PERFORMANCES OF ARSENIC REMOVAL FILTERS IN BANGLADESH GROUNDWATER

A.K.M Golam Murtuz(1), Mosfera Alam Chowdury(2) and Nadim R. Khandaker(1).

[1]Military Institute of Science and Technology, Mirpur Cantonment, Dhaka-1216.
[2]University of Information technology and Science, Jamalpur tower (Tower 2), Baridhara View, GA 37/1, Progoti Sharani, Baridhara J Block, Dhaka-1212

Abstract:
Bangladesh is a country where arsenic contamination of potable groundwater is a public health problem. In response to the arsenic problem, arsenic removal filters are being installed in arsenic affected communities to provide arsenic free water. This paper reports on the performances of five arsenic filters that are currently being marketed in Bangladesh. The filters are based on arsenic removal by ion exchange on to synthetic resins, adsorption onto metal oxyhydroxides, and the use of zero valent iron to remove arsenic by precipitation and co-precipitation followed by filtration. The five technologies were evaluated in different regional groundwater chemistries of Bangladesh. The evaluation program showed that the volume of arsenic contaminated water, an arsenic removal filter can treat is dependent on the quality of the groundwater. The inorganic phosphate content of the ground water to a great extent determined the life of the filters. In one particular regional ground water where all arsenic removal filters tested had short run lives had high total inorganic phosphate and pH greater than 7.5.

Keywords: *Arsenic; Bangladesh; Arsenic removal filter performance.*

1.0 NTRODUCTION:

Millions of people in Bangladesh are drinking arsenic contaminated groundwater (Khandaker and Brady, 2002). The affected populations are developing symptoms of chronic arsenic poisoning (UNICEF, 2000). Clearly there is an urgent need to provide cost effective arsenic removal systems to the affected communities. Based on this need different companies have started to manufacture and market arsenic removal water filters in Bangladesh. The objective of this paper is to report the results of an evaluation program carried out to evaluate the performance of the five more common arsenic removal water filters being marketed in Bangladesh. The intention of the evaluation program was to see that if variations in ground water chemistries would affect the performance of different arsenic removal filters. Performance dependent on ground water chemistries would call for extensive monitoring programs, an expensive proposition for a developing country such as Bangladesh.

The arsenic removal technologies that are being used in Bangladesh can be categorized into two sizes. Household units that serve the cooking and drinking requirements of a single family and small community unit that serve the cooking and drinking needs of ten or more families (Figure 1). The typical household water requirement for a rural Bangladeshi family of five for their cooking and drinking water needs is around 35 to 40 L of water. The description of the five technologies that were evaluated is described below. For the sake avoiding conflict of interest the names of the filter manufacturers will not be divulged but will be referred based on their active adsorption media or chemical ingredient.

This study reported in this paper for the first time evaluated the performance of arsenic removal technologies with the chemical characteristics of regional Bangladesh groundwater. The findings will enhance the successful implementation of arsenic filters in Bangladesh as a mitigation tool.

1.1 Ion-Exchange (IX) multiple household filter: The active ingredient in the IX arsenic removal filter is an anion exchange resin. Before filtration by the ion exchange media an oxidant is added to the source water and passed through gravel filled contact chamber where oxidation of the arsenic (III) to the charged form of arsenic, arsenic (V) occurs. After the contact chamber the water passes by gravity through a bed of anion exchange resin that removes the negatively charged arsenic (V) species in the water by ion exchange.

1.2 The hydrous cerium oxide (HCO) filter for single household use: The (HCO) filter consists of a prefabricated plastic shell containing a proprietary media designed to remove arsenic. The filter is a pour through filter with water flowing downwards through the filter bed. The HCO filter has a layer of sand on top of the media bed to remove turbidity and iron fouling. The process of arsenic removal by the filter is by adsorption onto hydrous cerium oxide grains.

1.3 Ferric coated activated alumina (FAA) arsenic removal filter for a single household use: The FAA filter consists of two plastic buckets placed in series on top of each other containing ferric-coated activated alumina media. The water poured into the system flows downward through the filter media. The arsenic in the raw water is removed by adsorption onto the ferric coated activated alumina media.

1.4 Granular ferric hydroxide based (GFH) small community system: Granular ferric hydroxide is used as the active ingredient for arsenic removal. The system consist of a sand pre-filter bed which remove turbidity and iron fouling, followed by the bed of granular ferric hydroxide which is the active ingredient that removes arsenic by adsorption.

1.5 Zero valent iron based (ZF) filter single household use: The ZF filter is based on the use of zero valent iron as the source of the active ingredient for arsenic removal. The filter consists of two plastic buckets in series placed on top of each other. The top bucket contains a top layer of sand followed by a layer of iron filing, and a bottom layer of sand. The bottom bucket consists of layers of sand and charcoal. The top sand layer in the top bucket serves as a pre-filter to remove turbidity and iron fouling. The iron-filing layer serves as the source for the active ingredient hydrous ferric oxide, which removes arsenic by the process of precipitation, co-precipitation, and adsorption. The subsequent sand and charcoal layers remove the arsenic rich solid iron hydroxide by filtration.

2.0 DESCRIPTION OF THE EVALUATION PROCESS:

In five different geological regions of Bangladesh suspected of having different ground water chemistries one unit each of the five arsenic removal filters being evaluated were installed. The wells at which the filters were installed were selected having total arsenic concentration around 300 ppb. Geological surveys conducted in Bangladesh report that only 5.1 percent of the arsenic contaminated wells in Bangladesh have concentrations higher than 300 ppb of arsenic (British Geological Survey, 2000). Thus choosing wells with concentrations around 300 ppb would be a worst-case scenario in terms of arsenic concentration likely to be faced by technology earmarked for Bangladesh arsenic mitigation. Once installed the arsenic removal filters were operated according to the manufacturers operating instruction, and at predetermined sampling frequencies both influent and effluent samples were collected and analyzed. For the water samples collected pH, total iron, and conductivity were measured immediately after sampling using field test kits. Laboratory analysis was done on the collected water samples for total arsenic, ratio of arsenic (III) to arsenic (V), total inorganic phosphate (reported as elemental P), silicates, and sulfates. Attempt was made to pass sufficient volume of water to attain breakthrough but due to logistical constraints it was not possible to attain breakthrough for all the units of the arsenic removal filters deployed. Breakthrough was defined as the effluent arsenic concentration exceeding the Bangladesh maximum contaminant level of 50 ppb.

3.0 RESULTS AND DISCUSSION:

Table 1 summarizes the quality of the ground water where the arsenic removal filters were evaluated. The water quality parameters that are reported in Table 1 are known to influence performance of arsenic removal technologies. The data in Table 1 is the average of the wells used in filter evaluation program in each of the five test regions.

The data in Table 1 indicates that the ground water chemistry varied regionally. Of note is the variation in the concentration of elemental P in the well water. The groundwater also had high TDS, with the presence of iron and silicate. The pH of the ground waters was near neutral except for one region, Hajigonj where the average pH of the well waters was the filters were tested was 7.7. As mentioned earlier the design of the experiment called for choosing wells in with concentration of arsenic around 300 ppb. Also of interest is the ratio of arsenic (III) to arsenic (V) in Table 1. The data shows that majority of the arsenic in the well waters where the technologies were tested were in the form of arsenic three.

The performance of the five different arsenic removal technologies in different regional groundwater is shown in Figures 2 through 6. The evaluation program showed that the volume of water that a filter can effectively treat below 50 ppb of arsenic (Government of Bangladesh Maximum Contaminant Level) varied between regional ground waters.

The ion exchange filter, IX is designed to serve a cluster of up to ten families had the worst performance of all the treatment systems in all regional ground waters (Figure 2). The IX small community filter could only treat 5847 liters of water in Nawabganj, the region where the system produced the maximum volume of treated water. This would satisfy the needs for ten families for only thirteen days and then the filter media would have to be regeneration. Frequent regeneration calls for added expense that the rural populations of Bangladesh can ill afford and not to mention of the required proper disposal of the regeneration water, which would contain high concentration of arsenic and sodium chloride.

The less than optimal performance of the ion exchange filter may be due to the high total dissolved solids (TDS) of the Bangladesh ground water and presence of phosphates and silicates in the ground water where the technologies were tested (Table 1). Figure 2 also shows that there was a correlation between decrease in ion exchange filter life and the concentration of total inorganic phosphate (reported as elemental P) in the groundwater. Literature reports that ion exchange systems for arsenic removal will not work in waters with TDS approaching 500 mg/L and competitive ions like phosphates and silicates can affect the life of ion exchange applications for arsenic removal (Clifford, 1999).

The metal oxides and hydroxide-based arsenic filters arguably performed substantially better than the ion exchange resin based filter IX. The hydrous cerium oxide based household (HCO) filter performed the best (Figure 3). Even in Hajigonj where the HCO filter media attained the fastest breakthrough the filter was able to produce 7778 liters of arsenic safe water thereby satisfying the cooking and drinking water needs of a family for six months. In many of the regions tested the filter media did not attain breakthrough for the filter monitoring period. In Faridpur the HCO filter could produce 53,280 liters of arsenic safe water without even attaining media breaking-through for the duration of performance monitoring. The volume of water produced would satisfy the cooking and drinking water needs of a rural Bangladeshi family for over three years. Clearly the performance of HCO filter is encouraging. As the case with the IX system there is a correlation between the HCO filter life and the amount of phosphate present in the groundwater. Figure 3 shows the performance of the HCO filter in the different regional ground waters along with the correlation between the decreases in filter life with increase in phosphate (reported as elemental P) in the groundwater.

The ferric coated activated alumina (FAA) household arsenic removal filter also showed its potential to remove arsenic from Bangladesh groundwater with variable performance. Except for one unexplainable total failure in performance in Manikganj, the range of volume of water an (FAA) filter could produce before attaining breakthrough 2,061 liters in Hajigonj to 8,451 liters in Faridpur (Figure 4). This would meet the cooking and drinking water needs for a rural Bangladeshi family from 45 days in Hajigonj to 187 days in Faridpur. The variability in performance of the FAA filter in different regions definitely points to the sensitivity of the FAA system to variations in regional groundwater chemistry. Correlating performance with total inorganic phosphate (reported as elemental P) shows that there is a definite correlation with decrease in the filter life with the increase in inorganic phosphate in the groundwater.

The maximum volume of arsenic free water the small community granular ferric hydroxide (GFH) based arsenic removal system could produce was 238,156 liters of water in Nawabganj (Figure 5). This would only satisfy the demands of 50 families for 106 days. The performance of the GFH unit was significantly lower in other regions, the lowest being in Hajigonj, where the unit could only treat 27,537 liters of water before media breakthrough occurred. This would only serve the cooking and drinking water needs for fifty families for twelve days. Again as the case with the ferric-coated activated alumina filter FAA the GFH filter was sensitive to the concentration of phosphate (reported as elemental P) in the groundwater (refer to Figure 5). Higher the phosphate concentration lower was the life of the filter.

The indigenous zero valent iron (ZF) filters also performed well except for the unexplainable aberration in Hajigonj (Figure 6). In Hajigonj groundwater the ZF filter unit failed badly, producing only 251 L of water, which would only meet the needs of a rural Bangladeshi family for 5 days. But in all other regions the performance of the ZF filter was encouraging. In Nawabganj where the breakthrough of the ZF filter occurred during the experimental monitoring period, the ZF filter could produce 8320 liters of water or satisfy the needs of a single family for 184 days. In other regions the ZF filter exceeded the performance in Nawabganj. The good performance of the ZF filter can be attributed to the combined mechanism of co-precipitation and adsorption on to the hydrating ferric oxide solids. Literature reports that coagulation using metal salts followed by microfiltration systems generally remove more arsenic in a mole of coagulation basis than by adsorption onto the metal oxide or hydroxide alone (McNeill and Edwards, 1997). As the case with the arsenic removal filters in the study the ZF filter performance was sensitive to the presence of inorganic phosphate (reported as elemental P) in the groundwater. Increase in groundwater concentration of total inorganic phosphate showed a definite correlation in the decrease in filter life (refer to Figure 6).

A plus of the ZF filter is that it is a technology developed in Bangladesh using locally available materials. For all other arsenic removal technologies discussed the adsorption media has to be imported.

An important point to note is that the minimum working life of all arsenic removal technologies occurred in Hajigonj. The least volume of arsenic contaminated water could be treated in Hajigonj before attainment of breakthrough. The Hajigonj groundwater (Table 1) had high total inorganic phosphorous levels; compounding this, was the high pH of the groundwater (pH = 7.7), along with silicates. Phosphates, silicates and even uncharged phosphorous and silica in colloidal form are known to reduce the arsenic capacity of most arsenic removal technologies (Clifford, 1999; McNeill and Edwards, 1997; Chwirka et al., 2000). The charged phosphates and silicates compete with arsenic for the existing adsorption sites and colloidal phosphorous and silica coat the surface of the adsorption media thereby restricting the surface available for arsenic removal. Also metal oxides and hydroxides at higher than neutral pH is associated with reduce arsenic removal capacity (Clifford, 1999; McNeill and Edwards, 1997; Chwirka et al., 2000). This is probably due to the reduction in the density of positively charged sites. As pH of the groundwater approaches the point of zero charge pH of the metal oxides and hydroxides the positive surface charge density decreases significantly, thereby decreasing the arsenic removal capacity (Chwirka et al., 2000).

Table 1 along with literature on groundwater chemistry of Bangladesh reports that at high groundwater arsenic concentrations the predominant arsenic species in Bangladesh groundwater is arsenic (III) (British at adversely Geological Survey, 2000). Arsenic (III) species below a pH of 9.2 is uncharged. Although arsenic (III) is removed by metal hydroxides by adsorption the efficiency and the absorption capacity is less than that for arsenic (V) (Clifford, 1999; McNeill and Edwards, 1997; Chwirka et al., 2000). Thus oxidizing the groundwater water prior to adsorption to convert the uncharged arsenite species to negatively charged arsenate ions could increase the capacity of the filters deployed in Bangladesh.

An important caveat of the whole evaluation process is that the arsenic removal technologies were evaluated at wells with arsenic concentration around 300 ppb, a threshold concentration value exceeded by only 5.1 percent of the wells in Bangladesh. In fact 84 percent of the wells in Bangladesh have concentrations between 5 to 100 ppb and at lower arsenic concentrations the more of the dissolved arsenic is in the form of charged arsenic V species (British Geological Survey, 2000). This implies that there is a definite possibility that at lower arsenic concentrations than 300 ppb the filter lives could be longer and economically more attractive.

4.0 CONCLUSION:

The performances of the arsenic removal technologies are dependent on the groundwater chemistry. Application of ion exchange technology in Bangladesh may be limited due to the high content of TDS in the Bangladesh groundwater. In regions of Bangladesh with high pH, and high total inorganic phosphorous the volume of water an arsenic removal technology can treat is greatly reduced.

Based on the conclusions of this study as a future scope of work cost- effective phosphate and iron removal filters need to be developed to prolong arsenic filter life in areas of Bangladesh with high phosphate that drastically reduces the life of arsenic removal filters.

References:

[1] British Geological Survey. 2000. Arsenic contamination of groundwater in Bangladesh: Volume 2. Final Report. WC/00/19.

[2] Chwirka, J.D., Thomson, B.M., and Stomp III, J.M. 2000. Removing arsenic from groundwater. Journal of American Water Works Association. 92(3): pp. 79-88.

[3] Clifford, D.A. 1999. Ion exchange and inorganic adsorption. In: Water quality and treatment. A handbook of community water supply. 5th Edition. McGraw-Hill INC. Washington D.C. pp. 9.1-9.91.

[4] Khandaker, N.R. and Brady, P.V. 2002. Finding a safe water arsenic concentration. Chemical and Engineering News. February 11. pp 2.

[5] McNeill L.S. and Edwards, M. 1997. Predicting arsenic removal during metal hydroxide removal. Journal of American Water Works Association. 89(1): pp. 75-84.

[6] UNICEF Bangladesh media brief; 2000. UNICEF Bangladesh, BCComplex, 1 Minto Road, Dhaka, Bangladesh.

Table 1. Selective groundwater quality parameters of the regional aquifers where arsenic removal filters were evaluated.

Region	As Total (mg/L)	As(III)/As_{total}	pH	TDS (mg/L)	[illegible] (mg/L)	Sulfate (mg/L)	Silicate (mg/L)	Iron (mg/L)
Bera	356	0.8	7.2	261	3.6	0	32.8	12.0
Hajigonj	421	0.6	7.7	255	8.8	0	23.8	2.4
Manikganj	499	0.7	7.3	497	0	0	21.5	11.4
Nawabganj	670	0.8	7.2	266	1.8	0	26.0	5.0
Faridpur	295	0.8	7.2	409	1.0	0	19.2	8.3

Fig 1. Pictures of household and community level arsenic removal filters being used in rural Bangladesh.

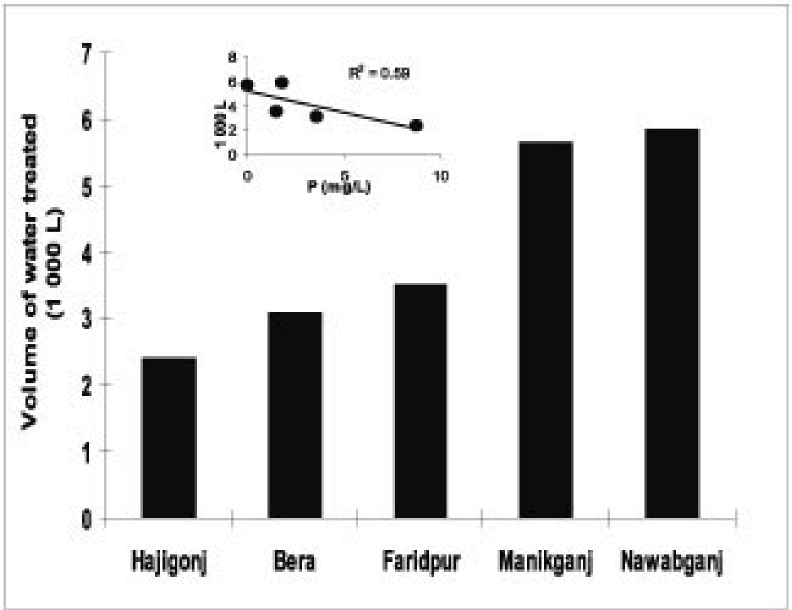

Fig 2. Bar chart showing the regional performance of the Ion-exchange filters along with the linear graph showing the correlation between groundwater total inorganic phosphate (reported as elemental P) and filter performance. The filled in bars in the chart represent filters that had attained breakthrough during the duration of the study where as the empty bars represent filters that did not attain breakthrough during the duration of the study.

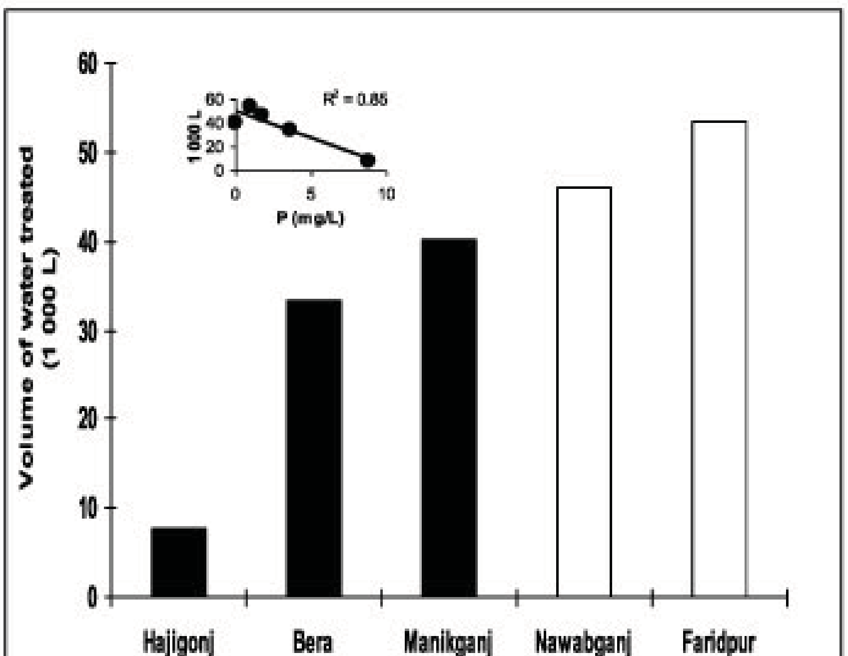

Fig 3. Bar chart showing the regional performance of the hydrous cerium oxide (HCO) filters along with the linear graph showing the correlation between groundwater total inorganic phosphate (reported as elemental P) and filter performance. The filled in bars in the chart represent filters that had attained breakthrough during the duration of the study where as the empty bars represent filters that did not attain breakthrough during the duration of the study.

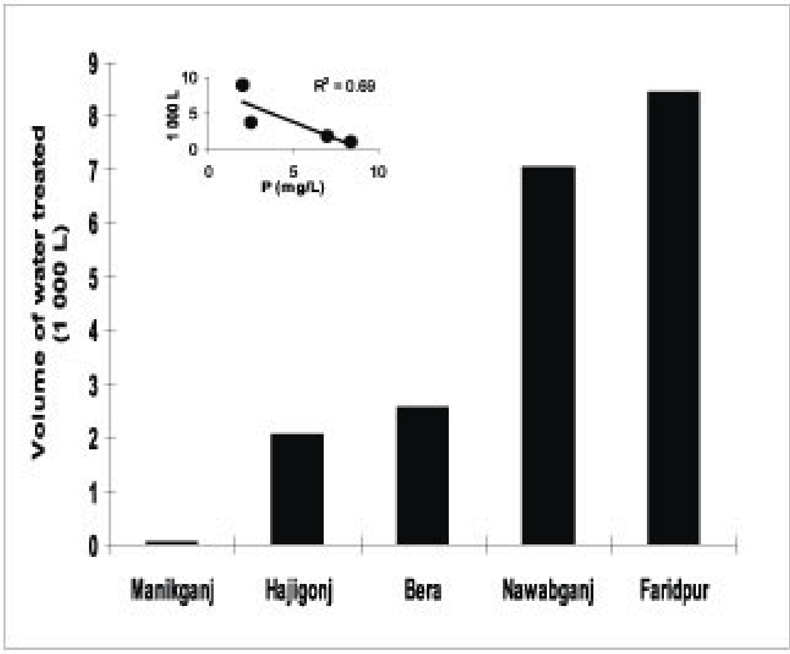

Fig 4. Bar chart showing the regional performance of the Ferric coated activated alumina (FAA) filters along with the linear graph showing the correlation between groundwater total inorganic phosphate (reported as elemental P) and filter performance. The filled in bars in the chart represent filters that had attained breakthrough during the duration of the study where as the empty bars represent filters that did not attain breakthrough during the duration of the study.

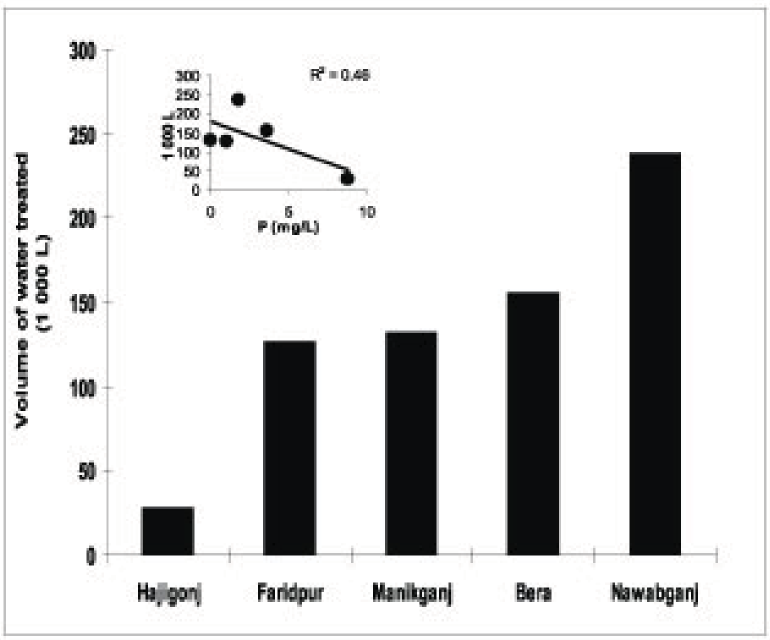

Fig 5. Bar chart showing the regional performance of the Granular ferric hydroxide based (GFH) filters along with the linear graph showing the correlation between groundwater total inorganic phosphate (reported as elemental P) and filter performance. The filled in bars in the chart represent filters that had attained breakthrough during the duration of the study where as the empty bars represent filters that did not attain breakthrough during the duration of the study.

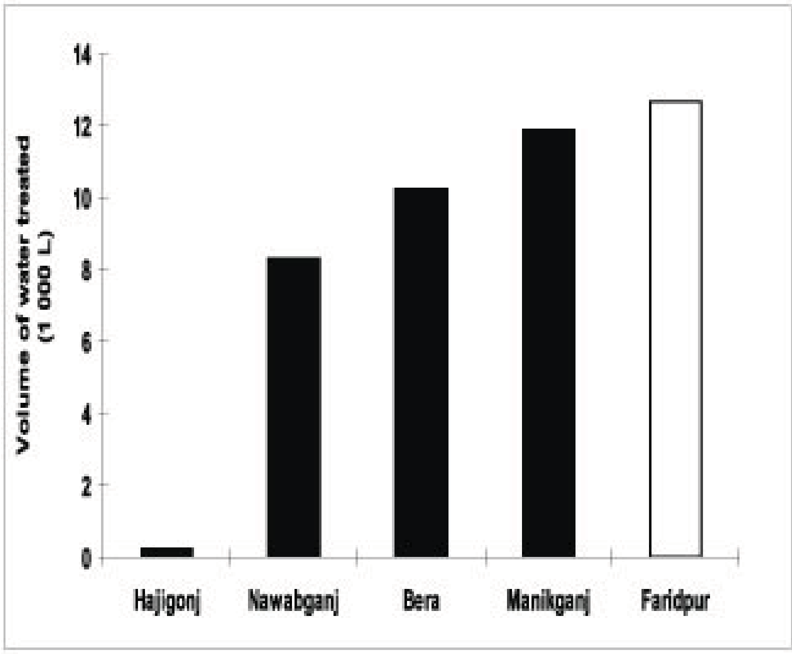

Fig 6. Bar chart showing the regional performance of the Zero valent iron based (ZF) filters along with the linear graph showing the correlation between groundwater total inorganic phosphate (reported as elemental P) and filter performance. The filled in bars in the chart represent filters that had attained breakthrough during the duration of the study where as the empty bars represent filters that did not attain breakthrough during the duration of the study.