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Original Research Paper

Performance Evaluation of Community Level Defluoridation Plants: A Case Study from Nagaur and Jodhpur, Rajasthan

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ABSTRACT

The Government of Rajasthan has started Rajasthan Integrated Fluoride Mitigation Programme (RIFMP), to provide fluoride free water in fluorosis endemic areas of the state. In the present study, community level defluoridation plants are investigated with regard to their defluoridation potential and determination of residual aluminium concentration in treated water at Nagaur and Jodhpur districts in Rajasthan, India. A total of 38 groundwater samples were collected from various community level Bio-Filter® media based defluoridation plants in fluoride rich villages of the study area. The fluoride concentration in raw water ranged from 0.9 to 3.61 mg/L in Nagaur and 1.18 to 2.54 mg/L in Jodhpur. The removal efficiency of plants operated in Nagaur lied between 88 to 100% except at Chapri Kallan II site (46%). On the other hand, the removal efficiency of plants operated in Jodhpur ranged from 97 to 100%, except at Jujanda (59%). The presence of residual aluminium in treated water was found to be in trace concentrations. The statistical analysis shows that fluoride uptake capacity has a strong correlation with fluoride concentration and alkalinity of raw water.

INTRODUCTION

Excessive ingestion of fluoride during the early childhood years may damage tooth-forming cells, leading to a defect in the enamel known as dental fluorosis (Yadav et al. 2009), and chronic ingestion of water containing excessive fluoride, causes skeletal fluorosis (Harrison 2005). Recent studies revealed that besides fluorosis, high consumption of fluoride can induce toxic effect to central nervous system (Valdez-Jiménez et al. 2011) and histopathological changes in other vital organs of the human body.

For centuries, fluoride toxicity in humans was considered to adversely affect bone systems mainly, but recent advancements have revealed some other aspects of its toxicity in human beings (Suthar 2011). Reported works showed that fluoride concentration in groundwater, which is the main source of drinking water in the Nagaur, Rajasthan, was higher than the consent limit by WHO which resulted in physiological disorders as well as dental and skeletal fluorosis in the villagers (Hussain et al. 2012, Suthar et al. 2008). The permissible limit of fluoride in drinking water is 1.0 mg/L as per WHO (WHO 2011) while permissible limit by the new Indian standards is 1.5 mg/L (ISO 10500, 2009).

The State Government of Rajasthan is implementing a project for fluoride mitigation, called Rajasthan Integrated Fluoride Mitigation Program (RIFMP) through public health engineering department (PHED) for all districts of Rajasthan. UNICEF, PHED, and various NGOs have initialised the RIFM program for combating the fluorosis in Rajasthan by signing the Project Co-operation Agreement (PCA) (Jain 2008, Savita 2008). The phasing of program is done on the basis of the fluoride concentration levels. Various phases of this project are shown in Table 1. Under the RIFM program, activated alumina (AA) and Bio-F (BF) adsorbent based defluoridation plants were installed in Rajasthan.

Present study evaluates the defluoridation potential of AA and BF based plants in two districts of Rajasthan, India. Statistical analysis was also performed to investigate the correlation of fluoride uptake capacity with water quality parameters.

MATERIALS AND METHODS

Study area: The study locations (Nagaur and Jodhpur) are situated in central part of Rajasthan, India. The total population of district Nagaur and Jodhpur are reported 3.30 million and 3.68 million respectively (Census 2011). The water samples were collected from 10 different locations of Nagaur district and 9 different locations of Jodhpur district. Nagaur district is a good combine of plains, hills and sand mounds as it is a part of great Thar Desert in India. The vast terrain of the district Nagaur spreads over a total area of over 17,718 sq km. The climate of the district is characterised by a dry

climate and hot summer. The average rainfall in the district is 361 mm and humidity stands at 51.5 percent.

Jodhpur district is among the largest districts in the state of Rajasthan. It is centrally situated in the western region of the state, and covers a total geographical area of 22,850 sq. kilometres. The district of Jodhpur lies at a height of 250-300 metres above sea level. The temperature varies from 49°C in summer to 1°C in winter. The average rainfall is 302 mm. There is no perennial river in the district, however, there are two rivers in the district viz., Luni River and Mithri River. Fig. 1 shows the location details of the area covered under the present study.

Water sample collection: In total, 38 samples were collected from 10 different locations of Nagaur and 9 different locations of Jodhpur. The sites of Nagaur are Jharod, Chugani, Chapri Kallan, Chapri Kallan II, Fogari, Fogari II, Bardwa, Mangalpura, Mangalpura II and Mangalpura III, while those of Jodhpur district are Sinla, Dungarnagar, Jujanda, Balunda, Pichyak, Lamba, Bala, Ravar and Olavi.

The samples were collected in pre-cleaned and sterilized polyethylene bottles, during the month of September 2011 from raw and treated streams of defluoridation plants.

Technology used for the plants: In Nagaur and Jodhpur, the treatment plants are based on biofilters employing defluoridation units. The media, named as OxiMax Bio-F®, is supplied by HES Water Engineers (India) Pvt. Ltd. Bio-F® is a biological adsorbent using natural shell as raw material. Its properties as per literature provided by manufacturer are as given below:

- Porous, crystal and hexagonal structure
- It is insoluble in water.
- Has high temperature tolerance.
- Low contact time needed about 3-5 minutes.
- Regeneration produces no hazardous material.

Bio-F media, used for the removal of fluoride, needs regeneration and backwash periodically. The frequency of regeneration and backwash is generally carried once in two months but may vary depending upon raw water fluoride concentration and the daily uptake of water from the system.

Experimental methodology: Present study was mainly focused on the determination of fluoride in raw and treated water of defluoridation units but other physicochemical parameter such as pH, TDS, chlorides, nitrates, sulphates, alkalinity, and aluminium were also analysed. The pH was

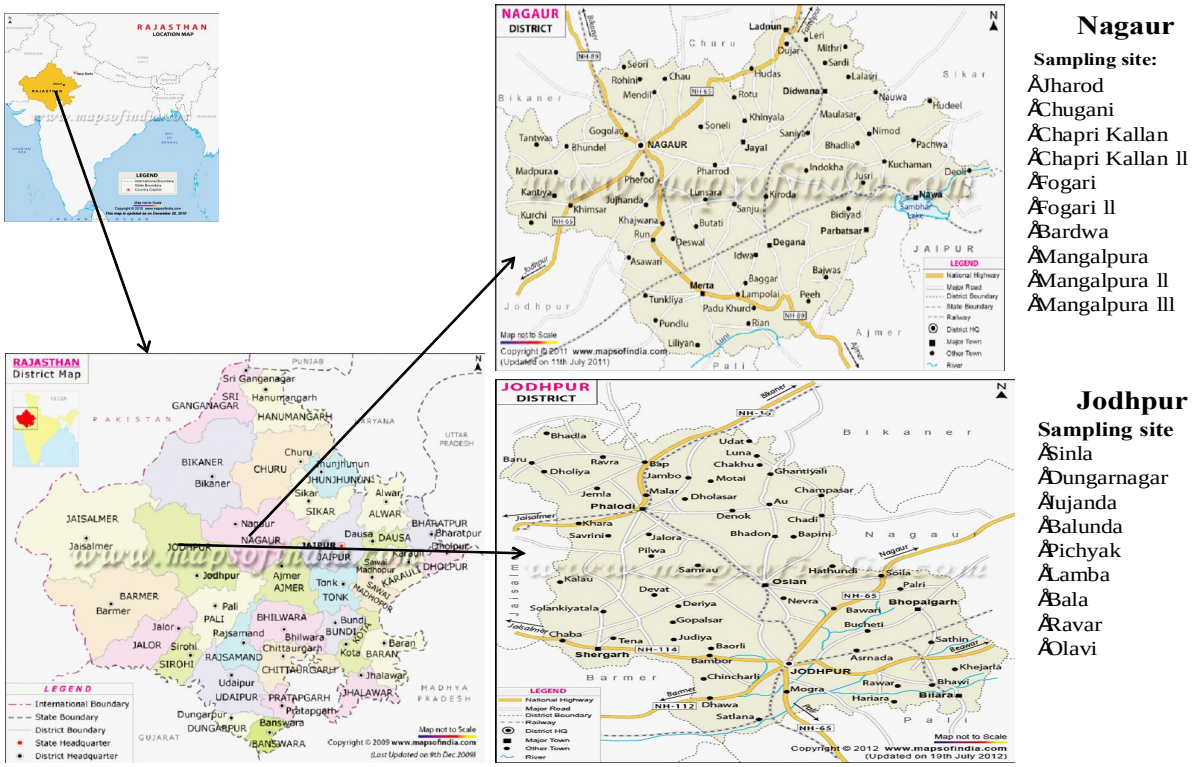

Fig. 1: Study area of interest.

Table 1: Proposed phases of RIFMP (Jain 2008).

Phase	Fluoride range (mg/L)	Number of Villages	Habitation	Total	Estimate (crores)
First (2004- 2005)	>5.0	1516	1127	2643	6.77
Second (2005-2007)	3.0–5.0	4250	3449	7699	18.50
Third (2007-2010)	1.5-3.0	6143	6812	12955	28.12
Total		11909	11388	23297	53.39

Table 2: Chemical Analysis of raw and treated water samples of Nagaur.

S. No.	Location	Sample Number	Sample Type	pH	TDS	Alkalinity	Chloride	Nitrate	Sulphate	Fluoride	Aluminium
1	Jharod	R1	Raw	8.46	1700	456	187.94	34.97	67.13	1.79	
		T1	Treated	8.36	1230	448	167.94	34.90	93.05	0.18	0.046
2	Chugani	R2	Raw	8.42	1200	368	263.92	35.46	77.90	0.90	
		T2	Treated	8.28	1200	316	261.92	35.43	76.54	0.00	0.054
3	ChapriKallan	R3(i)	Raw	8.26	1730	764	311.90	34.48	103.33	3.49	
		T3(i)	Treated	8.39	1750	700	393.88	34.97	115.80	0.00	0.035
4	ChapriKallan II	R3(ii)	Raw	8.40	1760	768	317.90	34.52	147.42	3.61	
		T3(ii)	Treated	8.35	1730	720	285.91	34.42	129.73	1.95	0.06
5	Fogari	R4(i)	Raw	8.51	2300	664	467.85	36.53	175.18	2.95	
		T4(i)	Treated	8.36	2380	644	473.85	36.53	182.90	0.33	0.026
6	Fogari II	R4(ii)	Raw	8.32	2350	740	499.85	36.05	162.19	3.07	
		T4(ii)	Treated	8.22	2400	660	307.90	36.20	170.96	0.00	0.028
7	Bardwa	R5	Raw	8.38	1810	604	345.89	33.70	238.24	2.48	
		T5	Treated	8.48	1890	524	359.89	33.32	192.83	0.00	0.055
8	Mangalpura	R6	Raw	7.74	2970	400	1293.60	34.97	291.52	2.24	
		T6	Treated	7.06	3320	176	1494.54	34.11	222.26	0.00	0.076
9	Mangalpura II	R7	Raw	7.43	3160	456	1405.56	34.94	289.42	2.31	
		T7	Treated	7.24	3440	320	1509.53	34.79	288.66	0.00	0.065
10	Mangalpura III	R8	Raw	8.40	3340	340	1494.54	34.84	265.06	1.96	
		T8	Treated	7.12	3380	240	1434.56	34.98	308.48	0.00	0.076

*All the values in mg/L except for pH value

measured by a pH meter (Electronics India, deluxe 101). Nitrates, chloride, alkalinity and sulphates were determined according to standard methods (APHA 2005) by using UV spectrophotometer.

Fluoride concentration was determined using ionometric standard method with a fluoride selective electrode (Thermo scientific Orion 5-star meter). A three point calibration was carried out using standard fluoride solutions of 0.1 mg/L, 1 mg/L and 10 mg/L. Total ionic strength adjusting buffer (TISAB) was added in all the standards and samples to maintain pH in the desired range (5-5.5). To avoid interference with the electrode performance, an ionic strength fixer buffer TISAB-II solution was added in 1:1 proportion to 10mL sample and allowed to stand for 5 minutes at room temperature before the readings were taken.

Preparation of TISAB-II: 4 g CDTA (1, 2-diaminocyclohexane tetra-acetic acid), together with 57 mL glacial acetic acid and 58 g NaCl was dissolved in about 500 mL distilled water. The pH of the solution was adjusted in the range of 5-5.5 by adding 130-140 mL of NaOH solution (5M) and diluted up to 1 litre with distilled water.

RESULTS AND DISCUSSION

The results of chemical analysis of various samples from villages of Nagaur and Jodhpur districts for various physico-chemical parameters like pH, conductivity, TDS, alkalinity, nitrates, sulphates, chlorides, fluorides and aluminium are shown in Tables 2 and 3.

The maximum concentration of fluoride in raw water was 3.61 mg/L in Nagaur district (Chapri Kallan II), while in Jodhpur (Bala) the maximum concentration of fluoride in raw water was 2.54 mg/L. The fluoride concentration in raw water ranges from 0.9 to 3.61 mg/L in Nagaur and 1.18 to 2.54 mg/L in Jodhpur.

The removal efficiency of Nagaur plants lies between 88 to 100% except Chapri Kallan II site, which had an efficiency as low as 46%. The removal efficiency of Jodhpur plants lies between 97 and 100% except Jujanda, which

Table 3. Chemical analysis of raw and treated water samples of Jodhpur.

S. No.	Location	Sample Number	Sample Type	pH	TDS	Alkalinity	Chloride	Nitrate	Sulphate	Fluoride	Alum-inium
1	Sinla	R1	Raw	7.64	2290	532	919.71	8.78	173.24	2.39	
		T1	Treated	8.46	2620	440	969.70	8.13	161.05	0.00	ND
2	DungarNagar	R1	Raw	8.23	2380	508	979.70	9.01	179.34	2.45	
		T1	Treated	7.97	2560	428	1009.69	8.56	168.37	0.06	ND
3	Jujanda	R1	Raw	8.44	1650	656	369.89	17.00	74.06	1.51	
		T1	Treated	8.14	1830	624	379.88	16.31	55.18	0.62	ND
4	Balunda	R1	Raw	7.96	2510	672	1019.68	15.38	76.03	1.18	
		T1	Treated	7.39	2750	552	994.69	14.31	73.57	0.00	ND
5	Pichyak	R1	Raw	7.71	2280	384	869.73	14.81	160.97	2.50	
		T1	Treated	7.52	2500	380	894.72	14.58	162.08	0.03	ND
6	Lamba	R1	Raw	7.97	2220	356	804.75	14.42	152.63	2.34	
		T1	Treated	7.87	2310	348	829.74	14.24	151.37	0.19	0.002
7	Bala	R1	Raw	8.15	2320	324	894.72	16.31	132.14	2.54	
		T1	Treated	7.63	2440	312	919.71	15.35	132.51	0.00	0.009
8	Ravar	R1	Raw	7.89	3130	604	1369.58	33.60	124.66	1.82	
		T1	Treated	7.48	3260	576	1194.63	33.51	124.55	0.00	ND
9	Olavi	R1	Raw	8.08	3120	596	1359.58	33.60	111.12	1.87	
		T9	Treated	7.91	3210	444	1179.63	33.56	114.41	0.00	ND

*All the values in mg/l except for pH value; ND: not detectable

had efficiency of 59%.

Fluoride uptake capacity: The average time for regeneration of these plants was about 75 days and the quantity of Bio-F used for each plant was 100 kg as informed by the representative of the Bio-F suppliers. Generally, consumption of water varies with season but on average 2000 litre water was consumed by the villagers. On the basis of above given information, uptake capacity of Bio-F (the amount of fluoride adsorbed on Bio-F at equilibrium, q_e (mg/g)), was calculated by the following mass balance relationship:

$$q_e = (C_i - C_f) \times \frac{V}{W}$$

Where, C_i and C_f are the initial and final liquid-phase concentrations of fluoride, respectively (mg/L), V the volume of the water consumed (L), and W is the weight of the Bio-F used (g).

Figs. 2 and 3 show the uptake capacity of defluoridation plants of Nagaur and Jodhpur districts. In Nagaur it varies from 1.35 mg/g to 5.23 mg/g while in Jodhpur it varies from 1.33 to 3.81 mg/g. Although the adsorbent media was same for each plant but uptake capacity for fluoride varies from place to place. The probable reasons may be pH of water and presence of co-existing ions (Maliyekkal et al. 2008). The dependence of fluoride uptake capacity on other co-existing ions is explained with statistical analysis in the later section.

Statistical analysis: Fluoride in water occurs in association with several other chemical constituents and therefore removal of fluoride from water by adsorption depends on their interaction with the sorbate, sorbent, and the solute. Some parameters that are of importance from engineering aspect are pH, presence of other ions (both anions and cations), and their combined effect (Rao & Karthikeyan 2011). The presence of sulphates, chlorides, nitrates and alkalinity can influence the removal of fluoride.

In this regard, correlation matrices between fluoride uptake capacity and various other water quality parameters were studied to see the dependence of fluoride uptake capacity on different co-existing ions present in water and it was noticed that most of the parameters bear statistically significant correlation and indicates towards close association of these parameter with fluoride uptake capacity. Table 4 shows the correlation between fluoride uptake capacity and different water quality parameters while Table 5 shows *p* value corresponding to correlation matrix for explaining the significance of correlation. Results show that fluoride uptake capacity has strong correlation ($r = 0.780$, $p < 0.0001$) with initial fluoride concentration and also shows correlation ($r = 0.668$, $p = 0.002$) with alkalinity. The fluoride uptake capacity shows some correlation ($r = 0.399$) with sulphate but it is not significant as its *p* value is high (0.091). Fluoride uptake capacity has not shown any good correlation with other parameters.

Influence of other water chemical parameters: The result shows that pH remained near neutral for all the samples and defluoridation did not result in any change in pH. The TDS ranges from 1200 to 3340 mg/L in raw water while there was slight increase in TDS of treated water of Nagaur district,

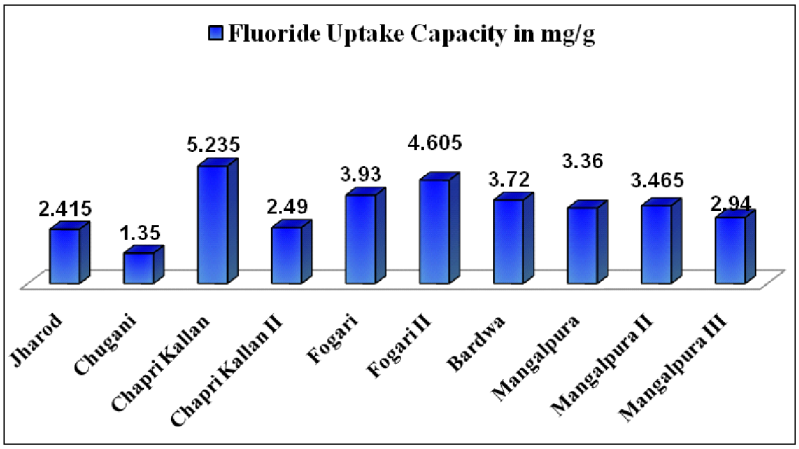

Fig. 2: Fluoride uptake capacity of defluoridation plants in Nagaur.

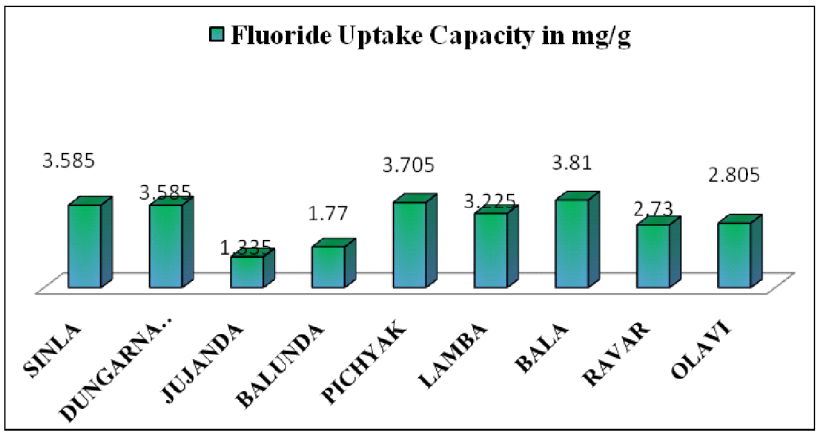

Fig. 3: Fluoride uptake capacity of defluoridation plants in Jodhpur.

Table 4: Correlation matrix between fluoride uptake capacity and different water quality parameters in Nagaur and Jodhpur.

Variables	Fluoride Uptake Capacity	pH	TDS	Alkalinity	Chloride	Nitrate	Sulphate	Fluoride
FluorideUptake Capacity	1							
pH	-0.157	1						
TDS	0.169	-0.535	1					
Alkalinity	0.668	0.194	-0.258	1				
Chloride	0.023	-0.650	0.943	-0.426	1			
Nitrate	0.078	0.315	0.085	0.174	-0.112	1		
Sulphate	0.399	-0.388	0.558	-0.027	0.501	0.200	1	
Fluoride	0.780	0.064	-0.056	0.871	-0.228	0.142	0.289	1

Values in bold are different from 0 with a significance level alpha = 0.05

but in Jodhpur it varied from 1650 to 3130 mg/L. TDS was found to increase in treated water due to defluoridation process as some soluble oxides and carbonates may have got dissolved from the Bio-F media. Higher concentration of TDS decrease the palatability and may cause gastrointestinal irritation in human and may also have laxative effect particularly upon transits (Ravindra & Garg 2007). No significant interference was observed on defluoridation in presence of other chemical constituents. Aluminium was analysed only for treated samples to find out whether or not it is exceeding

Table 5: p value corresponding to correlation matrix.

Variables	Fluoride Uptake Capacity	pH	TDS	Alkalinity	Chloride	Nitrate	Sulphate	Fluoride
FluorideUptake Capacity	0							
pH	0.520	0						
TDS	0.489	0.018	0					
Alkalinity	0.002	0.427	0.285	0				
Chloride	0.925	0.003	< 0.0001	0.069	0			
Nitrate	0.752	0.189	0.730	0.476	0.649	0		
Sulphate	0.091	0.101	0.013	0.911	0.029	0.413	0	
Fluoride	< 0.0001	0.794	0.819	< 0.0001	0.349	0.562	0.231	0

Values in bold are different from 0 with a significance level alpha=0.05

permissible limit prescribe by Bureau of Indian Standard IS 10500. The aluminium concentration varied from 0.026 to 0.076 mg/L in Nagaur and 0 to 0.009 in Jodhpur, which shows that all samples were within the consent limit.

Many samples had TDS and/or nitrates much higher than the values prescribed in BIS 10500. Though, through defluoridation, the fluoride concentration was brought within the permissible limits but the process reflected insignificant removal for aforementioned parameters. Therefore, authors suggest that only those high fluoride drinking water sources should be covered under RIFMP, which exceed the limits for fluoride only.

CONCLUSIONS

Based on analysis of samples collected from Nagaur and Jodhpur, Rajasthan, it has been observed that fluoride removal by Bio-F media based defluoridation plants found to be working satisfactorily as the residual fluoride in the treated samples was found below the acceptable limits. The presence of aluminium in treated water was in traces and below the standards for aluminium in drinking water prescribed by BIS 10500. Fluoride uptake capacity has shown correlation with initial fluoride concentration and alkalinity. Since the other parameters are above the prescribe limit of BIS 10500, the present study infers that only those drinking water sources should be targeted under RIFMP, which exceed the limits for fluoride presence as this process will have no effect of nitrates or TDS.

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