Assessing Iron (II) and Fluoride Removals by Indigenously Fabricated Household Water Filter of North Guwahati

Barun Kanoo and Mohammad Jawed

Abstract Groundwater is the major source of water for domestic purposes in Amingaon, North Guwahati, Assam which is contaminated with high concentrations of iron and fluoride. The household-level treatment for iron removal includes the use of indigenously fabricated water filter units comprising sand, gravel, and wooden charcoal. The filter media are arranged in layered form in RCC rings, tin containers, and plastic buckets. The RCC filter unit is the most commonly used, especially for iron removal. However, the contamination level of groundwater of Amingaon and the effectiveness of indigenously fabricated household filter units in iron and fluoride removal is neither estimated/evaluated by government agencies nor reported in the literature. The present study aims to investigate the level of contamination of groundwater for iron and fluoride as well as efficiency and effectiveness of an RCC filter unit in the removal of iron and fluoride over a period of 6 months. The groundwater in and around the IIT Guwahati campus has a high concentration of iron (0–11.3 mg/L) whereas the concentration of fluoride is in the range 0.13–0.66 mg/L. A set of two samples, one from the tube well and the other from the filtered water, was collected at an interval of 3 days from a selected household RCC filter. Water quality parameters, viz., iron, fluoride, pH, temperature, conductivity, turbidity, and dissolved oxygen were estimated for the collected samples of each set. The selected RCC filter unit is able to produce filtered water containing residual iron concentration of 0–0.08 mg/L from an initial iron concentration of 8.13–11.63 mg/L. The selected filter unit is also able to reduce the fluoride concentration from a value of 0.51–1.17 mg/L to 0.39–0.77 mg/L. The DO level in the groundwater increases as the same is poured into the filter unit thereby converting ferrous iron to ferric form. The ferric form of iron is filtered out as precipitate in the filter unit.

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1 Introduction

More than 80% of the rural population in Assam depends on groundwater resources for drinking and irrigation purposes [1]. However, even for a city like Guwahati, groundwater is the major source of domestic water consumption. The reason being that Guwahati is a fast-growing city with the present population of about a million and with an inadequate supply of municipal water, hence, people have no choice but to extract groundwater for domestic use. Unfortunately, the groundwater contains excessive concentrations of dissolved iron and fluoride. Iron concentration in and around Guwahati is observed to be in the range of 1–10 mg/L [2] and fluoride in the range of 0.3–7 mg/L [3]. Even higher concentrations of fluoride in the range of 0.2–18.1 mg/L have been reported from Karbi Anglong and Nagaon districts [3]. The groundwater concentrations of iron and fluoride in different areas of Guwahati city have increased over the years. This could be due to geological reasons such as dissolution of minerals rich in iron and fluoride [4, 5]. The increasing dependency on the groundwater reserves and hence going for boring at much greater depths with depletion of groundwater can also be attributed to the increase of iron and fluoride. Amingaon is a rural locality in North Guwahati on the outskirts of the Guwahati city across the river Brahmaputra. Though a lot of development is taking place in North Guwahati area due to the establishment of IIT Guwahati, higher secondary schools, many small- and medium-scale industrial units, and other public facilities such as super-specialty hospitals, the population of Amingaon is still deprived of piped municipal water supply. Hence, a large population of Amingaon has no alternatives but to depend on the groundwater for their domestic water needs. However, there are no literature available to indicate the level of fluoride and iron concentrations in the groundwater of Amingaon, North Guwahati [3, 6].

The research of the past has yielded a number of methods to remove iron and fluoride from groundwater. The methods of iron removal basically involve oxidation, precipitate settling, and filtration [7, 8]. The methods of fluoride removal involve coagulation, flocculation, and filtration as well as filtration or adsorption alone [9]. However, these methods not only appear to be sophisticated but also need costly chemicals and adsorbents in some cases. The sophistication of these methods for iron and fluoride removal as well as poor economic conditions of the rural population residing in Amingaon area appears to be the reasons for non-application on the ground. Therefore, the people of Amingaon use different types of indigenous household water filter units fabricated using reinforced cement concrete (RCC) rings, tin containers, and clay pitchers to prepare potable water from groundwater. However, the filtering media used in these filters invariably consisted of sand, gravel, and wooden charcoal arranged either in layered form or a mixture of the two or three media. The filtering material, its percentage in the indigenous filter, and its arrangement vary from place to place and house to house. A mesh or net with small openings is provided below the filtering media to prevent escape of sand from the filter unit. The groundwater is applied to the indigenous filter intermittently as per the requirement of the household for drinking and cooking purposes. These filters are fabricated and operated solely based on the experiences of the local population gained and transferred from the previous generations. However, the performance of these indigenously fabricated household water filters in removing iron and fluoride from groundwater has not been assessed so far.

Hence, the objectives of this study are (a) to obtain first-hand information of 8–10 households using indigenously fabricated household water filter units, (b) to assess the quality of groundwater of Amingaon area in North Guwahati with special attention on iron and fluoride concentrations, (c) to understand the fabrication, operation, and maintenance of a selected filter unit, and (d) to monitor the performance of the selected filter unit for its potential to remove iron and fluoride from the groundwater.

2 Materials and Methods

2.1 Field Survey

A field survey was undertaken up to a distance of 600 m from the boundary of the IIT Guwahati campus. During the field survey, the first step was to identify the households which were having and using indigenously fabricated household water filter unit for its drinking and cooking water requirements. The GPS location of the identified households was noted down. The second step was to have a face-to-face interaction with the house owner to seek information mainly with respect to (i) details of physical location such as prominent landmark near IIT Guwahati, Village, Taluka, (ii) household details such as name of the house owner, his/her age, and education levels; main livelihood; number of people residing, (iii) type of indigenously fabricated household water filter in use, (iv) physical water quality parameters, (v) health status (with special emphasis on teeth color) of residents. In addition, groundwater samples were also collected to assess the levels of iron and fluoride present in the water.

2.2 Monitoring of a Selected Indigenously Fabricated Household Water Filter Unit

The filter unit at House No. 9 (refer Table 1) with GPS location 26° 11′ 11.2″ N and 91° 42′ 02.6″ E was selected for continuous monitoring. The reasons for selecting this filter unit were (a) the source of groundwater was located at a distance

Table 1 Summary of surveyed household characteristics using traditional water units in Amingaon, North Guwahati

Location	Left of Faculty Gate facing Faculty School			Lothia Bagisa, Bodogaon			Near Main Gate	Near ASEB Gate	Right of Faculty Gate facing Faculty school	
Village	Ghoramara, North Guwahati			Lothia Bagisa, Bodogaon			Kating Pahar	Abhaypur Shishugram	Ghoramara, North Guwahati	
Taluka	GMC (North Guwahati circle)			GMC (North Guwahati circle)			GMC (North Guwahati circle)	GMC (North Guwahati circle)	GMC (North Guwahati circle)	
District	Kamrup			Kamrup			Kamrup	Kamrup	Kamrup	
House number	1	2	3	4	5	6	7	8	9	10
Latitude	26° 11′ 11.6″ N	26° 11′ 10.1″ N	26° 11′ 09.6″ N	26° 10′ 59.5″ N	26° 11′ 01.7″ N	26° 10′ 58.6″ N	26° 11′ 49.1″ N	26° 11′ 59.5″ N	26° 11′ 11.2″ N	26° 11′ 11″ N
Longitude	91° 42′ 08.2″ E	91° 42′ 04.3″ E	91° 42′ 04.9″ E	91° 41′ 40.3″ E	91° 41′ 38.7″ E	91° 41′ 40.6″ E	91° 41′ 40.6″ E	91° 42′ 12.8″ E	91° 42′ 02.6″ E	91° 42′ 02.4″ E
Distance from IITG campus (m)	400	100	100	100–200	300–400	100–200	100–200	600	50	50
Main livelihood	Electric maintenance works in IITG	Govt. service (irrigation department)	Agriculture, Rented house	Puffed rice business	IITG mess worker	Pig business	Dairy business	Welding and farming	Rented houses, Conductor in bus, Grass cutter in IITG	Labor
Family size	11	3	9	8	8	1	18	7	3	2
Water for drinking purpose	Double compartment filter and then candle filter	Candle filter and then boil	Direct	Traditional filter	Traditional filter	Direct	Well-Filter-Boil	Direct	Double compartment Filter	Traditional filter
Water for other uses	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct
Odor problem	Slight	Slight	Yes	Yes	Slight	No	No	No	Yes	Slight
Color problem	Slightly muddy	Reddish	Reddish	Slight reddish	Slight reddish	Clean	Clear	Muddy	Reddish	Slightly Reddish
Pale teeth	Yes	No	No	No	No	Slight	No	No	Yes	No
		No	Yes	Yes	No	No	Yes		No	Yes

(continued)

Table 1 (continued)

Location	Left of Faculty Gate facing Faculty School			Lothia Bagisa, Bodogaon			Near Main Gate	Near ASEB Gate	Right of Faculty Gate facing Faculty school	
Village	Ghoramara, North Guwahati			Lothia Bagisa, Bodogaon			Kating Pahar	Abhaypur Shishugram	Ghoramara, North Guwahati	
Taluka	GMC (North Guwahati circle)			GMC (North Guwahati circle)			GMC (North Guwahati circle)	GMC (North Guwahati circle)	GMC (North Guwahati circle)	
District	Kamrup			Kamrup			Kamrup	Kamrup	Kamrup	
House number	1	2	3	4	5	6	7	8	9	10
Agriculture water supply system	Yes, in small quantity							Yes (by pond and tube well)		
Cleanliness near the water resource	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Groundwater iron concentration (mg/L)	0.22	1.21	1.53	2.31	1.11	1.56	0.00	0.52	11.30	3.73
Groundwater Fluoride concentration (mg/L)	0.44	0.51	0.36	0.43	0.59	0.56	0.13	0.35	0.66	0.62

ASEB: Assam State Electricity Board, GMC: Guwahati Metropolitan Corporation from the bank of river Brahmaputra with possibly minimum infiltration of river water, (b) the assessed iron concentration of 11.30 mg/L was the highest in the area, and (c) filter location was close to the Environmental Engineering Laboratory of the Department of Civil Engineering, IIT Guwahati (at a distance of 50 m) which shall facilitate in quick transportation of the collected water samples and its analysis.

The filter unit at House No. 9 collects the water from the groundwater source and then filters the stored water according to their need. Hence, it was deemed essential to collect two samples at a time—the first sample was collected directly from the source groundwater (i.e., tube well), and the second one was collected from the filtered water. The collected samples were analyzed for temperature, pH, conductivity, turbidity, DO, iron, and fluoride—taken as important water quality parameters for monitoring of filter performance. The water samples were collected once in 3–4 days and analyzed since July 2017.

2.3 Fabrication, Operation, and Maintenance of a Selected Filter Unit

The selected indigenously fabricated household water filter unit (commonly known as traditional water filter) is made of two compartments of reinforced cement concrete (RCC) rings (as shown in Fig. 1)—the upper compartment is filled up with the filter materials such as sand, wooden charcoal, and gravel (shown in Fig. 2) while the lower compartment is used for the storage of the filtered water. In the top compartment, a mesh net is put at the bottom and then a sand layer of depth of around 7–8 cm whereas, at the top, there is a layer of gravel with a depth of around

(a) Front View (b) Top View

Fig. 1 Selected indigenously fabricated household water filter unit

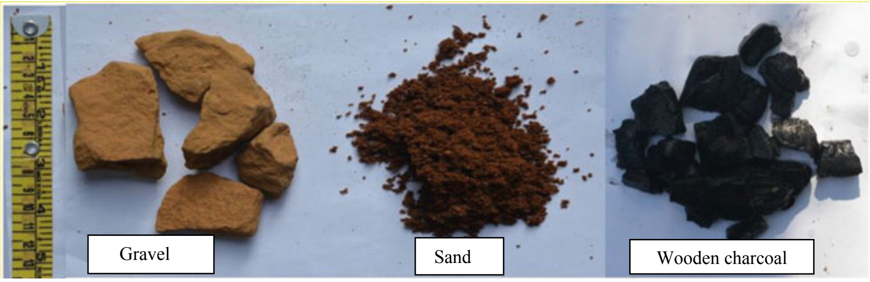

Fig. 2 Gravel, sand, and wooden charcoal used in the selected indigenously fabricated water filter unit

14–16 cm. Also, a layer of wooden charcoal is included as a filtering medium with a depth of 2–4 cm. The internal diameter of the filter unit is 32 cm and external diameter is 37 cm. The total height of the unit is 72 cm with each compartment of height 36 cm.

Approximately 8–10 L of the groundwater collected from the tube well is directly poured into the filter unit in one go for filtration. The filter unit is used to produce approximately 50–60 L of filtered water on a daily basis and the unit is operated for 3–4 months continuously. With use for 2–3 months, the filtration output decreases due to the formation of a reddish cake or a layer of precipitated iron on top of the filter media (as shown in Fig. 3) which indicated clogging of the filter unit. Once the filtration output decreases than the requirement of 50–60 L of filtered water per day, the sand and wooden charcoal are replaced with a fresh lot procured from the local market of Amingaon.

Fig. 3 Reddish layer formed on top of the filter media of the selected filter unit

2.4 Methods

Temperature, pH, conductivity, turbidity, DO, iron, and fluoride were selected as water quality parameters and were thus analyzed during the research work. Temperature and pH were determined by the digital pH meter (Model: μpH System 361, M/S Systronics India Ltd., India). Turbidity was measured using a digital turbidity meter (Model: 123, M/S Systronics India Ltd., India). Conductivity was measured with a digital conductivity meter (Model: LT-51, M/S Labtronics, India). DO was measured by the Azide Modification method [11]. DO level at the outlet was also measured by the micro-Winkler method (required only 1 mL of sample in contrast with 300 mL of sample required in the Modified Winkler's method [10]. Iron concentration in the water was analyzed by 1,10-Phenanthroline method [11] using a spectrophotometer (Model: Spectro V-11D, M/S MRC Ltd., the United Kingdom). The concentration of fluoride was analyzed by the SPADNS method [11] using a spectrophotometer. GPS locations were obtained using a smart mobile phone (Model: PA4C0020IN, M/S Motorola, India).

3 Results and Discussion

3.1 Field Survey

A field survey was carried out in Amingaon, North Guwahati area of 10 households using indigenously fabricated household water filter units in and around the campus of IIT Guwahati. The relevant information was obtained through personal face-to-face interaction with the house owner (or the landlady). The surveyed households were located at a distance of 50–600 m from the campus of IIT Guwahati and the number of members residing in the house varied from a low of 3 to a high of 21 persons. The educational level of the house owners was very diverse—from uneducated, class 5 pass, higher secondary pass to graduation (Bachelor of Arts) degree holder. The livelihood of the house owners was equally diverse—from daily wage workers to self-employed with small business or as welder, private, and government jobs. All of the surveyed households used one or the other type of traditional water filter units for their domestic water needs of drinking and cooking as the groundwater was reported to have odor problems and appeared to contain turbidity. The groundwater samples were also collected from the surveyed households for the assessment of concentrations of iron and fluoride. A brief summary of the surveyed households is presented in Table 1. The ranges of iron and fluoride concentrations in the groundwater of the surveyed locations are in the range of 0–11.30 mg/L and 0.13–0.66 mg/L, respectively. Pale teeth were observed in a few of the surveyed households which might not be attributed to fluoride as its concentration was within the permissible limits [12].

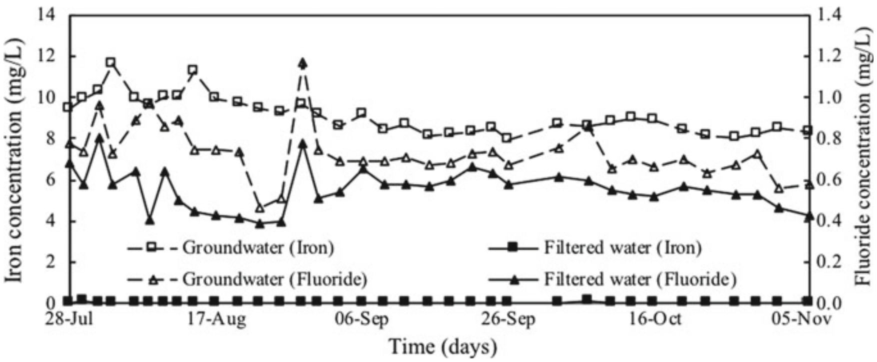

Fig. 4 Variation in iron and fluoride concentration during monitoring period of the selected filter unit

3.2 Performance Monitoring of the Selected Filter Unit

The performance of the selected filter unit was monitored since July 2017. The filter unit performance was assessed by estimating water quality parameters such as iron and fluoride concentrations, pH and temperature, conductivity and turbidity as well as DO levels on regular basis for water samples collected from the source groundwater and filtered water. The variation in iron and fluoride concentrations of groundwater and filtered water is presented in Fig. 4. The iron concentration ranged from 8.13 to 11.63 mg/L whereas fluoride concentration ranged from 0.51 to 1.17 mg/L in the groundwater samples. The groundwater after being filtered through the filter unit has had an iron concentration in the range of 0–0.08 mg/L while fluoride concentration was in the range of 0.39–0.77 mg/L. The concentration of fluoride in the filtered water was always within the permissible limit for drinking and cooking purposes. The removal of iron is taking place possibly due to oxidation of ferrous iron to ferric iron. The ferric iron is forming a reddish color cake which might be able to reduce the concentration of fluoride a bit.

The pH of the groundwater was measured immediately after the sampling to represent the true picture. The pH of the groundwater sample varied in the range of 6.17–6.81. The pH of the filtered water from the unit is in the range 6.82–7.51 which is within the permissible limit of 6.5–8.5 for domestic use [12]. It is observed that the increase in pH is favorable for the precipitation of iron. The temperature keeps on varying and is not constant. It very much depends on the weather conditions for that particular sampling day. The variation in pH and temperature is shown in Fig. 5.

The conductivity of the groundwater samples collected from the tube well and the filtered water did not show major changes and is almost the same ranging from 0.4 to 1.1 mS/cm. The turbidity of the groundwater varied in the range of 0.7–1.5 NTU. It is directly proportional to the time gap between sampling and analysis for turbidity. The main reason is oxidization of Fe^{2+} to Fe^{3+} and the formation of

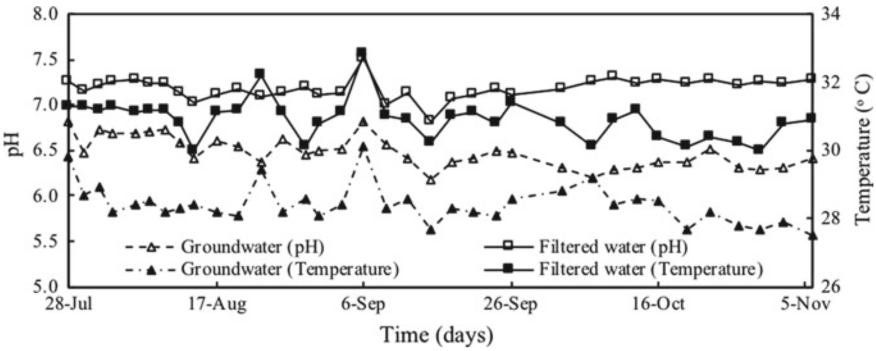

Fig. 5 Variation in pH and temperature during monitoring period of selected filter unit

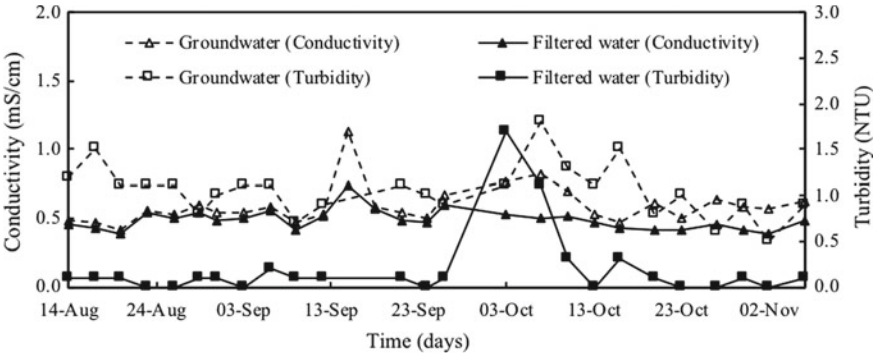

Fig. 6 Variation in conductivity and turbidity during monitoring period of the selected filter unit

precipitates which produces visible turbidity. The turbidity of the filtered water ranged from 0 to 0.2 NTU which is within the permissible limit of less than 1 NTU [12]. The variation in conductivity and turbidity of groundwater and filtered water is shown in Fig. 6.

The collected groundwater samples from the tube well showed no DO. However, when the groundwater is poured into the filter unit, it absorbed oxygen from the air and showed DO in the range of 1.0–2.4 mg/L. This level of DO might have helped in the conversion of ferrous iron into ferric iron and its retention on top of the filter media. Therefore, the mechanism of iron removal from the groundwater is the conversion of ferrous iron to ferric iron and its filtration through the filter media. The filtered water contained DO levels of 5.9–6.7 mg/L. The DO levels in the filtered water were also analyzed using the micro-Winkler method [10] which produced almost similar results with modified Winkler method. The variation in DO levels in groundwater, influent water to the filter, and filtered water is shown in Fig. 7.

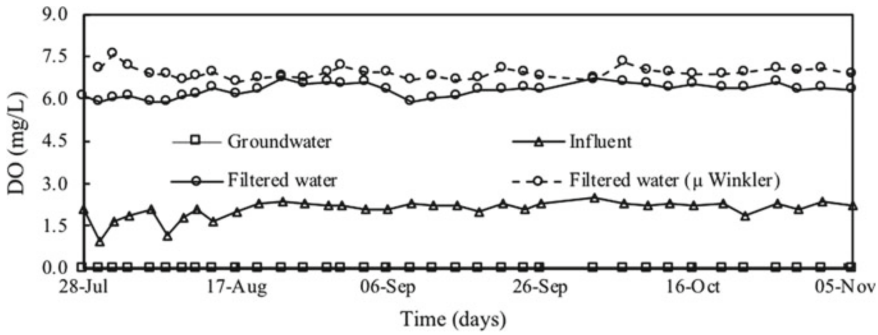

Fig. 7 Variation in dissolved oxygen during monitoring period of the selected filter unit

The monitored performance-related parameters of the selected indigenously fabricated household water filter unit are summarized on a monthly basis and presented in a tabular form in Table 2.

Table 2 Summary of monitored performance parameters for the selected water filter unit

Water quality parameters		Monitoring period		
		July 28, 2017 to August 31, 2017	September 01, 2017 to September 31, 2017	October 01, 2017 to November 06, 2017
Iron (mg/L)	Groundwater	9.94 ± 0.67 (15)	8.43 ± 0.40 (09)	8.50 ± 0.31 (11)
	Filtered water	0.03 ± 0.02 (15)	0.02 ± 0.01 (09)	0.04 ± 0.01 (11)
Fluoride (mg/ L)	Groundwater	0.80 ± 0.18 (15)	0.70 ± 0.02 (09)	0.68 ± 0.08 (11)
	Filtered water	0.55 ± 0.14 (15)	0.60 ± 0.04 (09)	0.53 ± 0.05 (11)
pH	Groundwater	6.59 ± 0.13 (15)	6.47 ± 0.17 (09)	6.33 ± 0.08 (11)
	Filtered water	7.17 ± 0.07 (15)	7.12 ± 0.18 (09)	7.25 ± 0.04 (11)
Temperature (°C)	Groundwater	28.53 ± 0.49 (15)	28.47 ± 0.67 (09)	28.20 ± 0.53 (11)
	Filtered water	31.30 ± 0.52 (15)	31.14 ± 0.7 (09)	30.53 ± 0.40 (11)
Conductivity (mS/cm)	Groundwater	0.51 ± 0.06 (07)	0.61 ± 0.20 (09)	0.62 ± 0.11 (11)
	Filtered water	0.48 ± 0.05 (07)	0.54 ± 0.09 (09)	0.45 ± 0.05 (11)
Turbidity (NTU)	Groundwater	1.11 ± 0.21 (07)	0.97 ± 0.15 (07)	1.05 ± 0.38 (11)
	Filtered water	0.07 ± 0.05 (07)	0.08 ± 0.07 (07)	0.33 ± 0.55 (11)
Dissolved oxygen (mg/L)	Groundwater	0.00 ± 0.00 (15)	0.00 ± 0.00 (09)	0.00 ± 0.00 (11)
	Influent water above filter media	1.93 ± 0.40 (15)	2.18 ± 0.11 (09)	2.25 ± 0.16 (11)
	Filtered water	6.23 ± 0.26 (15)	6.24 ± 0.21 (09)	6.46 ± 0.12 (11)
	Filtered water (by μ Winkler)	6.92 ± 0.25 (14)	6.84 ± 0.15 (09)	6.97 ± 0.17 (11)

[The data is presented in $a \pm b$ (c) format where a is the average value, b is the standard deviation, and c is the number of data points considered for obtaining the average and standard deviation]

4 Summary

The groundwater in and around IIT Guwahati campus has a high concentration of iron (0–11.3 mg/L), often exceeding the acceptable range of 0.3 mg/L whereas the concentration of fluoride in the range of 0.13–0.66 mg/L is within the acceptable limit of 1–1.5 mg/L for domestic purposes. The local population of Amingaon, North Guwahati, irrespective of educational qualification and age, livelihood and occupation, invariably use an indigenously fabricated household water filter units (also known as traditional water filters) fabricated of RCC rings, tin containers, and plastic buckets filled with filtering media comprising sand, gravel, and wooden charcoal in layered form. A selected filter unit is monitored since July 2017 that produced filtered water containing residual iron concentration of 0–0.08 mg/L from an initial iron concentration of 8.13–11.63 mg/L. The selected filter unit is also able to reduce the fluoride concentration from a value of 0.51–1.17 mg/L to 0.39–0.77 mg/L. The DO level in the groundwater increases as the same is poured into the filter unit thereby converting ferrous iron to ferric form. The ferric form of iron is filtered out as precipitate in the filter unit.

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