Technical Journal
River Research Institute ISSN: 1606-9277

IRON REMOVAL PERFORMANCE OF MULTI STAGE FILTRATION UNITS FROM GROUND WATER OF BANGLADESH

M. M. R. Mondol[1,2*]

Abstract

Iron is found widely distributed in both surface and ground waters in nearly all geographic areas. Dissolution of iron occurs by various processes and results in a variety of conditions regarding the concentration and chemical forms in which they are found in water. Iron in concentrations greater than 0.3 ppm stains plumbing fixtures and laundered clothes. Although discoloration from precipitates is the most serious problem associated with water supplies having excessive iron, foul tastes and odors can be produced by the growth of iron bacteria in water distribution mains. The iron problem has long been recognized in Bangladesh and many technologies have been developed for iron removal at municipal, community and household levels adopting the techniques of oxidation, sedimentation, precipitation and filtration process. To conduct this study six individual filtration units treating tube well water having iron concentrations ranging from 4.6 to 16 ppm installed at Sirajgonj, Cumilla and Jashore districts of Bangladesh have been selected. Crushed brick chips have been used as adsorptive media for the filtration units. Collected raw water samples and treated water samples from different chamber of the filtration units were tested in the laboratory for determining the concentration of residual iron and other relevant water quality parameters. The result reveals that higher the initial tube well water iron concentration, greater is the iron removal performance. Depending on raw water iron concentrations around 89.13 to 98.25 % iron removal performance have been achieved.

Keywords: *Concentration, DRF, Effluent, Iron, MSFU, Removal Performance, URF.*

Introduction

The presence of Fe and Mn in groundwater could confer colour, poor bitter taste, staining of laundry and plumbing fixtures (Mondol, 2020). Arsenic, on the other hand, is potential health hazard if its concentration is in excess of guideline value (Ahmed, 2005). Many arsenic containing ground water also contain significant level of iron and manganese due to natural geochemistry. The presence of iron in ground water is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply. In some places of Bangladesh the concentration of iron in ground water is at a much higher level than the limit acceptable to the rural people. People of those areas generally refuse to use tube well water and inclined to use pond and river waters (ITN-BUET, 2011).The national hydro-chemical quality surveys conducted by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE) have shown that in Bangladesh, large numbers of wells also exceed permissible limits for iron (Fe) and manganese (Mn) (Habib, 2013). In this survey, a total of 3534 groundwater samples from throughout Bangladesh, excluding the Chittagong Hill Tracts, were analyzed for arsenic, manganese, iron and a wide range of other water quality parameters (BGS and DPHE, 2001). About half of the wells surveyed exceeded the Bangladesh drinking water standard for iron (1 mgl^{-1}), and about three quarters exceeded the permissible limit for Mn (0.1 mgl^{-1}). Above these levels, people may be unwilling to drink the water, and turn instead to a better-tasting, but microbiologically less safe, water sources (Hasan and Ali, 2010). Iron in concentrations greater than 0.3mgl^{-1} stains plumbing fixtures and laundered clothes. Although discoloration from precipitates is the most serious problem associated with water supplies having excessive iron, foul tastes and odors can be produced by the growth of iron bacteria in water distribution mains. These filamentous bacteria, using reduce iron as an energy source, precipitate it, causing pipe encrustations. Decay of the accumulated bacterial slimes creates offensive tastes and odors (Steel, 1960). Dissolved irons are often found in ground water from wells located in shale, sandstone and alluvial deposits. Impounded surface water supplies may also have troubles with iron (Mondol, 2009).

This full research work has been taken for investigating the performance of simultaneous removal iron, arsenic and manganese under different conditions using multiple up-flow and down-flow gravel bed. The present study is a part of the full research and will be confined only in analyzing iron removal performance.

Iron (II) (Fe^{2+}) and Manganese (II) (Mn^{2+}) are chemically reduced, soluble, invisible in ferrous form (Abanda, 2021) and may exist in tubewell waters or anaerobic reservoir bottom water in absence of DO, at high CO_2 concentration (>100 mgl^{-1}), at lower pH (<6.5), lower alkalinity (<130 mgl^{-1} as $CaCO_3$) and complex with organic materials. On the other hand, Iron (III) (Fe^{3+}) and Manganese (IV) (Mn^{4+}) are oxidized, insoluble, visible in presence of DO, at higher pH value (>7.5) due to release of CO_2 concentration (<10 - 15 mgl^{-1}), higher alkalinity and in absence of organic materials (ITN-BUET, 2011).To remove soluble iron it is generally accepted that an oxidation process followed by a suspended solids removal process is most effective. Usually, oxidation of soluble iron is accomplished by simple aeration or chlorination/potassium permanganate application. Coagulation - flocculation with sedimentation and filtration are employed as solid removal processes (Ahmed, 2005).

During 1990 a study was conducted by WHO, UNICEF and DPHE on improved iron plants which showed that iron removal was satisfactory (WHO *et al.*, 1990). The iron concentration was reduced to around 1.5 ppm from 15 ppm with average cleaning period of 12 days (with minimum of 5 days). With the same interval of cleaning it has been observed that the higher the concentration in raw water the higher the concentration in treated water but it was not exceeded 2.5 ppm (Mondol, 2009). For the elimination of iron from hand pump tubewell water, In 1981, Aowal (1981) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber. Although an effective removal was achieved the length of run between cleaning was very short, less than 24 hours. The top layer of fine sand was

[1] Geotechnical Research Directorate, River Research Institute (RRI), Faridpur-7800, Bangladesh.
[2] Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.
[*] Corresponding Author (E-mail: mrmondol68@gmail.com)

needed to be removed, washed and dried for the next use, which is laborious and time consuming (ITN-BUET, 2011). In 1985-86 over hundred iron removal units, which were originally designed by BUET under a research programme, were built at Sirajgonj and Comilla (Hasan, 2003). These units are reported to fail due to lack of community participation in all activities of the project, faulty construction of the unit, difficulty in cleaning the filter due to short filter runs, complicated design of the unit. In 1988, DPHE with the help of UNICEF, Dhaka Bangladesh, designed and constructed iron removal plant for hand pump tube wells in different parts of Bangladesh (ITN-BUET, 2011). Those plants were also failed due to faulty design of sedimentation chamber, where flocs were gradually settled and mixed with treated water (Hasan, 2003). Removal of iron is generally hastened and made more efficient by letting water trickle downward or rise upward through gravel or other relatively coarse heavy materials (Mondol and Ahmed, 2014).

The iron problem has long been recognized in Bangladesh, and many technologies have been developed for iron removal at municipal, community and household levels. Municipal Iron Removal Plants (IRPs) were first installed in Bangladesh during the early 1980s (BRTC, 2006). After the detection of arsenic in ground water, many municipal IRPs are now being designed and used for removal of both iron and arsenic (Mondol, 2020). In the backdrop of the discovery of arsenic in many areas of the country, community treatment units designed for removal of both arsenic and iron are becoming popular. Many NGOs are now installing different types of such community-based iron/ arsenic removal plants. However, most of the plants have been constructed without following any technical design parameters (BRTC, 2006). It would be interesting to see whether Mn is removed significantly in the currently operational iron and/or Fe-As removal plants, which have been designed primarily for removal of iron and/or arsenic. Therefore, more research works are needed to find out suitable technologies for simultaneous removal of iron, arsenic and manganese from ground water.

Methodology

To conduct the study six spots were selected in 3 zones on the basis of different hydro-geological condition and iron, manganese and arsenic concentration present in ground water as shown in **Fig.1**. These spots are located in Sirajgonj,Cumilla and Jashore district of Bangladesh. In each spot one Multi Stage Filtration Unit (MSFU) was constructed.

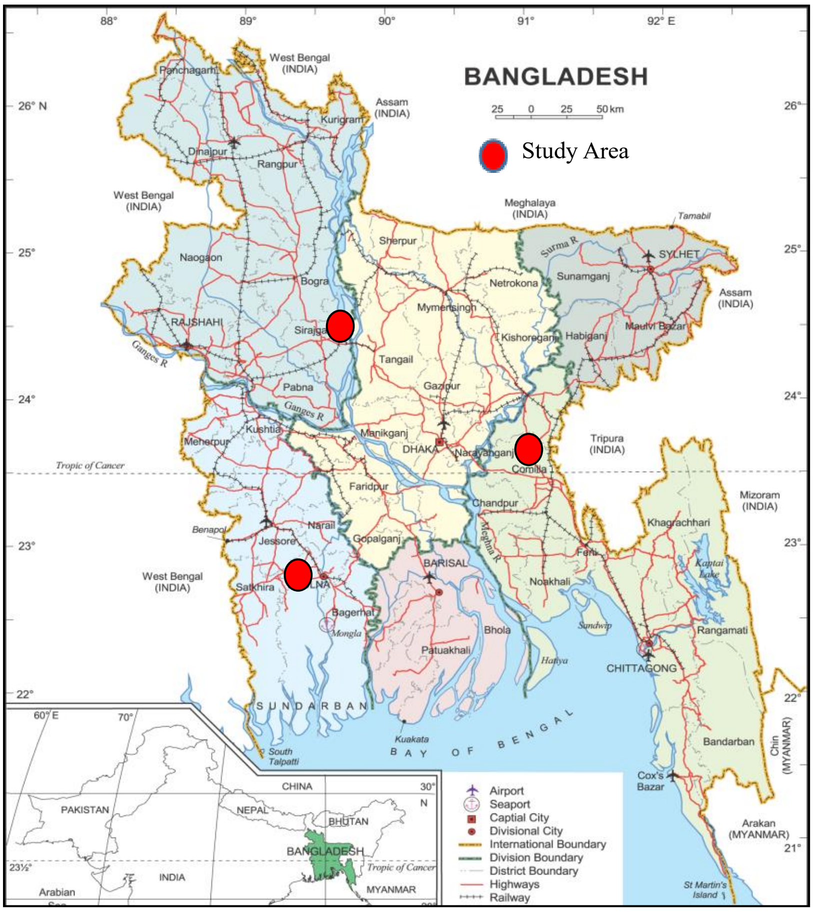

Fig.1. Location map of the study area.

The raw water and treated water from different locations of each MSFU were collected at suitable interval for subsequent analysis of iron, manganese, arsenic and other selected water quality parameters in the laboratory. Iron, manganese, arsenic concentrations were analyzed using Atomic Absorption Spectrophotometer (AAS). A number of samples were analyzed by HACH spectrophotometer for iron and manganese contents. Samples were collected in pre-washed

500 ml plastic bottles. Water samples in pre-washed bottles were acidified with 1 ml concentration Nitric acid, which were later used for analysis of dissolved arsenic, manganese and iron in the laboratory. The present study is a part of the full research and will be confined only in analyzing iron removal performance.

In the Construction of Multistage Filtration Units,a combination of down-flow at the beginning, an up-flow at the middle and a down-flow at the end have been incorporated. The MSFU is connected to the spout of tube well with a short piece of 75 mm PVC / flexible pipe as shown in **Fig. 2**.

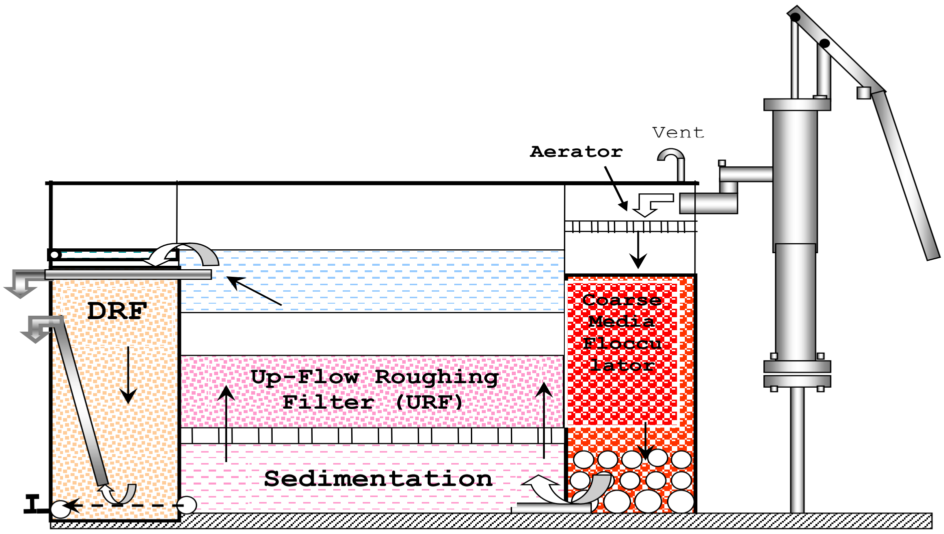

Fig. 2. Schematic diagram of the MSFU.

Table 1. Construction cost of MSFU.

Sl.No.	Item	Sub-item	Quantity	Unit price (TK.)	Estimated cost (TK.)
1	Bricks	Brick Flat Soling (BFS) for 5" brick wall	800 nos.	4.50	3600.00
2	Cement	Brick works, RCC works, CC works, etc.	9 bag	360.00	3240.00
3	Sand	Brick works, RCC works, CC works, BFS, etc.	80 cft	7.00	560.00
4	Khoa (#1 bricks)	RCC works, CC works,	40 cft	60.00	2400.00
5	M.S. Rod	RCC works	20 kg	45.00	900.00
6	Plumbing	3" PVC pipe, GI pipe, GI gate valve, GI socket, 3" Flexible inlet pipe, Strainer, Delivery pipe fittings, etc.	L.S.	-	2000.00
7	Burned bricks chips (khoa)	Flocculator, URF, DRF	40 cft	60.00	2400.00
8	Labour	Mason and Helper	6 days	(250+150)	2400.00
9	Local carriage		L.S.	-	1000.00
10	Miscellaneous		L.S.	-	500.00
Total TK./UNIT=					19000.00

Water entering the first chamber is distributed uniformly over the whole bed of course media through a porous thin ferro-cement plate placed on the top, resulting strip out of CO_2 and increase of pH value for the oxidation of soluble iron. Oxidation and subsequent precipitation of iron oxy-hydroxides occurs respectively on the top and within the interstices of coarse media which adsorbs arsenic oxyanions. Sinusoidal flow across the coarse media enhance collisions for the flocculation of precipitated particles. Comparatively larger flocculated precipitates settle at the bottom of the 2nd chamber. Maximum removal of precipitated particles occurs by sorption on to iron oxy hydroxides and mechanical straining during up-flow through the comparatively finer coarse media bed in the 2nd chamber, Up-flow Roughing Filter (URF). Final removal of precipitated particles occurs through sorption on to iron oxy hydroxides and mechanical straining during down-flow through the comparatively finer coarse media bed in the 3rd chamber, Down-flow Roughing Filter (DRF). Crushed brick chips have been used as adsorptive media for the filtration units.

Construction Cost of MSFU

On the basis of considering the materials and others market value as on 2008-2009 Financial Year the construction cost of MSFU have been furnished for each unit (**Table 1**).

Results and Discussion

i). Variation of Iron Concentration:

The variation of residual Fe concentration with length of filter run for MSFU-1, MSFU-2, MSFU-3, MSFU-4, MSFU-5 and MSFU-6 are presented in **Fig. 3-8** respectively.

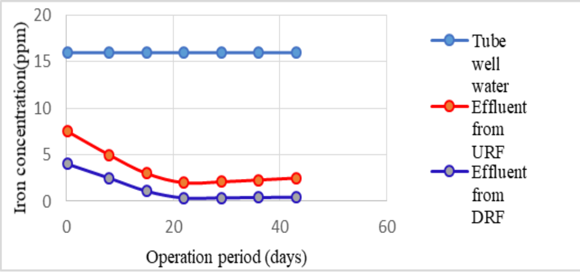

Fig. 3. Variation of average iron concentration in different treatment unit process of MSFU-1.

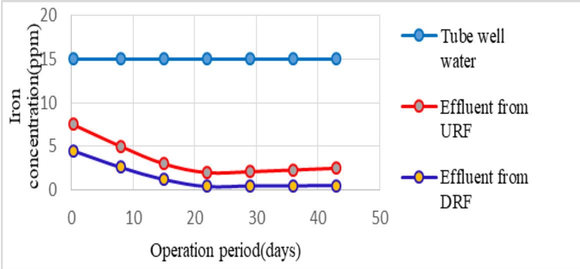

Fig. 4. Variation of average iron concentration in different treatment unit process of MSFU-2.

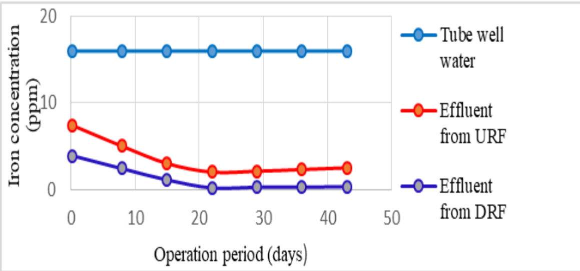

Fig. 5. Variation of average iron concentration in different treatment unit process of MSFU-3.

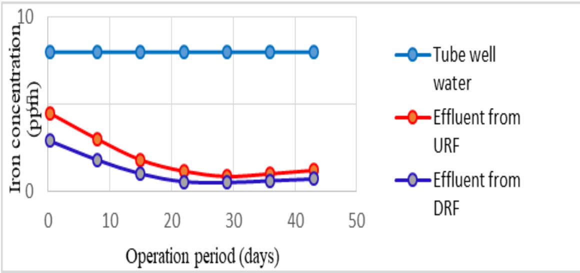

Fig. 6. Variation of average iron concentration in different treatment unit process of MSFU-4.

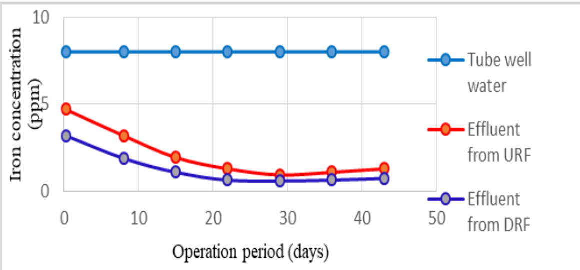

Fig. 7. Variation of average iron concentration in different treatment unit process of MSFU-5.

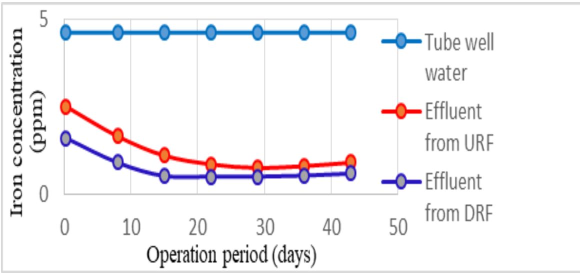

Fig. 8. Variation of average iron concentration in different treatment unit of MSFU-6.

Iron (II) (Fe^{2+}) and Manganese (II) (Mn^{2+}) are chemically reduced, soluble, invisible in ferrous form (Abanda, 2021) and may exist in tubewell waters or anaerobic reservoir bottom water in absence of DO, at high CO_2 concentration (>100 mgl^{-1}), at lower pH (<6.5), lower alkalinity (<130 mgl^{-1} as $CaCO_3$) and complex with organic materials. On the other hand, Iron (III) (Fe^{3+}) and Manganese (IV) (Mn^{4+}) are oxidized, insoluble, visible in presence of DO, at higher pH value (>7.5) due to release of CO_2 concentration (<10 - 15 mgl^{-1}), higher alkalinity and in absence of organic materials (ITN-BUET, 2011). The rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present and partial pressure of oxygen. Aeration is sufficiently rapid only if it is catalyzed by accumulation of oxidation products (Fe_2O_3 and MnO_2) on a porous bed. Previously precipitated iron (Fe_2O_3) serves to catalyze the oxidation of iron. Moreover, hydrous oxides of metal, e.g. ferric oxide, Fe (III) and manganic oxide, Mn (IV) have high sorption capacities for un-oxidized metal ions including Fe^{++} ion (Mondol, 2009).

Fig.3 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-1 (at Kodda, Sirajgonj). The raw water Fe content was 16 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 2 and 0.36 ppm indicating iron removal performance of 87.5 % and 97.75 %, respectively with a influent flow rate of 12 $l.min^{-1}$. This was due to gradually adsorption of precipitated iron flocs on the coarse media surfaces and gradually deposition of the flocs in the interstices. The removal was significant during the initial days with gradually less removal with time and then the reduction was slow in general.

Fig.4 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-2 (at Chala, Sirajgonj). The raw water Fe content was 15 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 2 and 0.41 ppm indicating iron removal performance of 86.67 % and 97.27 %, respectively with a influent flow rate of 12 $l.min^{-1}$.

Fig.5 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-3 (at Homna, Cumilla). The raw water Fe content was 16 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 2 and 0.28 ppm indicating iron removal performance of 87.5 % and 98.25 %, respectively with a influent flow rate of 12 $l.min^{-1}$.

Fig.6 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-4 (at Polua, Jashore). The raw water Fe content was 8 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 0.85 and 0.5 ppm indicating iron removal performance of 89.38 % and 93.75%, respectively with a influent flow rate of 12 $l.min^{-1}$.

Fig.7 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-5 (at Sadipur, Jashore). The raw water Fe content was 8 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 0.95 and 0.6 ppm indicating iron removal performance of 88.13 % and 92.5%, respectively with a influent flow rate of 12 $l.min^{-1}$.

Fig.8 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-6 (at Sonakur, Jashore). The raw water Fe content was 4.6 ppm and it decreased progressively in each chamber with time. With the passage of time the iron concentration in the effluent of URF and DRF decreased up to 0.73 and 0.5 ppm indicating iron removal performance of 84.13 % and 89.13%, respectively with a influent flow rate of 12 $l.min^{-1}$.

As the rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present and raw water iron concentration of MSFU-1, MSFU-2 and MSFU-3 are approximately same so the iron removal performance of these three plants are almost same. The iron removal performance of MSFU-4 was not observed as efficient as of MSFU-1, MSFU-2 and MSFU-3. Because the tube well water iron concentration of MSFU-4 was less than of MSFU-1, MSFU-2 and MSFU-3. Again as the tube well water iron concentration of MSFU-4 and MSFU-5 were same, so the iron removal performance of both plants were observed almost same. It is mentionable here that as the tube well water iron concentration of Sonakur (MSFU-6) was less than those of Kodda, Chalaj, Homna, Polua and Sadipur, so the iron removal performance of this plant was less than the others.

ii). Level of Performance:

On the basis of the above results and discussion the effect of raw water Iron concentration on Fe removal performance have been summarized (**Table 2**).

Table 2. Summary of the test results evaluating the effect raw water Iron concentration on Fe removal performance.

MSFU identification	Raw water Iron concentration (ppm)	Iron Removal %
MSFU-1	16	97.75
MSFU-2	15	97.27
MSFU-3	16	98.25
MSFU-4	8	93.75
MSFU-5	8	92.5
MSFU-6	4.6	89.13

The result reveals that higher the initial tube well water iron concentration, greater is the iron removal performance. Because the rate of ferrous iron oxidation is a function of ferrous iron concentration present in water. The level of performance have been presented in **Fig. 9**.

The trend of the iron removal performance with respect to initial iron concentration of tube well water achieved through the MSFU have been expressed through the equation,

$$y = 7.0146 \ln(x) + 78.48 \qquad \text{Eq. (1)}$$

Where, y = percentage of iron removal, x = tube well water iron concentration (ppm).

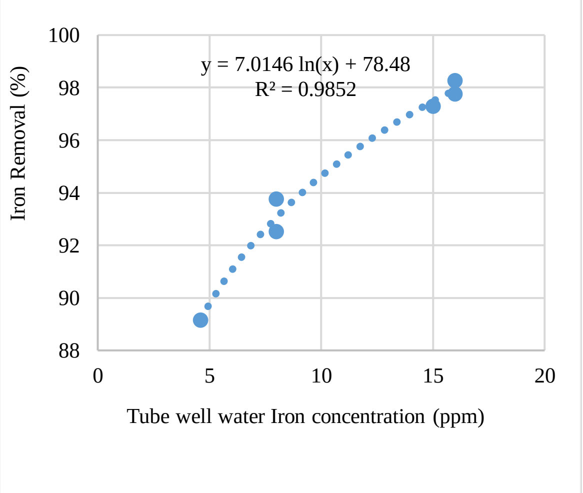

Fig.9. Effect of tube well water iron concentration on iron removal performance.

iii). Social Impact:

Presence of high concentration iron, arsenic and manganese in the tube well water discouraged the beneficiaries to use it for all domestic purposes. It was reported that before the construction of the MSFU(s) the tube wells were used only for toilet and cleaning purposes. After the construction of the

MSFU(s), the local people were attracted by the treated water quality and consequently the number of users were increased. The concentration of iron, manganese and arsenic in the treated water well below the acceptable limit of WHO guideline Value and Bangladesh Drinking Water Standard Value. As a result, people from the vicinity were inclined to use the treated water from the MSFUs and day by day number users were increasing since peoples from distant places started to use the treated water.

Conclusion

Through this study iron removal performance of Multi Stage Filtration Units (MSFU) treating tube well water having iron concentrations ranging from 4.6 to 16 ppm have been investigated. Investigation reveals that MSFU can be used effectively in removing iron from groundwater of Bangladesh. Depending on presence of raw water iron concentration around 89.13 to 98.25% iron removal performance was observed during the investigation. Iron removal performance was observed to be a function of initial iron concentration.

References

Abanda, V. (2021). Removal of Iron from Industrial Ground Water. *Trends Journal of Sciences Research.* 10.31586. 1-5. 10.31586/wastewater101005.

Ahmed, F. (2005). Development of community based arsenic & iron removal unit for rural water supply system, ITN Research Series 06, ITN-BUET, Dhaka, Bangladesh.

Aowal, A. F. S. A. (1981). Design of an iron eliminator for hand tube wells. *J. Indian W.W.A.* 13(1):65.

BGS and DPHE (2001). Arsenic Contamination of Groundwater in Bangladesh. Final Report, British Geological Survey and Department of Public Health Engineering, Government of the people's republic of Bangladesh.

BRTC (2006). Assessment of iron and manganese removal technologies for drinking water supplies in Bangladesh, Final Report, BRTC, BUET, Dhaka, Bangladesh.

Habib, M. E. (2013). Removal of manganese and arsenic from groundwater using manganese oxide coated sand. PhD Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Hasan, S. and Ali, M. A. (2010). Occurrence of manganese in groundwater of Bangladesh and its implications on safe water supply. *Journal of Civil Engineering (IEB).* 38(2): 121-128.

Hasan, K. M. (2003). Development of a community based arsenic - iron removal unit, M.Sc. Eng. Thesis, Dept. of Civil Engg. BUET, Dhaka.

ITN-BUET (2011). Assessment of the performance of modified AIRU under different hydro-goelogical conditions, International Training Network (ITN) and Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Mondol, M. M. R. (2020). Manganese removal from drinking water using roughing filtration. *Tech. J. River Res. Inst.*15(1):31-37.

Mondol, M. M. R. and Ahmed, F. (2014). Effect of tubewell water iron concentration on arsenic removal performance. *Tech. J. River Res. Inst.*12(2):127-135.

Mondol, M. R. (2009). Effectiveness of multistage filtration in removing iron, manganese and arsenic from ground water of Bangladesh, M.Sc. Engg. Thesis, Department of Civil Engineering. BUET, Dhaka, Bangladesh.

Steel, E. W. (1960). Water supply and sewerage. Fourth edition, Mc Graw-Hill Kogakusha, p. 217.

WHO, UNICEF, DPHE (1990). A report on study of improved iron plants.