DEVELOPMENT OF A GROUNDWATER ARSENIC REMOVAL FILTER USING BRICK CHIPS AND SAND

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ABSTRACT

Arsenic, one of the world's most hazardous chemical is found to exist within the shallow zones of groundwater of many countries in various concentrations. The arsenic crisis in Bangladesh has been described as one of the worst cases of mass poisoning in world history. It is estimated that about 35 to77 million people at a risk of exposure to drinking arsenic-contaminated tube-well water. The present study aims at developing a simple arsenic removal filter (ARF) adopting adsorption and co-precipitation with iron technique using brick chips and coarse sand, and to investigate the treatment efficiency of developed filter unit. Following the technique of atmospheric aeration, ferrous hydroxide in liquid phase was oxidized to ferric hydroxide solid phase which absorb and co-precipitates arsenic ions and finally strained out within the granular media of sand filter. To pursue the efficiency of developed filter unit, water quality parameters of treated water was analysed and compared with the water quality parameters of raw groundwater. It was found that the filter unit shows exceptional efficiency (100%) in removing arsenic. The iron removal efficiency was found to be approximately 98%. Complete color and pathogen removal (100%) was achieved through the developed ARF; however, other water quality parameters such as turbidity, alkalinity, hardness, manganese, biochemical oxygen demand, chemical oxygen demand, were found to be removed approximately 99%, 47%, 56%, 98%, 99%, 54%, respectively. Overall, the developed ARF is capable of removing arsenic to the standard limit without adding any chemicals.

Keywords: *arsenic removal filter, adsorption, co-precipitation with iron, groundwater, oxidation.*

1. INTRODUCTION

Arsenic contamination in groundwater is posing a major threat to drinking water resources in many countries like Afghanistan, Argentina, Australia, Brazil, Bulgaria, Canada, Cambodia, Chile, China, Egypt, Finland, Germany, Greece, Hungary, India, Iran, Japan, Mexico, Myanmar, Nepal, New-Zealand, Pakistan, Romania, Sri-Lanka, Spain, Sweden, Switzerland, Thailand, U.S.A. etc. (Stueben et al., 2003, van Geen et al., 2004, 2006, Dittmar et al., 2007, Farooq et al., 2010). It is a powerful poison on acute ingestion. It is extremely toxic on long term exposure to very low concentrations. It is not visible in water and food; even in highly contaminated water, it is clear and colorless. It has no taste, smell even at deadly concentrations that is why the presence of arsenic in drinking water is difficult to detect without complex analytical techniques. Bangladesh is grappling with the largest mass poisoning of a population in history because ground-water used for drinking purpose has been contaminated with naturally occurring inorganic arsenic. Arsenic contamination of water in tube-wells was confirmed in 1993 in the Nawabganj district. It was estimated that among the 125 million inhabitants of Bangladesh between 35 million and 77 million are at risk of drinking arsenic contaminated water (Khan et al. and Dhar et al., 1997). Arsenic in drinking water could cause skin, lung, liver, urinary bladder, and kidney cancer. Various other non-carcinogenic health effects like dermal, cardiovascular, neurological, respiratory, diabetes mellitus, gastrointestinal and reproductive and developmental effects are also due to chronic arsenic exposure through drinking water (Chakraborti, 2011). The most serious damage to health has taken place in Bangladesh and West Bengal, India. In 2000, a WHO report (Smith, et al., 2000) described the situation in Bangladesh as: "the largest mass poisoning of a population in history beyond the accidents at Bhopal, India, in 1984, and Chernobyl, Ukraine, in 1986." In 2006, UNICEF reported that 4.7 million (55%) of the 8.6 million wells in Bangladesh (UNICEF 2006) had been tested for arsenic of which 1.4 million (30% of those tested) had been painted red, showing them to be unsafe for drinking water due to presence of 50 ppb (UNICEF 2006). UNICEF estimates that 12 million people in Bangladesh were drinking arsenic Contaminated water in 2006, and the number of people showing symptoms of arsenicosis were 40,000, but could rise to one million (UNICEF 2006). Therefore, it is an urgent need to ensure the use of arsenic free drinking water. In this regard, different approaches could be applied such as treatment of surface water, rainwater harvesting, treatment of pond waters, use of deeper(>150 m deep) wells to extract low arsenic groundwater, and above all, exploring low-technology, low-cost, locally fitted systems for arsenic removal from groundwater, but all of these approaches are associated with some practical problems in terms of applicability, economy, infrastructure requirements, generic dissemination and future sustainability, although the last one has received considerable attention over the last two decades due to the possibility of wide-scale application in the field. Several arsenic removal technologies have been tested so far for arsenic remediation, including ion exchange, activated alumina, reverse osmosis, membrane filtration, modified coagulation/filtration, and enhanced lime softening (Berg, et al., 2006). However, none of these technologies are currently applied on a broad scale in developing countries like Bangladesh as they require sophisticated technical systems and are therefore unpractical in low income regions. However, for any effective technology to be appropriate for use in affected areas of developing countries like Bangladesh, it should ideally be simple, low cost, versatile, transferable, and should be adaptable to both points of use household units and community-based application (Visoottiviseth and Ahmed, 2008). The most common and useful technologies that have been utilized for arsenic removal in Bangladesh as well as in other developing countries are based on oxidation, co-precipitation and adsorption onto coagulated floss, and adsorption onto sorptive media (Ahmed, 2001). Considering the serious arsenic contamination in Bangladesh groundwater this paper aims at developing a simple method for arsenic decontamination of groundwater adopting co-precipitation with iron and subsequent sand filtration. Brick chips and coarse sand were used as filter bed material. Various water quality parameters before and after treatment was measured to investigate the efficiency of developed filter unit.

2. METHODOLOGY

2.1 Water Quality Parameter Analysis

Groundwater was collected from acute arsenic contaminated area. Physical, chemical and biological quality parameters of collecting water were measured and analysed. Physical parameter includes color, pH, turbidity; chemical parameters include alkalinity, arsenic, chloride, hardness, iron, manganese, total dissolved solids, bio-chemical oxygen demand, chemical oxygen demand, biological parameters include total coliform, faecal coliform.

2.2 Development Of Filter Unit

Figure 1 shows that, the unit process applied in the research work. Following the technique of atmospheric aeration, ferrous hydroxide in liquid phase was oxidized to ferric hydroxide solid phase and co-precipitate arsenic ions and finally strained out within the granular media of sand filter. During this process, the dissolved iron compound $Fe(OH)_2$ in the groundwater undergoes a natural chemical process called oxidation (when an element loses electrons) to produce a solid form or precipitate of $Fe(OH)_3$ which attracts arsenic to stick on it, a process called adsorption. This adsorption produces a co-precipitate of iron (III) hydroxide and arsenic. Final removal of precipitated particles both through sorption on to iron Oxy hydroxides and natural straining take place during down flow through the sand filter in the second bucket.

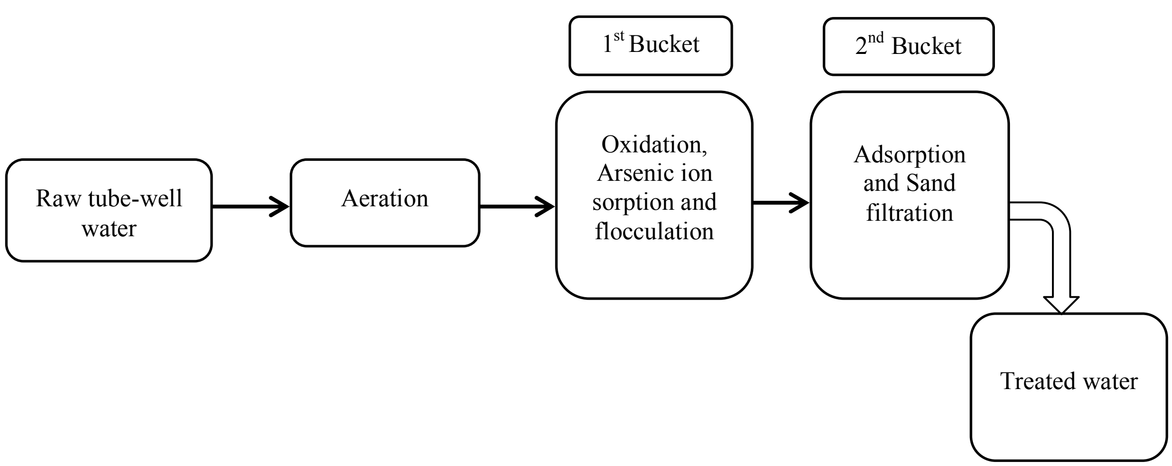

Figure 1: Flow diagram of the unit process of the filter unit.

2.3 Preparation Of Material

Two types of material were used. These were brick chips and coarse sand. Fresh bricks were collected from nearby kiln and broken into small pieces. They were sieved through ASTM standard sieve. The brick chips were used in this present work having a nominal size of 0.625 inches. Then the brick chips were washed several times with hot water to remove impurities. Locally available sand was collected. They were sieved #200 ASTM standard sieve to remove dust from sand. Then the sand was washed several times with hot water to remove the impurities present in it.

2.4 Design Of Filter Unit

For the removal of arsenic from ground water a model of the arsenic removal filter was developed using brick chips and coarse sand. The developed filter unit consists of two buckets, one bucket lies under another as shown in Figure 3. First bucket consists of an eight inch thick layer of brick chips (nominal size 0.625 in). Second bucket consists of an eight inch thick layer of coarse sand as shown in Figure 2. The structure of developed filter unit is very simple, easy to operate, transferable and useful especially for household use.

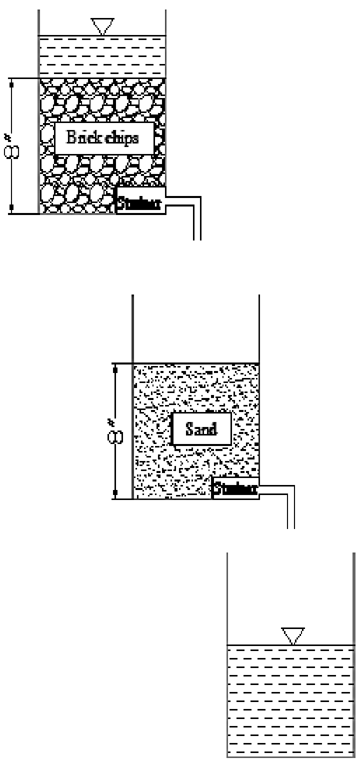

Figure 2: Line diagram of developed filter unit.

Figure 3: Experimental set-up of developed filter unit.

3. RESULTS AND DISCUSSION

The primary aim of the present study was to produce a simple household type arsenic removal filter unit and to analyse the performance of this filter unit. For the fulfillment of this work a simple, household use type filter unit was trained and detail laboratory tests and analysis was borne out through developing arsenic removal filter unit to investigate the change in some important water quality parameters. Although various water quality parameters were being studied, but the major concern was arsenic. Water quality parameters before and after filtering were analysed to investigate the removal efficiency of developed filter unit. From the table it was envisioned that most of the water quality parameters were found exceeding their standard limit set for water used in drinking purpose in Bangladesh, but after filtering most of the water quality parameters was met and satisfy the standard point of accumulation. The next table (table 1) reveals the summary of results obtained in the present study.

Table: 1. Summary of the test results of raw water and treated water with Bangladesh standards For drinking purposes.

Water quality parameter	Unit	BD Standards (ECR 1997)	Raw water	Treated water
pH	----	6.5-8.5	7.08	7.69
Color	Pt.Co.unit	15	902	0
Turbidity	NTU	5	146	1.02
Total Dissolved Solid	mg/L	1000	610	760
Total Alkalinity (as $CaCO_3$)	mg/L	---	327	172
Total Hardness (as $CaCO_3$)	mg/L	200-500	607	267
Chloride	mg/L	150-600	72.5	350
Arsenic	ppb	50	500	0
Iron	mg/L	0.3-1	11	0.13
Manganese	mg/L	0.1	3.6	0.07
BOD_5	mg/L	0.2	32.4	0.17
COD	mg/L	4	128	58.4
Total Coliform	N/100 mL	0	12	0
Faecal Coliform	N/100 mL	0	4	0

3.1 Arsenic Removal Efficiency

In Bangladesh the allowable limit of arsenic in drinking water was set 50 ppb. Figure 4 reveals that the variation of arsenic concentration in raw and treated water and standard value. From the analysis, it was found that the arsenic concentration in raw water was 500 ppb. After filtering through the developed filter unit arsenic concentration in treated water was found ‘0’ Pb. 100% efficiency in removal of arsenic was achieved through developed filter unit.

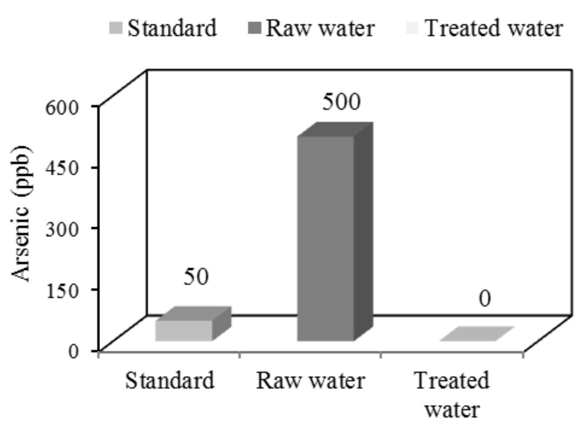

Figure 4: Variation of arsenic

3.2 Treatment's Performance For Other Parameters

Although main purpose was to investigate the removal efficiency of arsenic, other water quality parameters like p^H, color, turbidity, total dissolved solid, total alkalinity, total hardness, chloride, manganese, BOD_5, COD, total coliform, faecal coliform of treated water were measured to compare with Bangladesh standards for drinking purpose.

3.2.1 P^H

PH is the term applied to express the strength of the acid or alkaline condition of the resolution. It is a touchstone of the concentration of free hydrogen ion (H+) exactly the hydrogen ion activity. pH is an important parameter in assessing the water quality parameter. Acidic condition will run if the pH value decreases on the other hand, alkaline condition will appear if pH value increases. Bangladesh standard for pH is in the range 6.5-8.5 for the water used in drinking purpose. Figure 5 shows a variation of pH. From the analysis, it was found that before filtering pH was 7.08 and after filtering it was founded 7.69. Which indicates increase in alkaline condition, but it remains between the Bangladesh standard values 6.5-8.5.

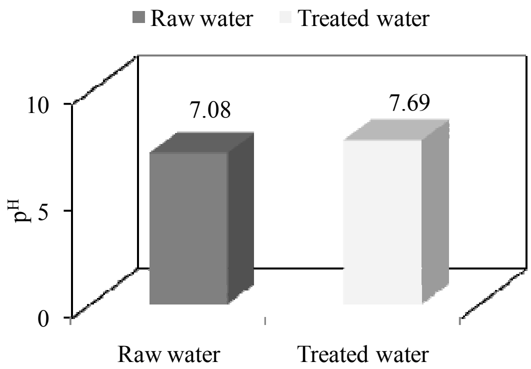

Figure 5: Variation of p^H

3.2.2 Color

Color in water is principally due to the presence of colored organic substances (primarily humic substances), metals such as iron, manganese or highly colored industrial wastes. Figure 6 shows the variation of color. The standard limit for Bangladesh of color in drinking water is 15 Pt. Co. unit. From the analysis, before treatment color was found 902 PT. Co. unit, but after filtering through developed filter unit it was found 0 PT. Co. unit. So the filter unit reveals 100 % efficiency in removing color like arsenic.

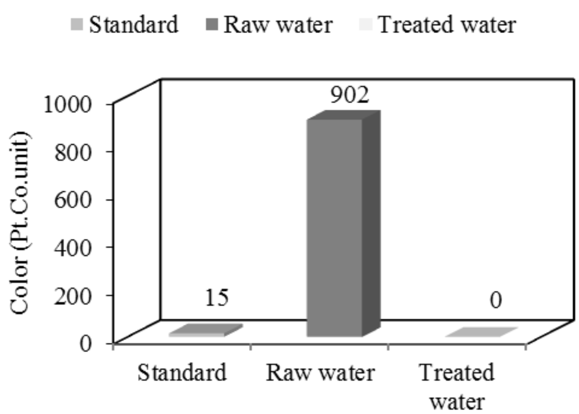

Figure 6: Variation of color.

3.2.3 Turbidity

Turbidity is an expression of certain light scattering and light absorbing properties of a water sample and depends, in a complex manner, on such factors as the number, size, shape and refractive index of the particulate matter present in the water. The standard limit for turbidity in Bangladesh is 5 NTU. Figure 7 displays the variation of turbidity. After analysing turbidity in raw water was found 146 NTU and it was cut down to 1.02 NTU after filtering through developed filter unit. Approximately 99% removal of turbidity was obtained by the developed filter unit.

3.2.4 Chloride

Chloride may present naturally in groundwater and may as well originate from diverse source such as weathering, leaching of sedimentary rocks, filtration of sea or ocean water. The maximum allowable limit of chloride in drinking water in Bangladesh is limited to 150-600 mg/L but in coastal areas it is restricted to 1000 mg /L. Figure 8 illustrates the variation of chloride content. From the analysis chloride content of raw water was to be 72.5 mg/L and after filtering it was found 350 mg/L. Figure 8 demonstrates that the chloride content after filtering increased, it might be ascribable to the presence of naturally occurring chloride content in brick chips or in a grain of grit used in the research study.

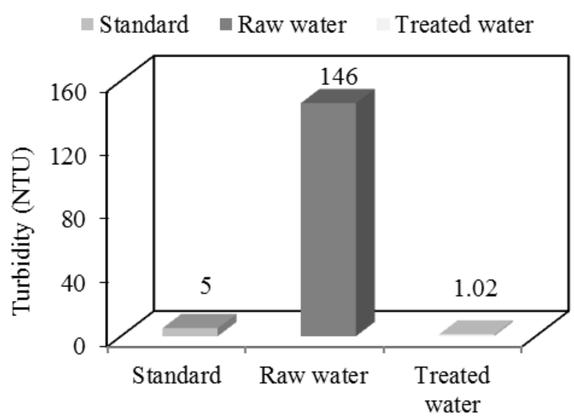

Figure 7: Variation of turbidity

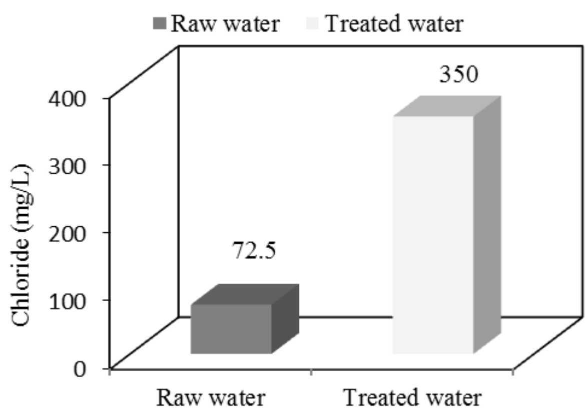

Figure 8: Variation of Chloride

3.2.5 Total Dissolved Solid

Total dissolved solid includes organic salts and little amounts of organic matter. The measure of dissolved solids present in urine is an important consideration in the suitability for domestic purpose. The standard value of total dissolved solid is 1000 mg/L in Bangladesh. Figure 9 lets out the variation of total dissolved solid before and after filtration. After analysing it was set up that after treatment total dissolved solid was increased, it might be ascribable to the addition of chloride concentration in treating water.

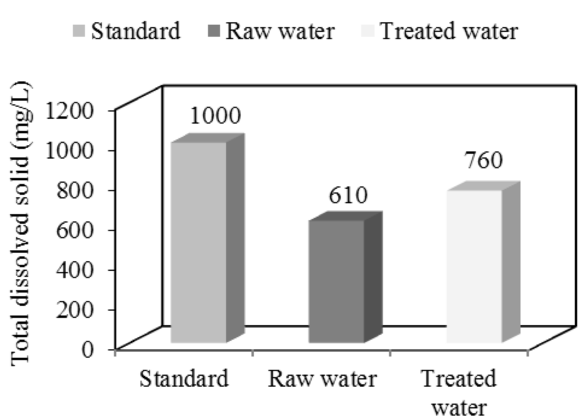

Figure 9: Variation of total dissolved solid

3.2.6 Iron

Iron in water may cause hardness, undesirable taste in beverages and may impart a reddish brown color to water. Iron in water is frequently accompanied by heavy growths of iron bacteria (Chrenothrix, Gallionella, etc.) In the Bangladesh allowable limit of iron in drinking water was imposed 0.3-1.0 mg/L. Remarkable efficiency in the removal of iron was observed during the filtration through developed filter unit. Figure 10 shows the treatment efficiency of iron. It was observed that after filtering through developed filter unit iron was found 0.13mg/L where in raw water it was found 11 mg/L. Thus the filter unit shows approximately 98% efficiency in removing iron.

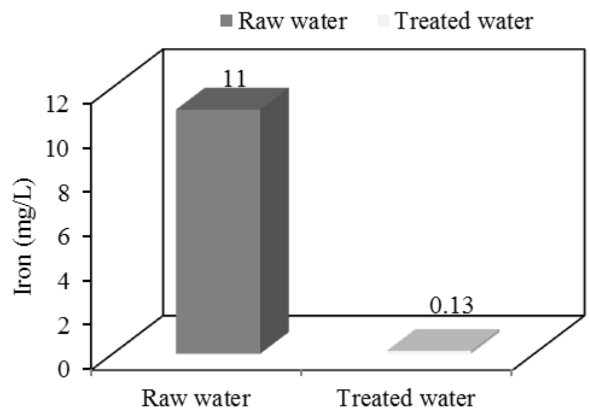

Figure 10: Variation of Iron.

3.2.7 Manganese

Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron. Manganese occurs naturally in groundwater sources and in soils that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas. However, in Bangladesh the standard limit of manganese was set 0.1 mg/L. Figure 11 represents the condition of manganese before and after filtration through developed filter unit. The name shows that raw water contains 3.6 mg/L manganese and it was cut down to 0.07 mg/L after filtering through developed filter unit. Approximately 98% removal efficiency of manganese was achieved by the developed filter unit.

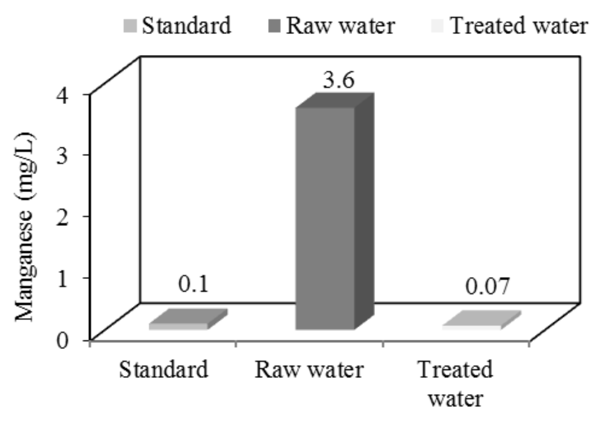

Figure 11: Variation of Manganese.

3.2.8 BOD_5

The amount of oxygen consumed by bacteria during microbial utilization of organics is called bio-chemical oxygen demand (BOD). The BOD therefore provides information on the biology-convertible proportion of the organic content of a sample of water. The oxygen consumed in 5 days is represented by BOD_5. Figure 12 represents the variation of BOD_5. 0.2 mg/L was set as a standard limit for Bangladesh. Before treatment BOD5 in raw water was found 32.4 mg/L, which designates that the presence of heavy quantities of organic substance. It was noted that after filtering through developed filter unit it was found 0.17 mg/L which indicates that most of the organic substance was taken out from new water.

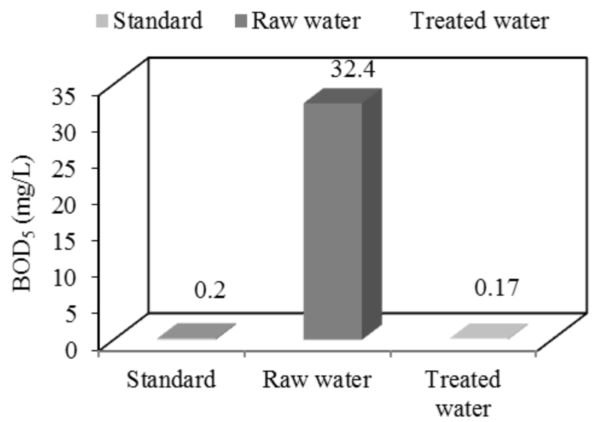

Figure 12: Variation of BOD_5.

3.2.9 Total coliform

Total Coliforms are a group of Bacteria that includes E. coli. Health problems associated with these pathogens include diarrhea, cramps, nausea and vomiting. Together, these symptoms comprise a general category known as gastroenteritis. Total Coliforms are used to determine the vulnerability of a system to faecal contamination. Figure 13 shows the variation of total coliform before and after filtration. From analysis, 12 nos /100 mL was found in raw water. But it was totally removed after filtering through developed filter unit.

3.2.10 Faecal coliform

Faecal coliform bacteria are a subgroup of total coliform bacteria. They exist in the intestines and feces of people and animals. The presence of faecal coliform in a drinking water sample often indicates recent faecal contamination. That means there is a greater risk that pathogens are present. Most of the waterborne pathogens are introduced through faecal contamination of water. Thus, any organism's native to the intestinal tract of humans and meeting the above criteria would be a good indicator organism. The organisms most nearly meeting these requirements belong to the faecal coliform group. Figure 14 shows the variation of faecal coliform. 100% removal was achieved during filtering through developed filter unit.

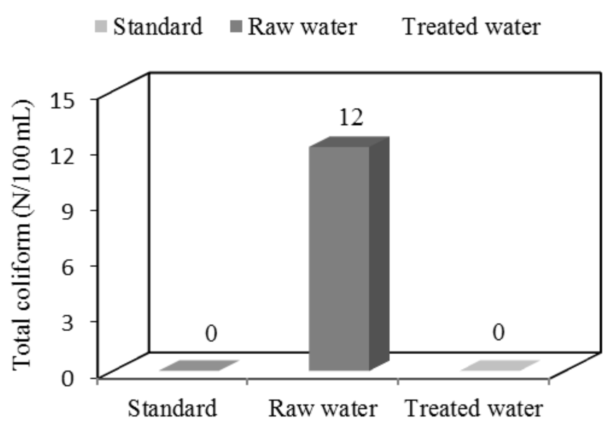

Figure 13: Variation of Total coliform

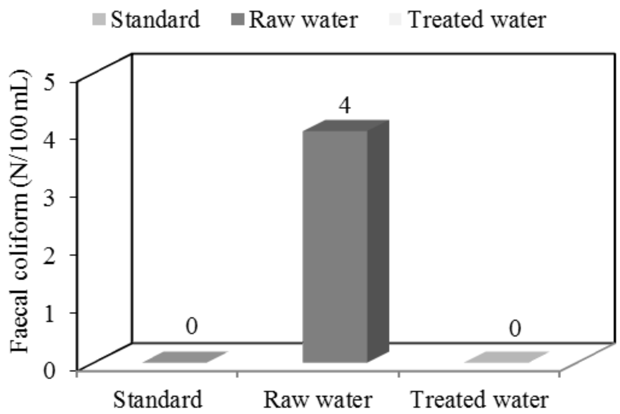

Figure 14: Variation of Faecal coliform

4. CONCLUSIONS

The present study focused on developing a household type arsenic removal filter (ARF) unit and to investigate the removal efficiency. A simple ARF unit was developed using brick chip and coarse sand. The filter unit consists of two buckets, in first bucket 8 inch deep layer of brick chips of nominal size 0.625 inches and another bucket 8 inch thick coarse sand was applied. The developed ARF is suitable for homemade approach for arsenic removal in local areas because of simplicity and easy operation and treatment. The fabrics employed in the developed filter unit are well usable. Water quality parameters of processed water through developed filter unit were studied. It was noticed that the filter unit reveals 100% effective in getting rid of arsenic from groundwater without adding any chemicals. Other water quality parameters like color, total coliform, faecal coliform were removed 100%, and turbidity, alkalinity, hardness, iron, manganese, biochemical oxygen demand, chemical oxygen demand, was removed approximately 99%, 47%, 56%, 99%, 98%, 99%, 54%, respectively. Most of water quality parameters were found to be met and satisfy the standard limit for Bangladesh.

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