Reverse osmosis units in groundwater based public water supply system in rural eastern Karnataka, India: an analysis

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Adequacy, eco-friendliness and desirability of continuation of reverse osmosis (RO) purification of groundwater for providing safe drinking water to villages in the groundwater resource-deficient eastern Karnataka, India, have been studied in 15 villages in 4 districts of the state, where high fluoride and uranium contamination has been observed. The results indicate that: (i) except in Chitradurga district, there are an inadequate number of RO facilities; (ii) RO water consumption is far less than the minimum amount recommended for drinking by WHO; (iii) while the benchmark of the best performance for RO membranes is >99%, the RO units in use show an average fluoride and uranium rejection percentage of 92.6 and 95.1 respectively; and (iv) similar to almost all RO units, the installed ones are also wasting water in the water-deficient eastern Karnataka and discharging concentrate with a higher percentage of contaminants into the environment. Better management of RO units and RO concentrate is required.

Keywords: Contaminants, environmental friendliness, groundwater, reverse osmosis, sustainable rural water supply.

THE total number of inhabited villages, towns and urban centres in Karnataka, India, is 27,309. There are 14,448 villages in eastern Karnataka and 80% of them lying to the east of 76.5°E longitude are dependent on groundwater for drinking purposes[1]. The IMIS database of the Government of India (GoI)[2], the Central Ground Water Board (CGWB) report[1], and unpublished data from the Groundwater Directorate, Government of Karnataka, all point to eastern Karnataka being a fluoride-endemic belt (Figure 1). Recent studies have shown that this region is also characterized by groundwater with a high concentration of uranium in several localities[2–5]. Chakraborti *et al.*[6] have shown high arsenic content in groundwater in parts of Yadgir, Raichur and Bellary districts, and also in eastern Karnataka.

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The Department of Rural Water Supply, Government of Karnataka, has been trying to address this contamination problem under the Jal Jeevan Mission of GoI by: (i) arranging piped water supply of surface water and (ii) installing reverse osmosis (RO) water purification units for purifying groundwater in the villages. The villages located within the command areas of irrigation and multi-purpose projects, for example, in several districts in the northern part of eastern Karnataka (north of Bellary district), have benefitted from piped water supply of surface water. However, the water does not always reach all the villages which are near the periphery of the command areas. The Department of Rural Water Supply, Government of Karnataka, has installed 12,911 RO units, 80% of which are in eastern Karnataka. To understand the adequacy, eco-friendliness of the RO process and desirability of its continuation as a sustainable approach in the long run, Divecha Centre for Climate Change (DCCC), Indian Institute of Science (IISc), Bengaluru, has been studying the composition of feed, purified and wastewater samples of the RO units. Here, we present the results of an ongoing study on RO processing in 15 villages of eastern Karnataka, where high fluoride and/or uranium contamination has been recorded in groundwater. Figure 2 shows the locations of these villages in the Chikkaballapur, Chitradurga, Kolar and Tumkur districts of eastern Karnataka. In all these districts, groundwater development has exceeded the total recharge. Therefore, they belong to the category of water-critical districts from the point of view of groundwater resources.

Status of RO water processing in the four districts under study

Adequacy of the number of units

Table 1 shows the number of villages served by RO processing units in relation to the total number of villages in the four districts under study and the population in these districts. A perusal of the table shows that 1123 RO units

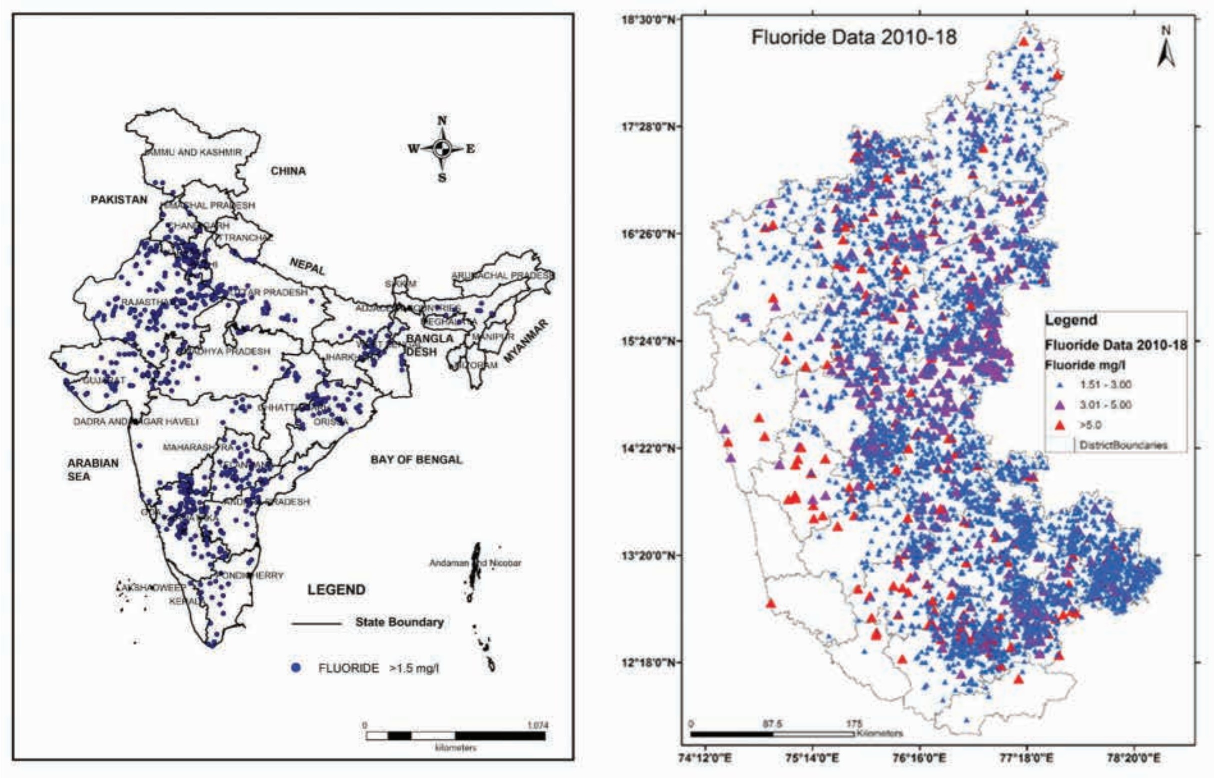

Figure 1. Map showing fluoride-endemic belt in the eastern part of Karnataka based on Central Ground Water Board[1] and 2010–18 data of the Integrated Management Information System, Government of India[2].

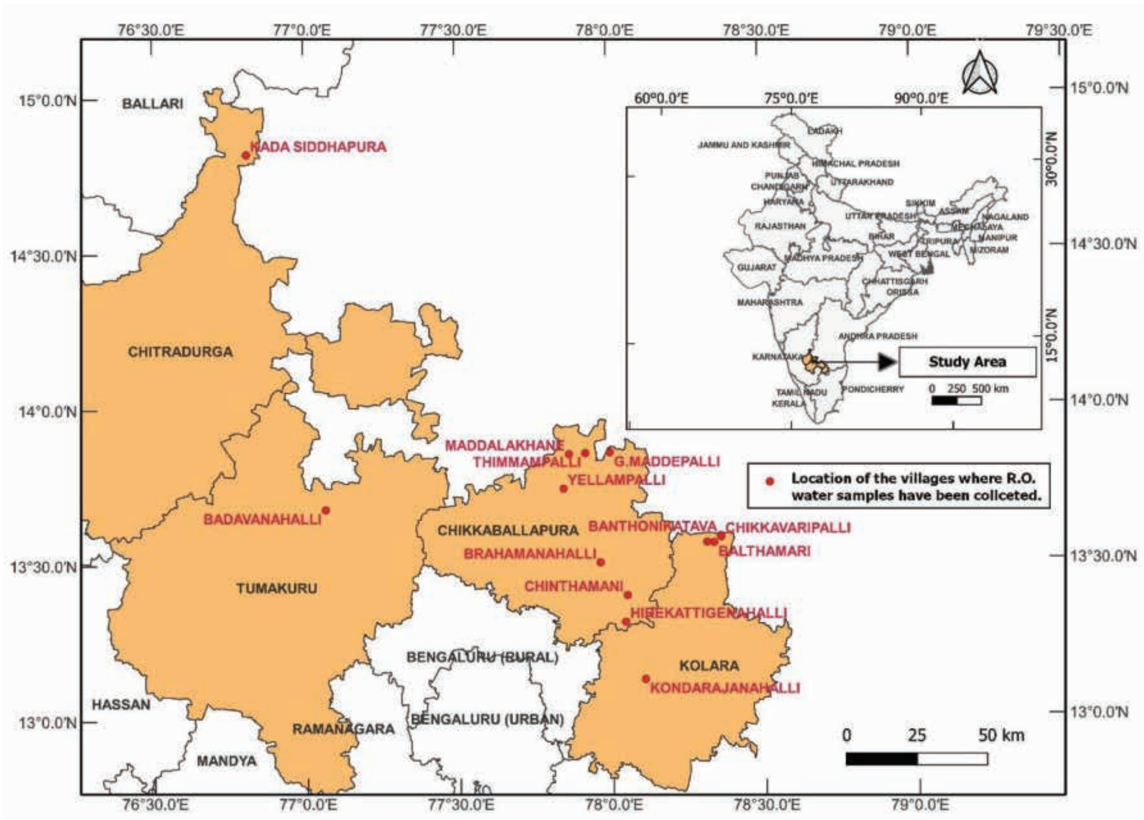

Figure 2. Map showing locations of villages in the Chikkaballapur, Chitradurga, Kolar and Tumkur districts of eastern Karnataka, where reverse osmosis processing has been studied.

Table 1. Number of reverse osmosis units in Chikkaballapur, Chitradurga, Kolar and Tumkur districts, Karnataka, in relation to the number of villages and population in these districts

District	Number of villages (District Government profile)	Number of installed RO units	Population census (2022)[17]	Population per RO unit	Capacity* (LPH)
Chikkaballapur	1515	703	1,254,377	1784	250–4000
Chitradurga	1063	1092	1,660,378	1520	250–4000
Kolar	2092	1123	1,540,231	1372	250–8000
Tumkur	2574	1504	2,681,449	1783	250–4000

*Capacity of 193 RO units is not available. For these units, the capacity has been taken as 500 LPH.

Table 2. Status of demand and supply of RO-purified water in selected villages in eastern Karnataka

District	Taluk	Village	Population (Jal Jeevan Mission, 2022; ref. 17)	Installed capacity of RO unit (LPH)	Estimated water requirement per day (l) (population × 5 l)	Minimum–maximum quantity of RO water (l) purchased by the population
Chikkaballapura	Sidlaghatta	Brahmanahalli	402	500	2010	NA
		Sadahalli/Kannapanahalli	630	500	3150	2000–2300
	Bagepalli	Maddalakhane	962	250	4810	2000–3200
		G. Maddepalli	1388	500	6940	1000–1200
		Thimmampalli	2213	250	11,065	1000–1400
	Chintamani	Chintamani (town)*	76,068	8000	380,340	30,000–35,000
Chitradurga	Molakalmuru	Ashok Siddapura	1280	250	6400	500–600
Kolar	Kolar	Kondarajanahalli/Ameeranahalli	2114	500	10,570	1700
	Srinivaspura	Kadirampalli	756	500	3780	1000–1500
		Balthamari	705	500	3525	1200–2400
		Mudimadagu	2170	500	10,850	2000–3000
		Chintamanapalli	824	500	4120	700–1500
Tumkur	Pavagada	Kariyammanapalya (Mugadalabetta)	2129	500	10,645	800–1100
		Aralikunte	768	500	3840	800–1000
	Madhugiri	Badavanahalli	4346	1000	21,730	1000–1500

*Town, census 2011; Town Panchayat does not have RO units, but there are multiple private water suppliers; the data presented here pertain to a private water supply agency (Jeeva Jala).

serve 2092 villages in Kolar district. Assuming that there is one RO unit per village, only 53% of the villages have this facility. If there is more than one unit in one village, the number of villages served would be even fewer. Similarly, 46% of villages in the Chikkaballapur district and 55% in Tumkur district have RO units. Only in the Chitradurga district there are greater number of RO units than the number of villages (1092 units for 1063 villages), which is creditable.

Consumption of RO purified water

Table 2 shows the requirement for drinking water according to World Health Organization (WHO) norms (5 litres/person/day) in the 15 villages. The minimum and maximum amount of RO-purified water purchased by the public from the RO units is also mentioned in the table. The amount of RO-purified water used by the public is far less than the minimum consumption recommended by WHO[7].

Quality of water samples

The feed water to the RO units was collected at the outlet valve of the borewell or the inlet point of these units. The RO-purified water – the permeate, was collected from the dispensing tap and RO wastewater – the concentrate was from the snout of the wastewater pipe. All samples were collected in pre-cleaned glass bottles following the protocols for collection, preservation and analysis of uranium by LED fluorimetry, as detailed in Srinivasan *et al.*[5] and for fluoride by ion chromatography (using Metrohm COMPACT 861, Switzerland) at the Indo-French Cell for Water Sciences, IISc, Bengaluru[8]. Table 3 gives the uranium concentration (μg/l) and fluoride concentration (mg/l) in the RO feed, permeate and concentrate water samples. The U and F concentrations observed in the samples were compared against permissible limits given by the Atomic Energy Regulatory Board (AERB), India and WHO. Table 3 also shows the percentage increase of the said contaminants in the concentrate with reference to feed water. The U and F rejection ratios were calculated using eqs (1) and (2) as follows[9]:

$$\text{Uranium rejection \%} = \left(1 - \frac{P_U}{F_U}\right) \times 100, \quad (1)$$

$$\text{Fluoride rejection \%} = \left(1 - \frac{P_F}{F_F}\right) \times 100, \quad (2)$$

Table 3. Uranium and fluoride concentration in feed (F), purified (permeate) and reject (concentrate) fractions in some RO units in eastern Karnataka

District	Taluk	Village	Month and year	Uranium (μg/l) concentration in RO water			Change in uranium % $(R_U - F_U)/F_U*100$	Uranium rejection % ($\bar{R}_U$%) $[1 - (P_U/F_U)]*100$	Concentration (mg/l) of fluoride			Change in fluoride % $(R_F - F_F)/F_F*100$	Fluoride rejection % ($\bar{R}_F$%) $(1 - (P_F/F_F))*100$
				F_U	P_U	R_U			F_F	P_F	R_F		
Chikkaballapura	Sidlaghatta	Brahmanahalli	February 2022	1101 ± 12.8	16 ± 1	1871 ± 2	70	98.6	1.5	0.1	3.1	104	93.3
			March 2022	3668 ± 12.1	120 ± 1	6808 ± 1	85	96.7	1.9	0.1	3.7	99	94.7
		Sadahalli	March 2022	86 ± 0.3	7.2 ± 1	107 ± 0.1	24	91.6	3.2	0.7	2.6	NA	78.1
	Bagepalli	Maddalakhane	February 2022	35 ± 0.2	0	60 ± 0.1	71	100.0	1.0	0.0	1.7	63	100.0
			March 2022	119 ± 0.2	6 ± 1	171 ± 1	44	95.0	1.1	0.1	1.9	68	90.9
		G. Maddepalli	February 2022	91 ± 0.2	20	210 ± 1	131	78.0	1.6	0.2	1.7	10	87.5
			March 2022	1175 ± 4	34 ± 0.1	1857 ± 6	58	97.0	1.6	0.2	2.2	32	87.5
		Thimmampalli	February 2022	338 ± 0.3	0	336 ± 1	NA	100.0	2.9	0.1	2.9	3	96.6
			March 2022	970 ± 2.1	18 ± 1	1099 ± 3	13	98.1	2.4	0.1	3.0	28	95.8
	Chintamani	Chintamani (Town)	February 2022	510 ± 1.8	1	1036	103	99.8	0.7	0.0	1.8	157	100.0
Chitradurga	Mulakalmuru	Ashok Siddapura (Hanumapura)	February 2022	60 ± 0.11	3	95 ± 2	58	95.0	1.5	0.0	2.0	32	100.0
Kolar	Kolar	Kondarajanahalli	February 2022	302 ± 3.7	34 ± 1	288 ± 1	NA	88.7	1.6	0.2	1.7	6	87.5
			March 2022	1195 ± 2.9	96 ± 1.4	1470 ± 24	49	92.0	1.8	0.2	2.5	43	88.9
	Srinivaspura	Kadirampalli	December 2021	65 ± 0.4	7	245 ± 0.5	277	89.2	2.6	0.2	2.7	5	92.3
			February 2022	132 ± 0.1	8 ± 1	175 ± 0.4	33	93.9	2.6	0.3	3.4	31	88.5
		Balthamari	December 2021	491 ± 2.7	4	939 ± 3	91	99.2	1.7	0.1	2.7	57	94.1
			February 2022	630 ± 0.3	3 ± 1	745 ± 10.9	18	99.5	1.8	0.1	2.1	18	94.4
		Mudimadagu	December 2021	27 ± 0.1	2 ± 1	43	59	92.6	0.7	0.1	0.9	40	85.7
		Chintamanapalli	December 2021	181	1	NA	NA	99.5	NA	NA	0.6	NA	NA
Tumkur	Pavagada	Kariyammanapalya	March 2022	70 ± 0.4	9	60 ± 2	NA	87.1	4.0	0.3	3.9	NA	92.5
		Aralikunte	March 2022	30 ± 0.1	0	33 ± 1	8	100	3.6	0.1	4.2	17	97.2
	Madhugiri	Badavanahalli	February 2022	382 ± 1	0	485 ± 1	28	100	0.7	0.0	1.0	28	100.0

where P_U is the concentration of uranium in the permeate, F_U the concentration of uranium in the feed, R_U the concentration of uranium in the reject, P_F the concentration of fluoride in the permeate, F_F the concentration of fluoride in the feed and R_F is the concentration of fluoride in the reject water. Table 3 also reports these ratios.

Results and discussion

The RO process has been utilized for more than 40 years to purify water from geogenic and anthropogenic contamination and improve water quality for drinking purposes[10]. The process has several advantages and disadvantages. Bhakar *et al.*[11] and Idrees[12] have generalized that the amount of concentrate discharged from the RO units is approximately three times greater than the amount of permeate or purified water produced. Our observations in the RO units in Karnataka are consistent with this generalization. Studies by CGWB show that in large parts of eastern Karnataka, groundwater resources have been overexploited and have reached the critical or overexploited stage with respect to water resource status[2]. Therefore, wastage of water is not desirable, especially in these sectors. It is also generally known that RO wastewater has a higher concentration of contaminants than feed water. This aspect is amply brought out by the analyses of most of the samples presented in this study (compare columns F* with R* and F with R in Table 3).

The uranium and fluoride rejection percentages are indicative of the efficiency of the RO units with respect to the disposal of these contaminants. Table 3 shows these results. The uranium rejection percentage ($\bar{R}_U$%) varies from 78 to 100 with an average of 95.1, while the fluoride rejection percentage ($\bar{R}_F$%) varies from 78.1 to 100 with an average of 92.6. The standard deviation for $\bar{R}_U$% is 5.6 and for $\bar{R}_F$% is 5.7. The benchmark for best performance for the RO membranes is ≥99% of the salt rejection capacity, according to Indika *et al.*[9]. Out of the 15 RO units under study, 5 (namely Chintamani, Balthmari, Chintamanapalli, Badavanahalli and Aralikunte) and 3 units (namely Chintamani, Ashok Siddapura/Hanumapura and Badavanahalli) satisfy this norm for uranium and fluoride respectively. It may be noted that the performance of two units, namely Chintamani and Badavanahalli, is up to the mark, both in respect of uranium and fluoride, while all other units do not satisfy the bench mark. In general, the performance of the RO units is better for uranium than for fluoride.

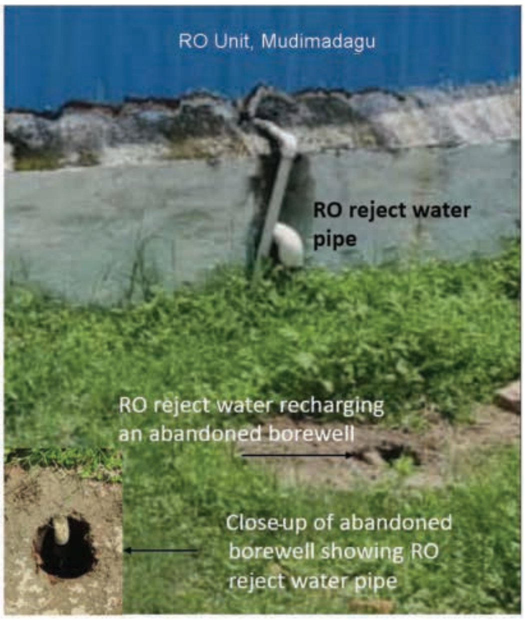

Figure 3. Photograph of the concentrate (reject) water pipe recharging groundwater in an abandoned borewell at Mudimadagu, Karnataka.

We observed that the concentrate (wastewater) is discharged in open channels or drains and seeps into the ground, ultimately recharging the groundwater and further contaminating it. There are also instances where the rejected water is being used for recharging the groundwater (Figure 3). Management of concentrate from the RO units, as practised at present, is unsatisfactory and not eco-friendly.

Often the permeate water produced by the RO units is deficient in minerals and vital elements required for the body, which may also lead to health problems[13]. For example, the process can remove fluoride content to levels much less than 0.5 mg/l, as seen in many sites in the present study. Consumption of such permeate water with very low fluoride content over extended periods can lead to dental caries in young children. While addressing the problem of dental fluorosis through the consumption of RO permeate water, one may head towards a condition that promotes dental caries. It does not appear to be a good bargain.

The RO system is based on the performance of membranes. Different types of membranes are in use in India. Polyamide, composite and cellulose acetate membranes are widely in use[14]. Normal filtering membranes cannot adsorb the dissolved contaminants and directly discharge them through the concentrate, as observed in the present study. We also observed that uranium concentration in the rejected water increased by 8–277% and fluoride by 3–157% (Table 3). In Maddalkhane, Chikkaballapur district, although the feed water had fluoride in desirable limits for drinking water, the concentrate from the RO unit had become enriched in fluoride to levels above the prescribed limit of 1.5 mg/l. These deficiencies in RO processing can only be overcome using more advanced versions of the RO units, which cost much higher than the normal units.

It has also been found in some instances that RO purification does not necessarily decrease the U and F concentration to permissible levels. For example, in the permeate water samples in Brahmanahalli, G. Maddepalli and Kondarajanahalli, uranium concentration was higher than the thresholds recommended by WHO and AERB. Fouling and scaling of the RO filters are known to affect their performance[15,16]. Maintenance of the RO units apart from the quality of the groundwater itself plays an important role in reducing fouling and scaling. There are no systematic studies on the various characteristics of groundwater in the study area that influence the fouling and scaling of the RO units. Such studies are now being undertaken.

Conclusions

Under the Jal Jeevan Mission of GoI, the Government of Karnataka has taken proactive steps to provide safe drinking water to the villages located in the fluoride-endemic belt in eastern Karnataka[17]. Groundwater with high uranium content is also encountered in many places in this fluoride-endemic belt. The Government of Karnataka has installed RO units to purify the groundwater used to supply drinking water in many villages. A study of feed, permeate and concentrate water samples of these RO units shows that while the process effectively reduces the pollutants to desired concentration in the permeate in majority of the studied units, they waste large quantities of water as a concentrate with a very high concentration of pollutants. This wastewater contributes to further polluting of the groundwater through seepage. There are instances where the concentrate water (wastewater from the RO units) is being used for recharging the groundwater through existing defunct borewells. Therefore, RO treatment in the long run does not appear to be environment-friendly. Further, there are instances where the RO units have not been able to remove pollutants to the desirable level of concentration, probably because of fouling and scaling of the RO membranes. In many cases, RO produces permeate with a very low concentration of fluoride, much less than 0.5 mg/l, which can lead to dental caries upon extended periods of consumption of such water. Although the RO treatment may temporarily mitigate the problem arising from fluoride, uranium and other pollutants, it seems not a sustainable and environment-friendly option. Studies on alternative approaches for providing drinking water need to be pursued to arrive at a more permanent and environment-friendly solution.

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