Fluoride distribution in drinking groundwater in Rajasthan, India

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Hydrofluorosis caused by fluoride-rich water was predominantly restricted in Rajasthan, India before the commencement of guinea-worm (*Dracunculus medinensis*) eradication programme in 1986. During implication of the programme, numerous bore- and tube-wells fitted with hand pumps were dug in villages even in the remote areas of the state, simultaneously closing down the traditional step/open-wells which were used as drinking water sources. Groundwater from tube- and bore-wells drawn from deeper sources in all the 33 districts of Rajasthan is found contaminated with varying amounts of fluoride (F), with most containing F above the maximum acceptable limits of 1.0–1.5 ppm. As a result, hydrofluorosis has become more rampant in rural Rajasthan. Extreme large amounts of F in potable water sources were detected in desert districts located in western Rajasthan (Thar Desert region). The findings of this article show how a well-intentioned medical health programme has led to the spread of another disease (hydrofluorosis) in Rajasthan. These findings can play an important role in the formulation and implementation of a health policy at the state level for mitigation and prevention of endemic hydrofluorosis.

Keywords: Groundwater, guinea-worm disease, fluoride distribution, hydrofluorosis, mitigation and prevention.

THE state of Rajasthan, India, is eco-geographically separated by the Aravali mountain range into two regions. One is the desert region in the west and the other is the forest belt in the east. At present, Rajasthan has a total of 33 districts, of which 12 are located in the western desert region. This study focuses on the problem of hydrofluorosis which is rampant in the state.

Sources of fluoride

The available important sources of fluoride (F) to humans and domesticated animals are fluoridated potable water, plants and crops grown on fluorotic soils, certain edible marine animals, phosphate feed supplements containing F, mineral mixture, medicines, cosmetics, dust in air and industrial F pollution[1,2]. Consumption/ingestion of F for a long time through fluoridated potable water causes serious health problems in the form of hydrofluorosis in both humans[3–5] and domestic animals[6–9]. The first two F sources mentioned above are natural and responsible for endemic fluorosis, whereas the remaining sources are man-made and restricted to a particular location[2].

In recent years, industrial F emissions have also been found to cause fluorosis. Several industries release F in both gaseous and particulate/dust form into surrounding habitats causing industrial F pollution[10]. Industry-emitted F contaminates not only the surrounding diverse terrestrial and aquatic ecosystems and their food chains, but also plants, grasses, crops and many other biotic communities on which humans and domestic as well as wild animals are generally dependent for food and water[11]. Prolonged periods of inhalation or ingestion of industrial F also causes mild to severe health hazards in the form of industrial and neighbourhood fluorosis[2,10–12]. In Rajasthan, groundwater used for drinking is the main source for chronic F intoxication in both humans and domestic animals.

Distribution of F in drinking groundwater

Prior to the introduction of guinea-worm (*Dracunculus medinensis*) eradication programme in 1986 (refs 13, 14), the main source of drinking water in Rajasthan was surface water from perennial ponds, reservoirs, lakes, dams, rivers, streams, etc. that were mostly free from the F contamination. However, in rural and remote areas, the main source of drinking water was bore/tube-wells fitted with hand-pumps, which were limited in number. Since water from these wells were contaminated with F, hydrofluorosis was predominantly restricted to these areas.

During the above-mentioned national health programme, numerous bore/tube-wells and hand-pumps were dug in villages even in remote areas of Rajasthan. Simultaneously all traditional drinking water sources, such as the step/open wells were closed to stop the reproductive cycle of the guinea-worm[15].

Studies have revealed that water in almost every bore/tube-well fitted with hand-pump located in rural areas of Rajasthan is contaminated with F[16–84], and most of them have F above the maximum acceptable limits of 1.0–1.5 ppm, which is not safe for both human and

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Table 1. District-wise distribution of fluoride (F) in drinking groundwater sources of Rajasthan

	F content (ppm)		
District	Range	Average	Reference
Ajmer	0.1–12.0	1.6	16
	0.0–16.2	2.94	17
	0.1–12.0	–	18
	0.24–17.6	–	19
	0.25–16.9	–	20
	0.3–14.2	–	21
Alwar	0.0–4.0	–	22
	1.5–9.9	–	23
	0.45–3.6	–	24
	1.1–1.8	–	25
Banswara	0.0–3.2	0.81	17
	0.1–4.6	3.75	26
Baran	0.0–2.0	0.59	17, 27
Barmer	0.2–10.9	–	22, 28
	0.0–19.6	2.3	29
	0.0–18.0	–	30, 31
Bharatpur	0.1–18.4	1.34	32
	0.1–18.4	–	22
	1.5–4.9	–	23
Bhilwara	2.1–24.0	6.0	33
	0.1–24.0	–	22
	0.0–7.4	1.77	17
	0.4–13.0	8.72	34–38
Bikaner	0.0–20.0	–	22, 28
	0.0–12.0	2.1	30
	1.5–9.9	–	23
Bundi	0.1–6.8	0.80	39
	0.0–5.0	0.88	17
Chittorgarh	0.0–6.6	0.67	17
Churu	0.0–30.0	1.9	22, 25
	0.0–32.0	–	30
	0.1–14.0	–	40
	1.2–7.8	–	41
Dausa	1.5–9.9	–	23
	0.2–14.9	–	42
Dholpur	1.5–4.9	–	23
Dungarpur	0.0–6.2	1.25	17
	0.1–10.8	6.0	43, 44
	1.5–9.9	–	23
Hanumangarh	0.5–8.5	5.75	45
	1.0–4.78	2.82	46
Jaipur	4.5–28.1	12.2	47
	1.2–15.0	6.3	48
	0.1–28.1	–	22
	1.5– >10.0	–	23
	2.17–10.14	–	49
	0.4–5.4	–	50
	1.20–18.0	–	51
	0.1–12.5	–	52
	0.20–6.45	–	53
	0.19–3.70	–	54
Jaisalmer	0.0–8.0	–	22
	0.0–8.0	1.7	29
	0.0–12.0	–	30
	3.0– >10.0	–	23
	0.6–4.74	–	55
Jalor	0.0–14.2	2.4	29, 56
	0.0–14.0	–	29
	1.5– >10.0	–	23
Jhalawar	0.0–1.2	0.19	17
	0.1–1.5	–	57
Jhunjhunu	0.0–12.0	–	30
	0.6–8.8	–	27
	1.5– >3.0	–	58
	0.6–1.4	–	59
	0.1–1.5	–	60
Jodhpur	0.1–12.8	–	61
	0.0–11.2	–	22
	0.0–22.0	2.4	29
Karauli	0.5–4.5	–	27
	1.5– >3.0	–	58
Kota	0.0–4.8	0.95	17, 39
Nagaur	0.1–12.3	–	22
	1.0–2.0	–	62
	0.0–90.0*	3.2	29
	0.0–34.0	–	30
	1.5– >10.0	–	23
	0.3–5.9	–	63
	0.64–14.62	–	64, 65
	1.1–6.6	–	66
	0.5–8.5	–	67-70
Pali	0.0–18.3	6.2	29
	0.0–14.0	–	30
	0.0–9.9	–	23
Pratapgarh	0.1–4.7	2.41	44, 71
Rajsamand	0.0–4.5	0.99	17
Sawai Madhopur	1.5– >10.0	–	23
	0.1–3.6	–	72
Sikar	0.0–15.0	–	30
	1.5– >10.0	–	23
Sirohi	0.0–8.0	–	22
	1.5–9.9	–	23
	1.0–16.0	11.17	73
	1.0–14.0	–	74
	0.18–13.0	–	75
Sri Ganganagar	0.1–28.2	–	76
	0.0–26.0	1.6	29
	0.5–5.0	3.5	45
Tonk	0.0–4.0	–	22
	1.50–11.82	–	77
	0.08–11.30	–	78
	0.5–10.7	–	79
	0.26–9.60	–	80
	0.6–15.8	–	81
	1.10–14.62	–	82
Udaipur	0.1–21.6	4.5	83
	0.0–11.65	1.11	84
	0.1–21.6	–	22
	0.0–5.9	0.84	17
	0.1–7.0	5.87	61

*Source is open well, now closed.

animal health[1,15]. At present, data on F concentration (ppm) in drinking water sources in all 33 districts of Rajasthan are available (Table 1). Figure 1 shows the highest F concentration (ppm) in drinking groundwater of each district of Rajasthan. Data on F concentration in drinking water sources of Baran, Bundi, Chittorgarh, Dausa, Dholpur, Jhalawar, Karauli, Kota, Pratapgarh, Rajsamand, Sawai Madhopur and Sikar districts are not sufficient to determine the exact status of F level in these districts. Therefore, more extensive surveys on F distribution in drinking water sources of these 12 districts are necessary[15,17]. All fluoride endemic districts can be categorized

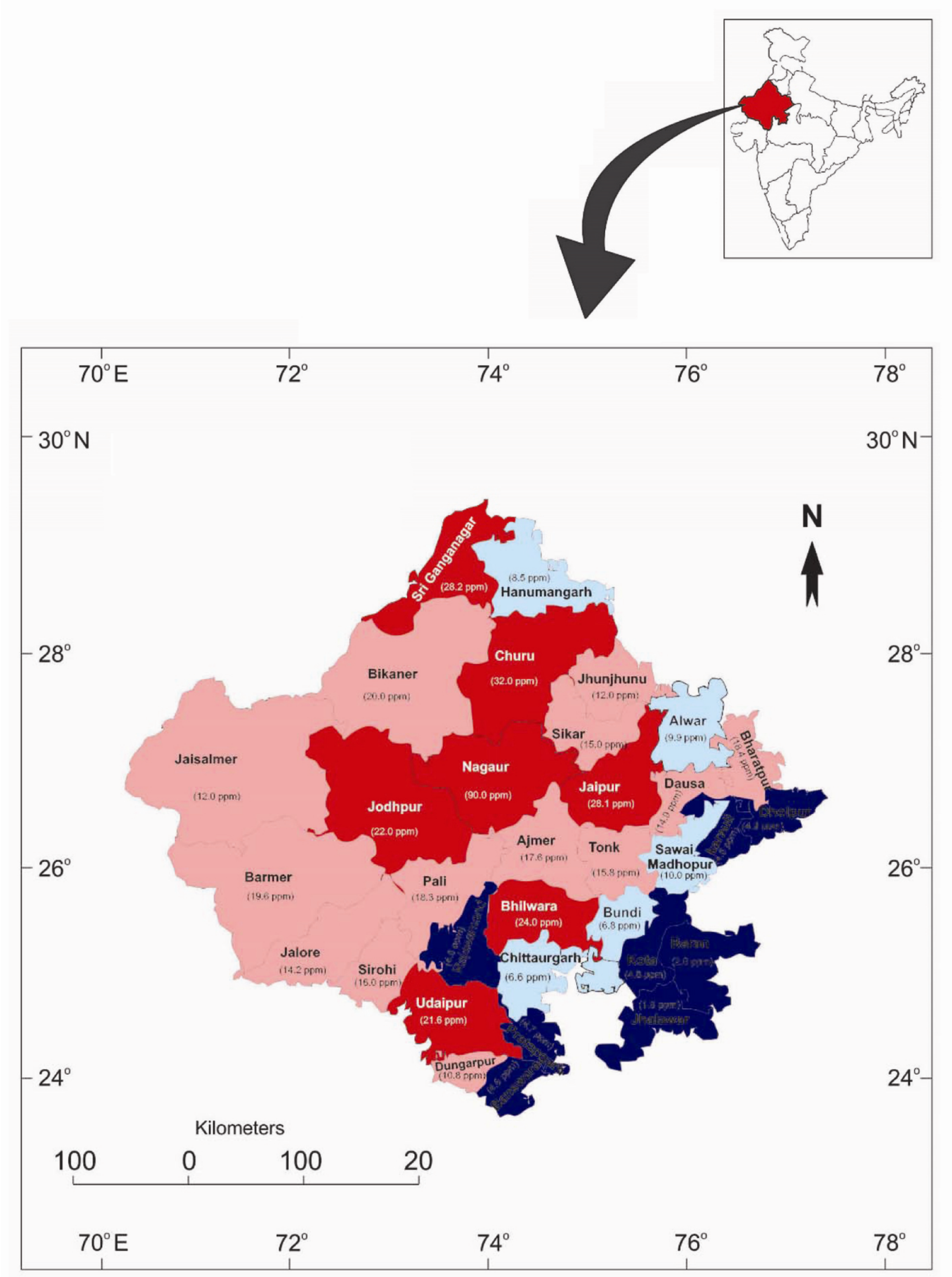

Figure 1. Map of Rajasthan showing district-wise fluoride distribution in groundwater sources. Districts having fluoride in the range 1.5–5.0, 5.1–10.0, 10.1–20.0 and >20.0 ppm are indicated by deep blue, light blue, light red and deep red colours respectively.

into four groups based on the F range, viz. 1.0–5.0 ppm (first group), 5.1–10.0 ppm (second group), 10.1–20.0 ppm (third group) and >20.0 ppm (fourth group) (Table 2). Based on F range, 22 districts belonging to the third and fourth groups are highly prone to chronic F poisoning in Rajasthan.

Table 2. Categorization of 33 districts of Rajasthan based on F range in drinking water

Group one F 1.0–5.0 ppm +	Group two F 5.1–10.0 ppm + +	Group three F 10.1–20.0 ppm + + +	Group four F > 20.0 ppm + + + +
Jhalawar	Chittorgarh	Dungarpur	Udaipur
Baran	Bundi	Jhunjhunu	Jodhpur
Rajsamand	Hanumangarh	Jaisalmer	Bhilwara
Karauli	Alwar	Jalore	Jaipur
Banswara	Sawai Madhopur	Dausa	Sri Ganganagar
Pratapgarh		Sika	Churu
Kota		Tonk	Nagaur
Dholpur		Sirohi	
		Ajmer	
		Pali	
		Bharatpur	
		Barmer	
		Bikaner	

+, + +, + + + and + + + +, Degree of F intolerance.

Estimation of F in perennial surface water sources, ponds, lakes, dams and large reservoirs of each district is also necessary, as these are also drinking water sources for both domestic and wild animals. However, only one scientific report on F concentration in the surface waters is available from the tribal rural areas of southern Rajasthan[44]. This report has revealed that many of the perennial large ponds and reservoirs located in tribal rural areas of Banswara, Dungarpur and Udaipur districts are contaminated with F (0.1–3.05 ppm). These surface waters sources can also cause hydrofluorosis in domestic and wild animals. Therefore, the need for surveys on F contamination of freshwater bodies in all 33 districts is emphasized. However, not a single report on chronic F poisoning in any species of wild animals has been reported so far in the country.

Reasons for high F concentration

Presence of abnormally high F concentration in groundwaters of all 33 districts of Rajasthan is not due to anthropogenic reasons. It is due to natural cause of higher abundance of F-bearing minerals in the host rocks and sediments[15]. The important rocks are granites, gneisses, mica, schists, limestone, sandstone, phosphorite, shales, clays, acid igneous rocks, basalts, alluvium, etc. and these contain fluorotic minerals accounting for F in the range 180–3100 ppm (average). Their chemical behaviour like decomposition, dissociation, dissolution and interaction with water is considered to be the main cause of F in groundwater[17]. Distribution of F is also related to regional hydrogeological and climatic condition. Besides the hydrogeological set-up, climate and physiography are other important factors[15,17]. The areas of less rainfall have waters with higher F content compared to groundwater in high rainfall areas, despite similar hydrogeological formation[15,17]. Thus groundwater in districts like Chittorgarh, Udaipur and Banswara receiving higher rainfall have low F content compared to Ajmer and Bhilwara districts[17]. Physiographically, it is found that hilly areas have water with low F content when compared to the plain areas. Dilution along with rapid flushing out of salts in high rainfall and hilly areas result in low F content in waters of these areas[17]. The weathering and leaching process, mainly by moving and percolating water, also plays an important role in reducing or increasing of F concentration in groundwater. Other factors like chemical composition, presence and accessibility of F minerals to water and contact time between the source of minerals and water also govern the release of F into water[15,17].

Effect of F exposure

Consumption of fluoride-rich water over long periods leads to chronic exposure to fluoride ingestion and results in its accumulation predominantly in hard tissues such as teeth and bones causing diverse adverse changes that appear in the form of dental fluorosis (dental mottling) and skeletal fluorosis (osteal deformations) in humans[1] and animals[85]. Besides these maladies, gastrointestinal discomforts, neurological disorders, impaired endocrine and reproductive functions, teratogenic effects, renal effects, genotoxic effects, apoptosis, excitotoxicty, etc. have also been reported in humans as well as in domestic and laboratory animals[15,85–90]. These toxic effects due to chronic F exposure in soft tissues or organs are generally known as non-skeletal fluorosis.

De-fluoridation

Although hydrofluorosis is irreversible/untreatable[91], it can be mitigated/controlled by consumption of water containing F less than 1.0–1.5 ppm or F-free drinking water (de-fluoridation of water), improving the nutritional status of the population at risk and spreading public awareness.

De-fluoridation of F-containing water could be done using suitable techniques at both domestic and community-based levels. The Nalgonda de-fluoridation technique has been found to be simple, low-cost and reasonably effective[92].

In many F endemic states, including Rajasthan, this technique has been adopted at the domestic as well as community level for de-fluoridation of drinking groundwater[15]. Tube and bore-wells fitted with hand-pumps under the supervision of Public Health and Engineering Department of the Rajasthan Government in several villages are attached with de-fluoridation units containing activated alumina. Though the technique is affordable and gives good results, its success rate at the community level is still poor. In several places, it has failed because of lack of community participation and responsibility, proper monitoring and maintenance. It is being increasingly realized that instead of such efforts, harvesting and conserving rainwater is a better procedure to obtain F-free drinking water. Another way is to supply treated water of perennial reservoirs to villages.

Conclusion

Based on published scientific data, it is evident that drinking groundwater sources such bore-wells and hand-pumps in rural areas of all 33 districts in Rajasthan are contaminated with F, and most of them have F beyond the permissible limits of 1–1.5 ppm. Ingestion of such water for a long time is a health hazard for both humans and domestic animals. Therefore, a provision for supply of F-free water is needed in all F-endemic villages of Rajasthan. Flouride examination of perennial surface water sources is also essential in Rajasthan, as some instances of high F content have been recognized. The present study provides important information pertaining to district-wise F distribution in drinking groundwater that could be useful in the framing of health policies at the state level for the prevention and control of endemic hydrofluorosis.

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