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Contamination and Removal of Iron and Fluoride from Groundwater by Adsorption and Filtration: A Review

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Abstract

The problems related to groundwater contamination by Iron and Fluoride are common and serious all over the world, especially in developing countries. Excess amounts of these contaminants have created health problems. For this reason, the maximum permissible limit for iron given by WHO and BIS is 1 mg/l, however 0.3 mg/l is the desirable limit. For fluoride, the maximum permissible limit is 1.5 mg/l but as per WHO the desirable limit is 0.8-1.2 mg/l. While as per EPA and PHS the optimal levels of Iron and Fluoride in drinking water is 0.3 mg/l and 0.7 mg/l respectively. Therefore, the knowledge of removal of these ions from water is essential. Adsorption is a technique which can be effectively used for removal of these ions from groundwater. In the present paper an attempt has been made to study the iron and fluoride contamination, their effects to health and environment and removal their removal from groundwater using the process of adsorption and adsorptive filtration.
Keywords: Iron, Fluoride, Adsorption, Groundwater Contamination

I. INTRODUCTION

Water is one of the most important and indispensable natural resource present in earth. It nourishes and sustains life on earth and is available in abundance as a free gift of nature. Though availability of water is abundant, amount of freshwater water is very less. As per data, Earth's surface is covered with 71% of water. Out of which 96.5% is covered with oceans, 0.9% other saline water and 2.5% is fresh water. Of this 2.5%, 68.6% is in glaciers and ice caps, 30.1% groundwater and 1.3% surface water. Groundwater, which is one of the purest forms of freshwater, is used by 90% of rural population in India for domestic purposes [9]. It is often contaminated by natural (geological formations, volcanic activities etc.) as well as manmade (industries, power plants etc.) sources. Groundwater contamination by iron and fluoride is one of the major problems in this area.

Iron is the 2nd most abundant metal and 4th most abundant element in earth's crust which accounts for about 4.6%. Iron is present in water in two forms i.e. the soluble ferrous iron and the insoluble ferric iron. Ferrous iron is clear and colourless whereas ferric iron is reddish brown in colour [19]. Iron is a very essential mineral for human body. It helps in development of red blood cells, maintains energy metabolism, transports oxygen in blood and reduces anaemia and fatigue [5].

Fluorine is 13th most abundant element in earth and is available as fluoride ion in earth's crust in variety of compounds such as fluorspar, sodium fluoride, sodium fluorosilicate etc. It is most electronegative of all elements [9]. Within limits, fluoride is essential for humans. It prevents infants from dental caries.

Excessive contamination of groundwater by iron and fluoride and their adverse effect on human health in many parts of the world has led to the importance of their decontamination studies.

II. INDIAN AND INTERNATIONAL SCENARIO

Groundwater contamination by iron and fluoride can be seen globally in various countries including India. In the case of iron, high concentration in groundwater has been observed in more than 1.1 lakh habitations in India. The highest concentration of 49 mg/l has been reported in a hand pump at Bhubaneswar. Groundwater contaminated from iron (>1.0 mg/l) has been reported from Andhra Pradesh, Assam, Bihar, Chhattisgarh, Goa, Gujarat, Haryana, J&K, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal and Andaman & Nicobar islands. Globally, high iron contamination is observed in countries like Bangladesh, Cambodia, China, Egypt, Kenya, European countries like Netherlands, Ireland etc.

In case of fluoride, high concentrations have been observed in 19 states in India (Table 1). The highest concentration upto 48.32 ppm has been reported. Due to this, atleast 25 million people in 18 states are suffering from fluorosis. Globally, high concentration of fluoride and hence occurrence of fluorosis has been observed in countries like America, China, Countries of

Europe, Countries of Asia, East African countries, Sri Lanka, Turkey, Kenya and parts of South Africa [9]. In Kenya and South Africa level of fluoride exceeded 25 ppm.

III. IMPACT ON HEALTH AND ENVIRONMENT

There are various noticeable effects on health and environment due to using groundwater having higher amounts of iron and fluoride. In case of iron, presence of excess amount in water can have harmful effects in daily activities. Effects of excess iron in can be stated as environmental effects and health effects.

Table – 1
Fluoride affected states in India [9]

States	*Fluoride, mg/l*	*States*	*Fluoride mg/l*
Andhra Pradesh	*0.4-29*	*Karnataka*	*0.2-7.79*
Assam	*1.6-23.4*	*Kerala*	*0.2-5.40*
Bihar	*0.2-8.32*	*Madhya Pradesh*	*1.5-4.20*
Chhattisgarh	*High*	*Maharashtra*	*0.11-10*
Delhi	*0.2-32*	*Orissa*	*0.6-9.2*
Gujarat	*1.5-18*	*Punjab*	*0.4-42*
Haryana	*0.2-48.32*	*Rajasthan*	*0.1-10*
J & K	*0.5-4.21*	*Tamil Nadu*	*0.1-7*
Jharkhand	*0.5-14.32*	*U.P*	*0.2-25*
		West Bengal	*11.4-14.47*

A. Environmental Effects:

- Stains laundry and sanitary ware. (concentration>0.3 mg/l)
- Reduction in carrying capacity of distribution pipes because of deposition of iron oxides and bacterial slimes.

Gives an astringent type of taste to water and different beverages made from it.

Health effects: Iron is a potent oxidizer and excess amount is stored in pancreas, liver, spleen and heart. It can damage body tissues which causes Cirrhosis, Liver cancer, Cardiac arrhythmias, Diabetes, Alzheimer's disease and different bacterial and viral infections [5].

In case of fluoride, within permissible limits fluoride helps in protection and development of teeth and bones [37]. It also prevents dental caries in children. But excess fluoride causes various harmful effects listed in Table 2.

Table – 2
Effects due to Fluoride contamination

Sl. No.	*Fluoride concentration*	*Health effects*
1	*>Permissible limit*	*Effects neurodevelopment in children*
2	*1-4 mg/l*	*Fractures and skeletal fluorosis*
3	*>4 mg/l (or 12 mg/day)*	*Kidney injury leading to polyuria and dehydration*
4	*>1 mg/l (range: 4-21 mg/l)*	*Dental fluorosis*
5	*50 mg/l*	*Suppresses endocrine glands like thyroid*
6	*0.5 mg/l*	*Effects aquatic organisms of soft water*

B. Treatment of water containing iron and fluoride using adsorption technique

Adsorption is the process in which atoms, ions and molecules adhere on the surface of a material. Due to this, a layer of adsorbate (atoms to be adsorbed) is formed on the adsorbent (material which adsorbs). Adsorption is basically a surface phenomenon and includes the whole of volume of the adsorbent. Adsorption process takes place due to physical or Van der Waals forces (physisorption) and chemical (chemisorption) forces due to chemical bonds, between adsorbate and adsorbent.

Adsorption and adsorptive filtration are two of the best techniques for removal of iron and fluoride due to:

- Cheaper than other treatment options.
- The adsorbent can be regenerated, which is cost saving.
- There is no sludge generation in adsorption.
- Useful metal ions can be recovered from adsorbent after regeneration.

IV. CONCLUSION

Many researchers have worked in this field and developed new techniques and materials for Iron and Fluoride removal from water. (Table 3 & 4).

Future work: In our future work we may try to design and develop a technique based on adsorptive filtration for the removal of Iron and Fluoride from groundwater.

Table – 3
Summary of various works carried on Adsorption of Fluoride

(CT: Contact Time, RE: Removal efficiency, AC: Adsorption Capacity)

Sl. No.	Authors and Year	Adsorbent(s)	Fluoride concentration used	Adsorbent dosage	pH	Results
1	A.V. Jamode et al. 2004 [6]	Treated leaf powder of neem, papal and khair trees	10 mg/l	10 g/l	2	Maximum removal with CT 1.5 hrs.
2	Sushree S. Tripathy et al. 2005 [39]	Alum-impregnated activated alumina	25 mg/l	8 g/l	6.5	Maximum RE 92% with CT 3 hrs.
3	A.R. Tembhurkar et al. 2006 [4]	Powdered activated charcoal	5 mg/l	2 g/100 ml	2	Maximum removal 94% with CT 120 mins.
4	K.A. Emmanuel et al. 2008 [17]	Indigenously prepared activated carbons from plants and commercial activated carbon(CAC)	1-8 ppm	3 and 3.5 g/l	9	Maximum removal is by prepared Carbon 89% whereas 32% for CAC.
5	Pradip K. Gogoi et al. 2008 [28]	Acid activated kaolinite clay of mesh size 300	3 mg/l	10 gm/100 ml	4	Adsorption percentages are 47.3, 50.11, 50.62 and 55.23 resp. at 25, 40, 50 and 60°C. CT 100 mins.
6	Waheed S. Deshmukh et al. 2009 [41]	Carbonised rice husk	5 mg/l	10 g/l	2	Maximum removal 75% with CT 120 mins.
7	Nagesh Lakshminarayan et al. 2011 [26]	Brushite-calcite mix and powdered neem and pipal leaves	5 ppm	1 g/l brushite-calcite and 20 g/l neem and papal powder	-	Brushite-calcite mix was superior in removing fluoride than the bioadsorbents
8	V.Veeraputhiran et al. 2011 [40]	Phyllanthus emblica	3 ppm	0.75 gm	7	Maximum removal is 82.1%.
9	R. Bhaumik et al. 2011 [32]	Eggshell powder	5 mg/l	2.4 gm/100 ml	2-6	Maximum removal is 94% with CT 120 mins.
10	Roberto Lavecchia et al. 2012 [33]	Bauxite powder of size 1.18 mm	5-50 mg/l	-	7	AC 3.125 mg/g.
11	S.T. Ramesh et al. 2012 [35]	Bottom ash of size 300 µm	10 mg/l	100 mg/100 ml for 293 K, 80 mg/100 ml for 303 K and 60 mg/100 ml for 313 K	6	Maximum monolayer AC is 16.26 mg/g at 303 K. Optimum CT 105 mins.
12	Kefyalew Gomoro et al. 2012 [18]	Thermally treated lateritic soils	0.99-3.85 mM	2 g/50 ml	-	Maximum fluoride removal capacity was 47 mmol/kg
13	Patil Satish et al. 2012 [29]	Mangrove plant leaf powder (MPLP), Almond tree bark powder (ATBP), Pineapple peel powder (PPP), Chiku leaf powder (CLP), Toor plant leaf powder (TPLP) and Coconut coir pith (CCP)	5 ppm	10 g/l	2	Uptake of fluoride was found in order MPLP > CCP > TPLP > CLP > PPP > ATBP with optimum CT 60 mins.
14	Bhagyashree M. Mamilwar et al. 2012 [7]	Bark of babool	5 mg/l	5 g/l	6-8	Maximum AC was observed with optimum CT 8 hrs.
15	N. Gandhi et al. 2012 [27]	concrete(1:2:4), ragi seed powder, red soil, horse gram seed powder, orange peel powder, chalk powder, pineapple peel powder and multhani matti	12 mg/l	1 g/100 ml	-	Maximum removal by chalk powder (86%) whereas minimum removal by concrete (53%).
16	Yi Zhang et al. 2013 [42]	Bentonite/Chitosan beads	10 mg/l	0.1 g/50 ml (mix:3 g bentonite in 10 g chitosan)	5	Maximum AC was 1.164 mg/g with CT 480 mins.
17	Pali Shahjee et al. 2013 [30]	Bleaching powder	5 ppm	7.3 g/100 ml	10	Maximum removal was 90% with CT 8 hrs.
18	Aash Mohammad et al.2014 [2]	Powdered groundnut shell (GS), sweet lemon peel (SLP) and banana peel (BP)	20 mg/l	GS = 12 g/l BP = 16 g/l SLP = 14 g/l	GS = 7 BP = 6	RE, GS = 89.9% BP = 59.55% SLP = 94.34% CT, GS = 75 mins

					SLP =4	BP = 60 mins SLP = 40 mins
19	Dwivedi Shubha et al. 2014 [11]	Citrus limetta (Mosambi) peel powder	5 mg/l	10 g/l	7	Maximum removal was 82.5% with CT 30 mins. and agitation speed of 125 rpm.
20	Jadhav A.S. et al. 2014 [16]	Maize hush fly ash size 60 µm	7 mg/l	2 g/50 ml	2	Maximum removal was 86% with CT 120 mins.
21	Manisha Poudyal et al. 2015 [21]	Granular activated carbon (GAC) and domestic sewage sludge (SS)	5 mg/l	2 g/l	7	Maximum removal 88% for SS and 78% for GAC with CT 180 mins.
22	Sunita Goyal et al. 2014 [38]	Powdered leaves of neem, pipal and kikar	10 mg/l	10 g/l	2	Maximum removal 80% with CT 1 hr.
23	Ergovic Ravancic et al. 2015 [12]	Nutshell activated carbon	25 mg/l	10 g/l	7	Maximum removal was 46% at 25°C.

Table – 4
Summary of various works carried on Adsorption of Iron

Sl. No.	Authors and year	Adsorbent(s)	Iron concentration used	Adsorbent dosage used	pH	Results
1	M.H. Isa et al. 2004 [24]	Oil palm by products (fibre, shell and ash)	20 mg/l	500 mg/100 ml	5	Maximum removal 97% CT 90 mins.
2	Subramanyam Vasudevan et al. 2008 [36]	Aluminium alloys and stainless steel (electrode in adsorption and kinetics study)	25 mg/l	-	6.5	Maximum RE 98.8%.
3	K.S. Beenakumari 2009 [19]	Coconut shell charcoal and MnO_2 modified charcoal	10 ppm	500 ppm	6.35	MnO_2 modified charcoal reduced iron concentration from 10 ppm to 0.2 ppm within CT 4 hrs.
4	R. Shokoohi et al. 2009 [34]	Dried activated sludge from food industrial wastewater treatment plant	10 mg/l	0.9 g/100 ml	7	Maximum removal 95% CT 150 mins.
5	G. Anusha 2011 [13]	Bael fruit based activated carbon	0.2 mg/l	1.5 g/150 ml	5	RE 60% CT 20 mins.
6	B.K. Baruah et al. 2011 [8]	Bamboo charcoals	0.3-4 mg/l	1.5 kg (total for filtration)	Greater than 7.5	Maximum removal 74.24% Thickness of filter bed 6-14 inches.
7	Ahamad K.U. et al. 2011 [3]	Processed wooden charcoal (WC) and sand	5 mg/l	WC = 2.621 g Sand = 11.212 g	5.5	Filter bed with WC at top and sand at bottom yielded good removal.
8	A. Akber Hussain et al. 2012 [1]	Acanthaceae activated carbon	50 mg/l	25 mg/50 ml	3-6	Maximum removal 95% with CT 60 mins.
9	Irvan Dahlan et al. 2013 [15]	Mixture of ash from rice husk, palm oil fuel ash and coal fly ash	60 mg/l	0.9 g/100 ml	2	Maximum RE 99.8% with agitation time 40 mins.
10	Desai B. et al. 2013 [10]	Drum stick powder	0.25 mg/l	6 g/l	8.7	Maximum removal 96% at with CT 2.5 hrs.
11	Masoud Rohani Moghadam et al. 2013 [22]	Pomegranate peel activated carbon	20 mg/l	1 g/l	6	Maximum AC 18.52 mg/g.
12	G. Anusha et al. 2014 [14]	Almond shell activated carbon	0.05-1 mg/l	1.5 g/150 ml	5	Maximum RE 89% with CT 20 mins.
13	R. Balaji et al. 2014 [31]	Sugarcane bagasse (SCB) and coconut coir (COC)	17 mg/l	50 mg/l	4-5	Maximum removal: SCB=93%, COC=96%, CT 60 mins.
14	A.S. Mahakalkar et al. 2014 [5]	Waste orange peel activated carbon	1-10 ppm	2 g/50 ml	2	Maximum removal 90.542% with CT 60 mins.
15	Matsumoto M. et al. 2015 [23]	Filter paper with cedar bark and powder	10 $mmol/dm^3$	50 mg	-	Ferric ion showed highest AC with CT 6 hrs.
16	Mohammed Modu Aji et al. 2015 [25]	Groundnut shell activated carbon	3.11 mg/l	5 g/100 ml	6.8	Maximum adsorption efficiency 90% with CT 45-60 mins.
17	Manel Ruiti et al.	Charcoal	10 mg/l	0.1 g/l	7	Maximum AC of adsorbent was

	2015 [20]					*9.95 mg/g with CT 20 mins.*

(CT: Contact Time, RE: Removal Efficiency, AC: Adsorption Capacity)

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