.2. Drinking Water Quality Parameters*

Treated water quality parameter (such as pH, EC, TDS, As, $NO_3^-$, $PO_4^{3-}$) of these two plants were within the WHO standards, except $NH_3$ (0.01-1.89 mg/l) and $Fe^{++}$ (1.0 – 1.21) for long term uses (Table 2).

***Table 2.*** *Comparison of drinking water quality parameters of SIDKO and AIRPs with World Health Organization (WHO).*

| Plants Name | Parameters | WHO standard | Raw water | Treated water | Plants Name | Parameters | WHO Standard | Raw water | Treated water |
|---|---|---|---|---|---|---|---|---|---|
| AIRP1 | $P^H$ | 6.5-8.5 | 7.84 | 8.11 | AIRP1 | Electric Conductivity (EC) µs/cm | 2000 µs/cm | 751 | 809 |
| AIRP2 | | | 8.14 | 8.29 | AIRP2 | | | 720 | 672 |
| AIRP3 | | | 8.16 | 8.33 | AIRP3 | | | 621 | 808 |
| AIRP4 | | | 7.84 | 8.36 | AIRP4 | | | 847 | 727 |
| SIDKO | | | 8.07 | 8.08 | SIDKO | | | 1085 | 775 |
| AIRP1 | Iron ($Fe^{++}$) mg/L | 0.3-1.0 mg/L | 3.91 | 0.54 | AIRP1 | Total Dissolved Solid (TDS) mg/L | 1000 mg/L | 375 | 304 |
| AIRP2 | | | 3.12 | 0.46 | AIRP2 | | | 360 | 836 |
| AIRP3 | | | 1.0 | 1.21 | AIRP3 | | | 311 | 305 |
| AIRP4 | | | 0.30 | 0.30 | AIRP4 | | | 424 | 363 |

| Plants Name | Parameters | WHO standard | Raw water | Treated water | Plants Name | Parameters | WHO Standard | Raw water | Treated water |
|---|---|---|---|---|---|---|---|---|---|
| SIDKO | | | 0.35 | 0.29 | SIDKO | | | 543 | 387 |
| AIRP1 | | | 0.19 | 0.26 | AIRP1 | | | 1.27 | 0.30 |
| AIRP2 | | | 0.3 | 0.45 | AIRP2 | | | 2.18 | 1.89 |
| AIRP3 | Phosphate ($PO_4^{3-}$) mg/L | 5-6 mg/L | 0.71 | 0.46 | AIRP3 | Ammonia ($NH_3$) mg/L | 0.5 mg/L | 0.47 | 0.01 |
| AIRP4 | | | 0.11 | 0.22 | AIRP4 | | | 1.26 | 0.06 |
| SIDKO | | | 1.07 | 0.17 | SIDKO | | | 0.32 | 0.02 |
| AIRP1 | | | 7.45 | 2.5 | AIRP1 | | | 130.5 | 38.5 |
| AIRP2 | | | 4.25 | 7.06 | AIRP2 | | | 203.5 | 43.5 |
| AIRP3 | Nitrate ($NO_3^-$) mg/L | 45 mg/L | 2.25 | 0.01 | AIRP3 | Arsenic (As) µg/L | 50µg/L For Bangladesh | 27.5 | 10.5 |
| AIRP4 | | | 0.01 | 0.3 | AIRP4 | | | 9 | 5 |
| SIDKO | | | 1.9 | 0.2 | SIDKO | | | 20 | 4 |

### *3.3. Correlation Studies*

Interrelationship studies between different water quality parameter are very helpful in understanding the geochemistry of the study area. The regression equation for the parameter having significant correlation of other constitutes. The correlation table 3 indicates that TDS-EC: 0.9999, Arsenic-iron: 0.8837 and $Fe^{++}$ - $NO_3^-$: 0.9413 are strongly positive correlated and ammonia-arsenic: 0.0.8257 is moderately positive correlated (Table 3). The correlation table 4 indicates that TDS - $NO_3^-$: 0.9015, $NH_3$ - $NO_3^-$: 0.9801, TDS - $NH_3$: 0.9643 and, As - $NO_3^-$: 0.8773 are strongly positive correlated and $Fe^{++}$ - $PO_4^{3-}$: 0.7156, $NH_3$ – As: 0.7731 is moderately positive correlated (Table 4).

***Table 3.*** *Karl Pearson correlation matrix for raw water samples in the study area.*

| | pH | $Fe^{++}$ (mg/L) | $PO_4^{3-}$ (mg/L) | $NO_3^-$ (mg/L) | EC (µs/cm) | TDS (mg/L) | $NH_3$ (mg/L) | As (µg/L) |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| $Fe^{++}$ (mg/l) | -0.1311 | 1 | | | | | | |
| $PO_4^{3-}$ (mg/l) | 0.6179 | -0.4939 | 1 | | | | | |
| $NO_3^-$ (mg/l) | -0.1472 | 0.9413 | -0.2684 | 1 | | | | |
| EC (µs/cm) | -0.1770 | -0.4654 | 0.4852 | -0.3224 | 1 | | | |
| TDS (mg/l) | -0.1749 | -0.4695 | 0.4870 | -0.3267 | 0.9999 | 1 | | |
| $NH_3$ (mg/l) | -0.1203 | 0.6376 | -0.7523 | 0.3509 | -0.3742 | -0.3763 | 1 | |
| As (mg/l) | 0.1487 | 0.8837 | -0.4205 | 0.7235 | -0.3878 | -0.3911 | 0.8257 | 1 |

***Table 4.*** *Karl Pearson correlation matrix for treated water samples in the study area.*

| | pH | $Fe^{++}$ (mg/L) | $PO_4^{3-}$ (mg/L) | $NO_3^-$ (mg/L) | EC (µs/cm) | TDS (mg/L) | $NH_3$ (mg/L) | As (µg/L) |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| $Fe^{++}$ (mg/l) | 0.3466 | 1 | | | | | | |
| $PO_4^{3-}$ (mg/l) | 0.5542 | 0.7156 | 1 | | | | | |
| $NO_3^-$ (mg/l) | 0.0599 | -0.1941 | 0.4899 | 1 | | | | |
| EC (µs/cm) | -0.4228 | 0.4905 | -0.2119 | -0.6929 | 1 | | | |
| TDS (mg/l) | 0.2102 | -0.2651 | 0.4660 | 0.9015 | -0.8771 | 1 | | |
| $NH_3$ (mg/l) | 0.1761 | -0.1707 | 0.5470 | 0.9801 | -0.7826 | 0.9643 | 1 | |
| As (mg/l) | -0.1325 | -0.0232 | 0.4398 | 0.8773 | -0.3029 | 0.5853 | 0.7731 | 1 |

### *3.4. Distance and Collection Time for Drinking Water Collection from Water Source and Households*

Maximum collectors are close to plant location within one half kilometer (69%) (See Fig. 3), as a result, their collection time and travelling distance are reduced, about 76% households require less than 15 min for drinking water collection (Fig. 4).

### *3.5. Most Important Issues for Drinking Water Selection*

Proper selection of drinking water is necessary for keeping good health. In the study area 84% households choose arsenic free water, 10% households choose collection time and distance and 6% households choose good test as the main criteria for their drinking water source selection (Fig. 5).

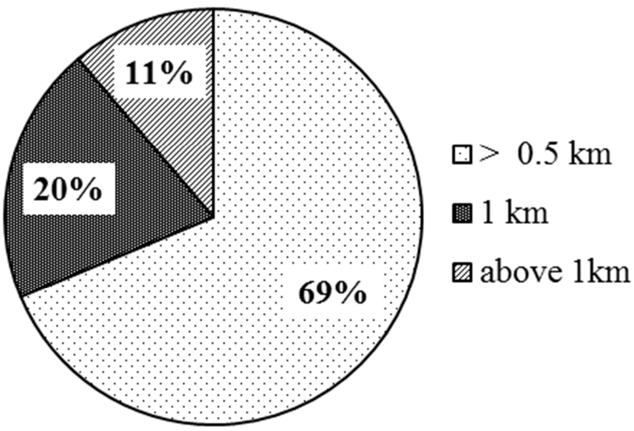


***Figure 3.*** *Drinking water collection time.*

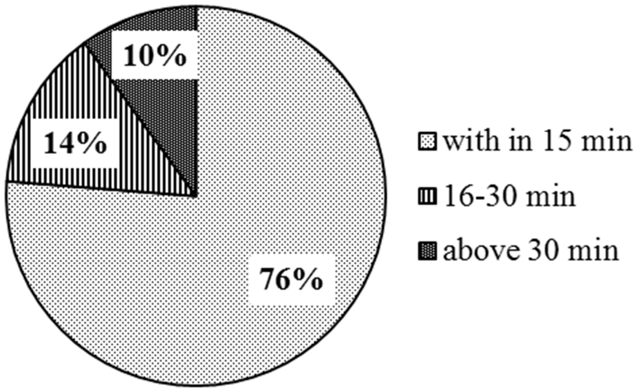


*Figure 4. Distance between source and households.*

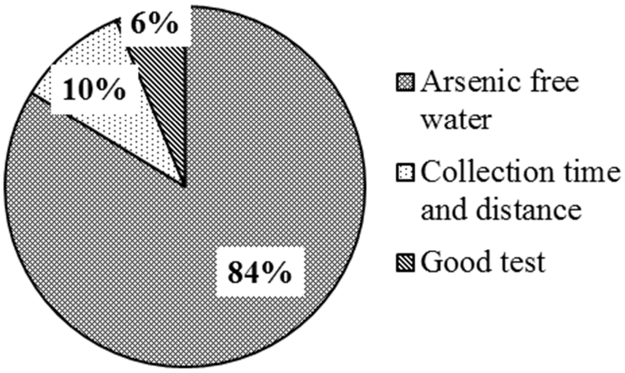


*Figure 5. Most important issues for drinking water selection.*

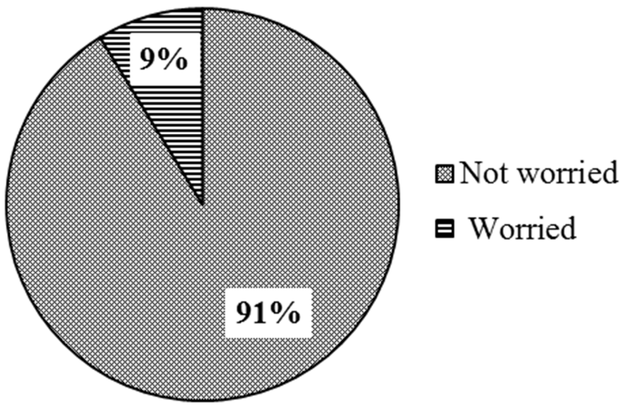


*Figure 6. Worriedness about Arsenic at present drinking water sources.*

### *3.6. Worriedness About Arsenic at Present Drinking Water Sources*

According the field survey result about 91% households (Fig. 6) said they are not worried about their present drinking water uses because they think that it is properly treated by this plants and arsenic disease are not see after using it. On the other hand, 9% households are worried about arsenic because they think that arsenic removal is not possible by these simple plants.

## 4. Conclusion

Many people in the study area relied on either AIRP or SIDKO arsenic removal plant because studied areas is highly arsenic affected. Performance of the AIRP and SIDKO arsenic removal plant is somewhat dependent on the operation, maintenance and continuous monitoring. Removal efficiency of SIDKO is better than AIRP because it is newly constructed and its operation and maintenance occurs regularly. All of those performances are satisfactory because each plant fulfilled the criteria of WHO drinking water quality standard. Qualitative field survey result represent that in the study area most of the households (84%) choose arsenic free water for their drinking water sources selection and at present they are not worried (91%) about arsenic contamination. Due to the reduction of collection time and distance it acceptability are increased. For attaining its success and ensuring safe drinking water in long future different types of government and non-government should come forward for creating awareness or consciousness among local community about the proper operation and maintenance of existing Arsenic removal plants.

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