Removal of iron from groundwater by ash: A systematic study of a traditional method

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Abstract

A traditional method for removal of iron from ground water by using ash has been systematically investigated. Ashes from five different sources, viz., banana rind, banana pseudostem, banana leaf, rice husk and bamboo has been studied. The principle applied is enhanced precipitation of iron at high pH caused by ash. The study included laboratory analysis of some relevant chemical parameters of the ashes and the efficiency of the ashes in removing iron from prefabricated water with respect to quantity of ash and corresponding increase in pH of water. The ash of banana pseudostem has been found to be most suitable for removal of iron. A low-cost and easily made iron removal system for household use has been designed and tested in the laboratory. The ash of banana pseudostem has been found to remove iron to below 0.3 ppm without increasing the pH above the acceptable limit. The optimum values of the different parameters for removal of iron are 200–300 mg l^{-1} ash, 1.0 l h^{-1} flow rate and 1 h of contact time with ash for groundwater having [Fe] of about 2.20 ppm. The amount of ash can be increased for groundwater having higher [Fe] and can be decreased gradually during continuous use of the system. Acceptability of the method has been examined based on chemical analysis of the treated water. Increase in the essential minerals such as Ca, K has been observed in the water after treatment. The designed iron removing system is expected to be suitable for household use.
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1. Introduction

Iron is one of the most abundant elements of the earth's crust. Groundwater easily gets contaminated with iron usually in its (+II) valence state. Although iron is an essential mineral for human, its presence in groundwater above a certain level make the water unusable mainly for aesthetic considerations such as discoloration, metallic taste, odor, turbidity, staining of laundry and plumbing fixtures. Moreover, iron oxides, which are formed in reservoirs upon aerial oxidation of dissolved iron promotes growth of micro-organism in water. Thus, World Health Organization has set a guideline value of 0.3 ppm of iron in drinking water [1].

Aeration and separation is the most common method for removal of iron from groundwater in public water supply systems, which is however not so popular at domestic level. The iron content in surface water is very low due to natural aerial oxidation of iron to its oxides, which subsequently separate out. There are various other methods for iron removal from groundwater, viz., ion-exchange method [2], oxidation with oxidizing agents such as chlorine and potassium permanganate [3], activated carbon and other filtering materials [4], supercritical fluid extraction [5], bioremediation [6] and treatment with limestone [7].

Traditional knowledge or practices sometimes provide vital clue to solving great problems. Assam is a state in the eastern part of India, where the groundwater is highly contaminated with iron [8–10]. The villagers in Assam have been traditionally using charcoal/ash–sand filtration systems for removal of iron. The charcoal is sometimes used without ash, often mixed with ash and sometimes it is mostly ash. The ash–charcoal mixture

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used is obtained from different types of firewood including bamboo. They indiscriminately use any ash or ash–charcoal mixture. Interestingly, the water, which is obtained from hand tube-well or ring-well is put in the filter system and collected through the filter immediately, did not seem to retain iron. The iron free water was then sometimes subjected to zeolite filter before use. The use of ash or charcoal is expected to facilitate removal of iron by making the water alkaline, which subsequently precipitates iron as geothite or ferrihydrite [11–13]. However, no systematic scientific study on this traditional practice has been reported, whereas, such a study is also necessary to ensure safety in using the treated water.

On the other hand, the ash obtained from banana rind of a particular species of banana, viz., *Musa Sapiontum* Linn., is still used for cooking as a substitute of edible soda by villagers in Assam. The ash obtained from banana rind, banana pseudostem and rice husks are used also for washing cloths and utensils in Assam and Manipur, a neighboring state. Rice husk and its ash have been reported to be useful for removal of phenols from aqueous solution [14,15]. Banana ash is known to be rich in potassium [16]. In these cases also, potassium salts or hydroxide are expected to facilitate washing in addition to the function of the ash as a scrubber. Villagers put pieces of leaf of banana into milk in container to increase self-life of fresh milk during transportation. The potassium of banana leaf probably makes the milk alkaline and thereby inhibits degradation. The uses of the above-mentioned plant materials prompted us to choose their ashes, viz., ashes obtained from bamboo, rice husk and rind, pseudostem and leaf of banana. These materials are not known to be toxic, rather at least one product from all the plants is edible. The objectives of the present work were to evaluate the ashes with respect to their relevant chemical parameters, their effect on pH of water, their efficiency in removing iron, selected chemical parameters of water after treatment and finally to design a low-cost system for the filtering process.
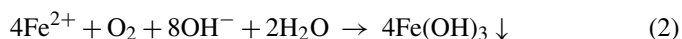
2. Materials and method

The active materials, i.e., ashes were prepared by burning the dried plant materials. A 500 mg of the dried materials taken in a porcelain crucible was burnt at 500 °C in a muffle furnace for 4 h [17]. Since the oxides or salts of the metals of our interest, viz., Na, K, Ca, Mg and Fe are soluble in acidic medium, the metal ions were extracted from the ash by heating and stirring it on a magnetic stirrer cum hot plate for 10 min with 10 ml of 1 M HCl [17]. A small fraction of the ash remained insoluble and was filtered out using Whatman Grade 2 filter paper. The filtrate was then transferred into a 50 ml volumetric flask and diluted to the mark with double distilled water. This solution was used for determination of the metal ions in all five types of ashes. The relevant metal ions present in the solutions (ash samples) were determined by using atomic absorption spectrophotometers models—Chemito AA203 or Perkin-Elmer Analyst 200. The ashes used for iron removal study were also prepared by burning the dried materials in muffle furnace at 500 °C for 4 h. The Fe concentrations in the filtrates were sometimes determined by the 1,10-phenanthroline method [18] also

using a Hitachi U-2001 UV–vis spectrophotometer fitted with thermostated cell holders. The pH of the filtrates was measured using a Systronics μ-pH system 361. Total alkalinity (TA) was determined by the standard titration method [19]. Total hardness (TH) was calculated from concentrations of Ca^{2+} and Mg^{2+} ions [20].

The efficiency of the ashes of these plant materials in precipitating iron from groundwater was initially studied by mixing the different ashes with fixed quantities of water in closed conical flasks (Erlenmeyer flasks), since the dissolved iron is separated from water mainly by the increase in the pH and not by adsorption on the ash, unlike in the case of charcoal. A 50 ml of ground water having Fe concentration of 2.20 ppm were placed in a conical flask and varying amounts of ashes were added to them, stirred on a magnetic stirrer for 1 min in order to mix the ash thoroughly and filtered after 1 h using Whatman Grade 2 filter paper. The concentrations of Fe and pH of the filtered water were determined in order to identify the suitable ash.

The principle applied in the study has been oxidation of iron by aeration and precipitation of iron by increasing pH by adding the ashes. Ground water is generally deprived of oxygen and so has a high content of reduced iron. Iron exists in solution in the ferrous state, usually as ferrous bicarbonate. It can only remain in solution in the absence of oxygen, and generally when the pH is below 6.5. When such water is treated with ash, viz., ash of banana pseudostem, KOH is formed in water from K_2O and K_2CO_3 present in the ash. In the presence of oxygen at high pH, the soluble Fe^{2+} is converted to insoluble geothite (FeOOH) or ferrihydrite ($Fe(OH)_3$) [11–13]:

$$2Fe^{2+} + O_2 + 2OH^- \rightarrow 2FeOOH \downarrow \qquad (1)$$

$$4Fe^{2+} + O_2 + 8OH^- + 2H_2O \rightarrow 4Fe(OH)_3 \downarrow \qquad (2)$$

The precipitation is sufficiently rapid when the pH is above 7.5. However, the pH of the treated water should remain within the optimum range of 6.5–9.5. Optimization of pH is necessary to increase the removal efficiency within acceptable pH.

An iron removal technique that involves precipitation by the ash of banana pseudostem and aerial oxygen coupled with a reverse filtration has been fabricated as shown in Fig. 1. This simple iron removing system has been designed for household use and is similar to the one used in the rural areas except that a cloth filtering bed with reverse filtering is used here instead of a sand filter. The system consists of an precipitation unit (Part A) made up of Al-alloy of approximately 20 cm of radius to oxidize soluble iron and collection unit (Part B) with a polyester cloth fixed filter bed to separate the precipitates at the bottom. In Part A, ash converts soluble iron salts into insoluble geothite or ferrihydrite. Iron containing ground water is mixed with ash by stirring with a rod for 1 min in Part A. The Part A is kept open so that the water remains in contact with air for promoting oxidation. A tap in the outlet of the Part A controls the flow rate. Gravitational sand filter is used in the traditional method of iron removal. However, in the present system, a polyester cloth is used in the filter bed along with reverse filtering. A cyclic crossed metallic or bamboo frame is fixed at 1 in. above the inlet to Part B at the lower side of Part B. A ring of approximately
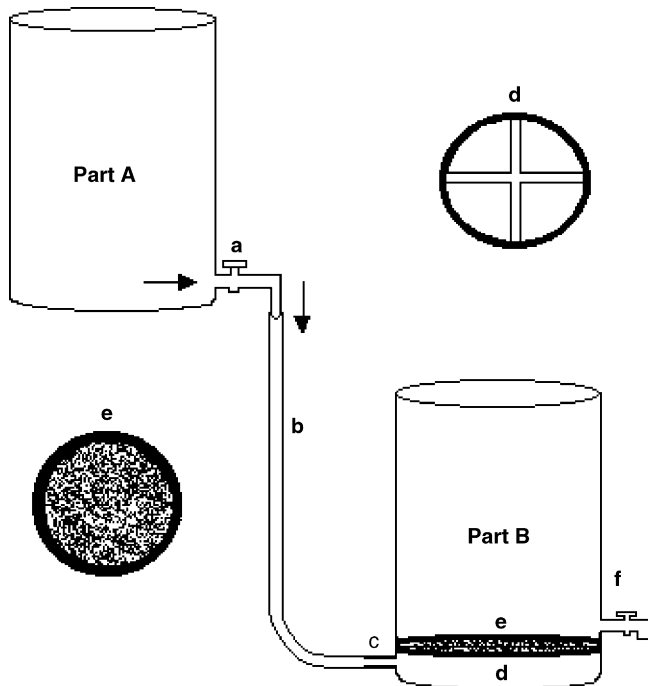
Fig. 1. Iron removal system for treatment of groundwater by treatment with ash and reverse filtration. Part A: (a) outlet for water treated with ash cum tap to control filtration rate, (b) rubber or plastic tube. Part B: (c) inlet to Part B, (d) cross shaped fixed filter support that is placed 1 in. above the inlet, (e) circular ring of about 1/4 in. thickness to hold the polyester cloth which is placed above the support d, (f) outlet for purified water.

the deposited iron precipitates and also for cleaning or replacing the cloth-filter when needed.

The trials were made in the laboratory with prefabricated water. The iron content of the freshly withdrawn groundwater was determined by atomic absorption spectroscopy and the prefabrication with [Fe] of 2.20 and 5.20 was done by adding calculated amount of freshly prepared ferrous sulfate to freshly withdrawn groundwater. The initial pH of water was about 6.8. The amount of dissolved oxygen and Mn in the groundwater was not taken into consideration in the present study although inclusions of these are relevant parameters. Removal of iron by the present system has been studied with prefabricated water with the two initial iron concentrations, viz., 2.20 and 5.20 ppm with varying quantities of ash at varying contact times of water with ash and at flow rates of 1.0, 1.5 and $2.0\,1\,h^{-1}$.

3. Results and discussion

The results of determination of the metal ions, viz., K, Na, Ca, Mg and Fe in the ashes are shown in Table 1. Potassium was the major element in all the samples which is 563.4, 595.0, 550.0, 175.0 and 77.0 in banana pseudostem, banana leaf, banana rind, rice husk and bamboo wood, respectively. It is present above 500 ppm in the ashes obtained from all three parts of banana plant. Sodium contents were very low compared to potassium as expected. The Ca content also is high in all three samples of banana plant, compared to rich husk and bamboo wood. As the

19 cm in diameter and 3 cm in thickness wrapped up with one or two layers of polyester cloth of medium mesh size (the exact mesh size is not known) is placed tightly on the fixed frame. The water passes upward through the cloth filter bed leaving the suspended solids below the cloth. Care has been taken to ensure that there is no gap between the ring and the inner side if the Part B, to avoid upward passage of water without being filtered. An outlet tap is fixed just above the filter bed in the Part B for collecting the iron free filtered water. The reverse filtering allows settling of the precipitates of iron at the bottom of the collection unit without affecting much the polyester cloth filter, which can last for long time. There are provisions for flushing out

Table 1
Amounts of some elements in ppm present in the ash of banana (pseudostem, leaf and rind), rice husk and bamboo wood

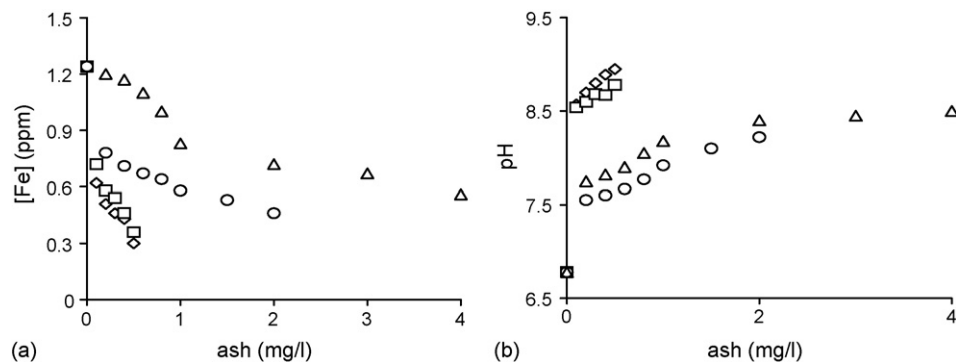| Element	Amount present in ash (ppm)				
	Banana			Rice husk	Bamboo wood
	Pseudostem	Leaf	Rind		
Fe	0.54	0.40	0.96	0.82	0.80
Ca	32.15	50.49	40.00	14.60	46.50
Mg	7.91	2.31	4.56	2.47	8.66
K	563.40	595.00	550.00	175.00	77.00
Na	1.31	1.84	1.78	1.94	1.47

Fig. 2. Concentration of Fe in ppm (a) and pH (b) of filtrate water vs. amount of different ashes in $mg\,l^{-1}$ of water after precipitation of iron in Erlenmeyer flask by mixing with ash of rice husk (△), bamboo wood (○), banana rind (□) and banana pseudostem (◇). Initial concentration of Fe = 2.20 ppm, initial pH 6.80 and residence time = 1 h.

Table 2
Selected water quality parameters, viz., pH, concentrations of Na, K, Ca and Mg, total hardness and total alkalinity before and after treatment with varying quantities of banana pseudostem ash with retention time of 1 h in the fabricated iron removal system

Parameter	Before treatment	After treatment with ash and filtering, amount of ash added (mg l^{-1})					Acceptibility limits
		200	250	300	350	400	
pH (upper limit)	6.80[a]	8.10	8.30	8.55	8.80	9.00	6.5–9.5[b]
Na (ppm)	5.62	8.22	8.70	9.35	9.80	10.45	200.00[c]
K (ppm)	8.75	45.24	53.40	61.86	68.90	76.55	–
Ca (ppm)	0.72	1.14	1.25	1.35	1.48	1.60	–
Mg (ppm)	2.61	3.90	4.50	4.95	5.40	5.82	–
Total hardness (ppm)	12.55	16.91	21.65	23.75	25.94	28.00	500.00[c]
Total alkalinity (ppm)	69.54	128.10	143.60	156.72	175.00	200.00	–

[a] Initial value.
[b] Optimum pH range.
[c] WHO guideline values.

quantity of ash obtained from banana leaf is very small compared to the others, it was excluded from the further studies.

Iron content and pH of the filtered water after precipitation of iron by the ashes in conical flasks, are shown in Fig. 2. The drinking water guideline values of WHO for iron is 0.3 ppm [1]. Although no health-based guideline value was proposed for pH in the 1993 guideline and pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters, the optimum pH required is in the range of 6.5–9.5 (Table 2). The acceptable maximum pH limit for public water supply is also considered as 8.5 [21]. It can be seen from the figure that with other parameters remaining same, only about
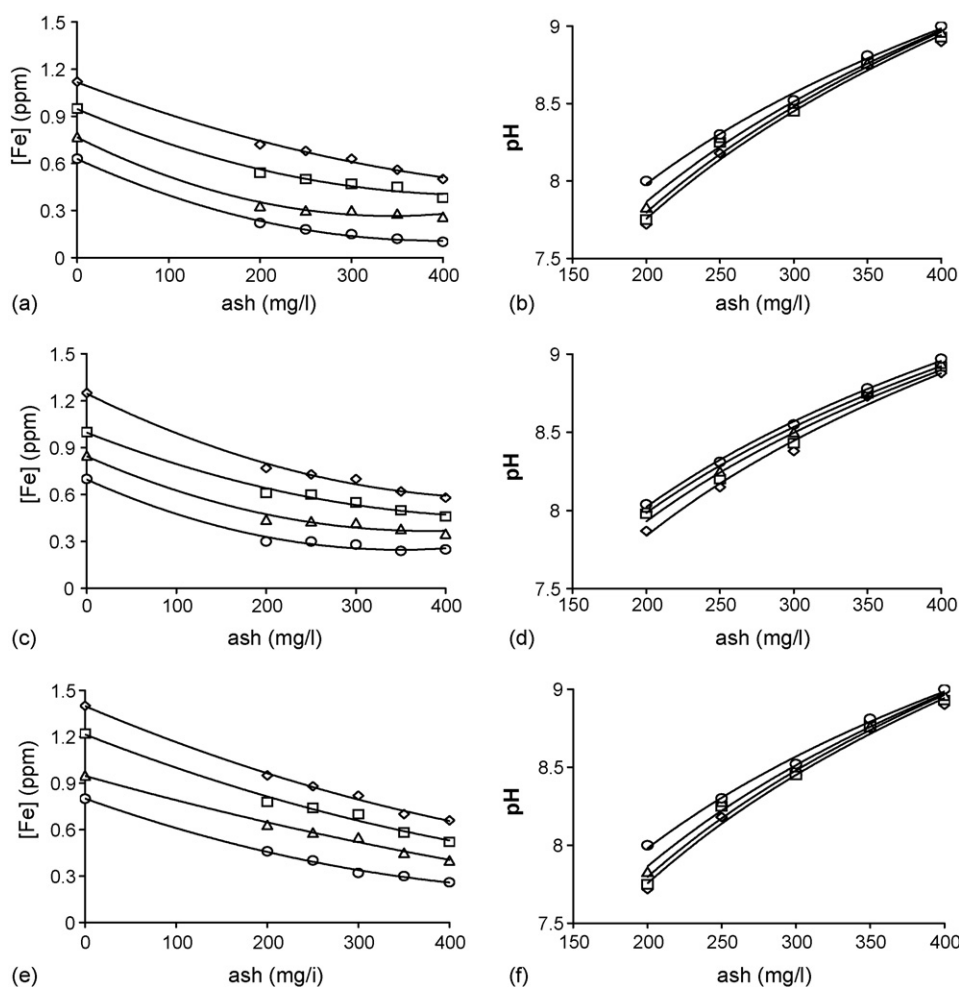

Fig. 3. Concentration of Fe in ppm and pH vs. amount of added ash in mg l^{-1} of water obtained from the fabricated filter system shown in Fig. 1 at varying residence time and flow rate with initial [Fe] = 2.20 ppm and initial pH 6.80. Residence time: 5 min (◊); 30 min (□), 1 h (△) and 2 h (O). Flow rates: 1 l h^{-1} (a and b), 1.5 l h^{-1} (c and d) and 2 l h^{-1} (e and f).

$0.5\,mg\,l^{-1}$ of the ashes of banana pseudostem and banana rind decreases the concentration of Fe to 0.30 and 0.36 ppm, respectively. The trends in the plots for these two ashes indicate that further increase in the amounts of these two ashes should further lower the iron concentration. Whereas, $4\,mg\,l^{-1}$ of rice husk ash and $2\,mg\,l^{-1}$ of bamboo ash decreased the Fe concentration to only 0.56 and 0.46 ppm, respectively (Fig. 2). The poor removal of iron by rice husk ash suggests that the iron is not removal by sorption on silica, which is a major component of the rice husk ash [22,23]. One can notice in Fig. 2 that even without addition of ash the concentration of Fe decreased from 2.20 ppm to about 1.21 ppm which can be attributed to removal of iron due to aerial oxidation alone.

The pH of water with added ashes, were found to increase in the order: bamboo < rice husk < banana rind < banana pseudostem (Fig. 2). On the addition of rice husk ash and bamboo wood ash $4\,mg\,l^{-1}$ and to $2\,mg\,l^{-1}$ increased the pH of the water to 8.50 and 6.78, respectively. However, $0.5\,mg\,l^{-1}$ of the ashes of banana pseudostem and banana rind which could reduce the Fe concentration to or near to the WHO guideline value, increased the pH up to 8.95 and 8.78, respectively, which

are within the optimum pH range of 6.5–9.5. The poor iron removal by rice husk and bamboo wood ashes can be attributed to lower potassium content of these ashes and corresponding less enhancement of pH.

From the above data, it has been seen that the ashes of banana pseudostem and banana rind are the most effective materials for iron precipitation compared to the other three plant materials. This observation explains the traditional use of banana ash as base but slightly differ with the traditional preference of banana rind over the pseudostem for the purpose. The results however indicate banana pseudostem ash as the best candidate for precipitating iron from groundwater. Moreover, the availability of the pseudostem is much higher compared to the rind. Henceforth, the further study of removal of iron by using the fabricated water treatment and filtering system has been confined only to banana pseudostem.

The fabricated iron removing system described above (Fig. 1) has been used for studying its effectiveness in bringing down the iron level to below 0.3 ppm. Some results with water of two initial iron concentrations, viz., 2.20 and 5.20 ppm of iron at flow rates of 1.0, 1.5 and $2.0\,l\,h^{-1}$ are shown in Figs. 3 and 4.
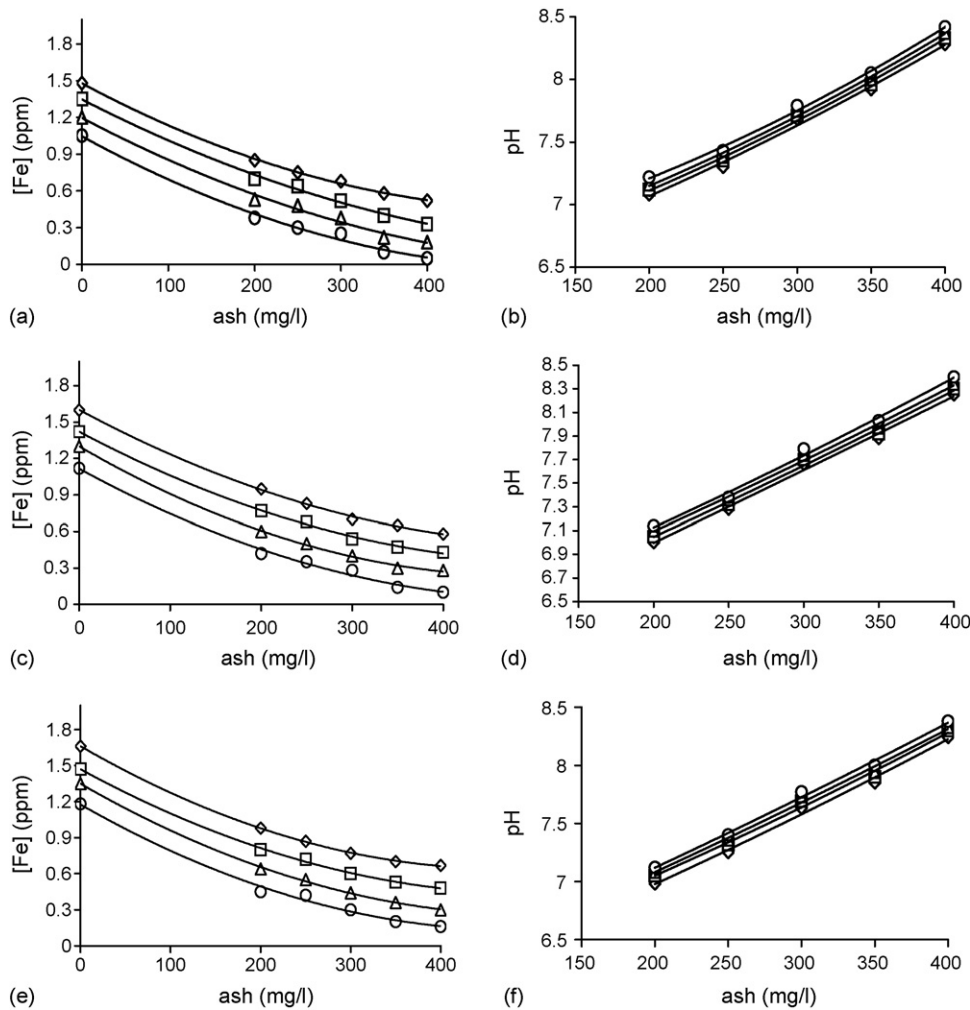

Fig. 4. Concentration of Fe in ppm and pH vs. amount of added ash in $mg\,l^{-1}$ of water obtained from the fabricated filter system shown in Fig. 1 at varying residence time and flow rate with initial [Fe] = 5.20 ppm and initial pH of 6.80. Residence time: 5 min (◇); 30 min (□), 1 h (△) and 2 h (○). Flow rates: $1.0\,l\,h^{-1}$ (a and b), $1.5\,l\,h^{-1}$ (c and d) and $2\,l\,h^{-1}$ (e and f).

Better iron removal is observed with increase in the amount of ash, higher residence time and slower filtration rate. However increases in the quantity of ash and residence time increase the pH as well. On the other hand an increase in the flow rate of water results in poorer iron removal and lesser elevation of the pH. This can be attributed to escape of minute iron hydroxide or oxide particles through the filtering bed at higher flow rate. It has also been observed from Figs. 3 and 4 that larger quantity of ash and higher residence time is required to bring down the Fe concentration to the 0.3 ppm level. Interestingly, the increases in the pH, from its initial value of 6.8, were less with initial [Fe] of 5.20 ppm than with initial [Fe] of 2.20 ppm. This is obvious because with higher initial [Fe], more ash and hence more hydroxide ions is used up in precipitating Fe as hydroxide. It is desirable to have the upper limit of pH lower than 9.5. Thus, an amount between 200–350 mg l^{-1} of the ash, a flow rate of 1.0 l h^{-1} and a residence time of 1.0 h seem to be the optimum values of these parameters.

The efficiency of the fabricated iron removing system and the increases in the pH of the water have been studied also with continuous use of the same filter bed for 34 h and the results are shown in Fig. 5. The Fe removal system was run for 34 h because at about 34 h, the [Fe] and pH level off in their plots versus time. The difference in iron removing ability of the present system with added banana pseudostem ash from that without added ash as shown in the figures clearly indicates that with added ash the system works much more efficiently. It can be seen from the figure that [Fe] is gradually decreased from 5.20 and 2.20 ppm to 0.52 and 0.40 ppm, respectively, even in the absence of the ash. The observed decrease in iron concentration in the absence of the ash is attributed to aerial oxidation of the dissolved iron. On the addition of 200, 250, 300 and 350 mg l^{-1} of the ash, [Fe] decreased to below 0.30 ppm after run time of 22, 18, 14 and

12 h, respectively, for initial [Fe] of 5.20 ppm with flow rate and residence time were 1.5 l h^{-1} and 5 min, respectively. On the other hand, with initial [Fe] of 2.20 ppm, under same flow rate and residence time the [Fe] is brought to below 0.30 ppm by 200, 250, 300 and 350 mg l^{-1} of the ash after run time of 16, 14, 12 and 10 h, respectively. It is evident from the results shown in the figures that iron removal becomes better on continuous use of the same filter bed (polyester cloth) for long time. This may be attributed to decrease in the mesh size of the cloth due to sticking of precipitate to the filtering cloth, on continuous use of the same filter bed. Another reason for this may be an increase in actual amount of ash due to accumulation of excess ash in the ash treatment compartment, which is added from time to time. This explanation is supported by the increase in the pH of the filtered water on continuous use of the bed. Nevertheless, even after continuous use of the filter bed continuously up to 34 h when the container A (Fig. 1) was refilled for 17 times, the pH remained within 8.5 except for water having 2.20 ppm of iron with 350 mg l^{-1} ash (Fig. 5d). On continuous use of the system, the increases in pH were less for water having [Fe] of 5.20 ppm than in the case of 2.20 ppm suggesting consumption of more hydroxide ions with higher concentration of iron.

Some selected chemical analyses of the water before and after filtration have been carried out and the results are shown in Table 2 and Fig. 6. The values of all parameters, viz., TH, TA, [K], [Na], [Ca], [Mg] and the upper limit of pH of the water increased upon treatment from their initial values with increase in the amount of ash. The values of the TH and TA increased from initial values of 12.6 and 69.6 ppm to maximum values of 28.0 and 200.0 ppm, respectively, with 400 mg l^{-1} of ash. Similarly, the concentrations of K, Na, Ca and Mg increased from their initial values of 8.75, 5.62, 0.72 and 2.61 ppm to 76.5, 10.5,
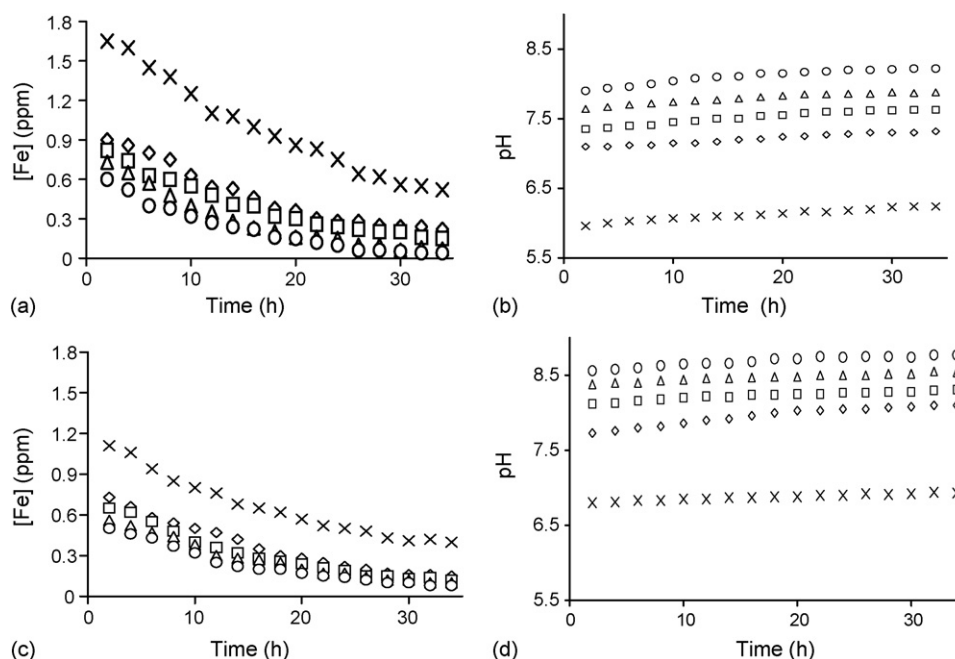

Fig. 5. Concentration of Fe in ppm (a and c) and pH (b and d) of treated groundwater obtained from the fabricated iron removal system vs. run time with initial [Fe] = 5.20 ppm and pH 6.00 (a and b) and 2.20 ppm and pH 6.80 (c and d). Amount of ash in mg l^{-1} of water: 0.0 (×), 200 (◊), 250 (□), 300 (△) and 350 (O).
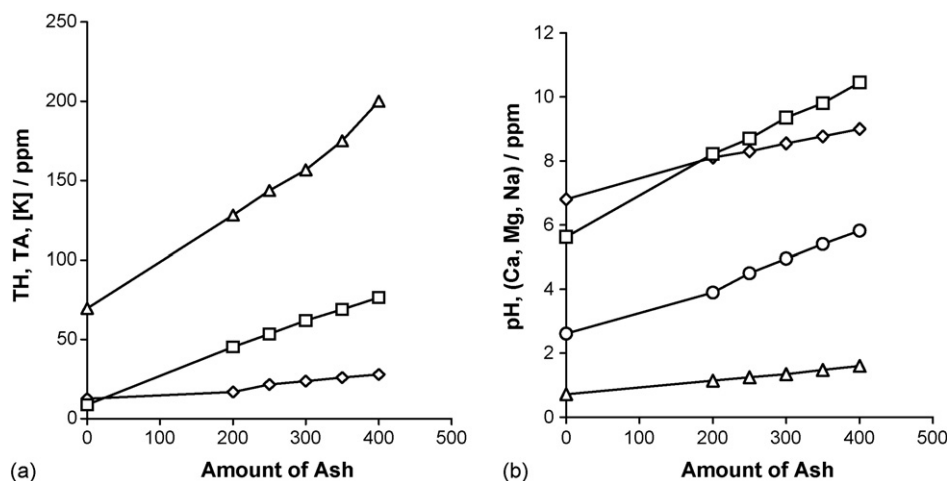
Fig. 6. Selected chemical parameters of water before and after filtering after treatment with ash of varying amounts in mg l^{-1}. Symbols: (a) $\triangle$, TA; $\square$, K; $\diamond$, TH; and (b) $\square$, Na; $\diamond$, pH; $\bigcirc$, Mg; and $\triangle$, Ca.

1.6 and 5.62 ppm, respectively, with 400 mg l^{-1} of ash. The maximum pH values of the treated water increased from its initial value of 6.80 to 8.01, 8.30, 8.55 8.80 and 9.00 with added ash amounts of 200, 250, 300, 350 and 400 mg l^{-1}, respectively. Nevertheless, none of them was found to increase beyond the guideline values, when the quantity of the ash was in the range of 200–350 mg l^{-1} of water.

4. Conclusion

The traditional method of using ash for removal of iron from groundwater can remove iron to desired level without increasing the pH beyond the acceptable limit. Among the different plant ashes studied, the banana pseudostem ash has been found to be most suitable for removal of iron. The ash enhances removal of iron. The designed iron removing system is expected to be suitable for household use. The optimum values of the different parameters for removal of iron are 200–300 mg l^{-1} ash, 1.0 l h^{-1} filtration rate and 1 h of residence time for groundwater having [Fe] of about 2.20 ppm. The amount of ash can be increased for groundwater having higher [Fe] and can be decreased gradually during continuous use. The technique has some advantages, viz., low manufacturing cost, almost nil recurring cost, no electricity requirement, simplicity in use and increase in the essential minerals such as Ca, K in the treated water.

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