Incidence of fluoride in the groundwater of Purulia District, West Bengal: a geo-environmental appraisal

Fluoride contamination in drinking water is a burning environmental issue of the world today. A cursory glance at this problem reveals that the people of nearly 29 countries are affected with 'fluorosis' due to intake of fluoride-rich water. India also figures in this list, as the menace of this deadly poison is being reported from many parts of the country[1,2].

Ingestion of excess fluoride in the human body may cause dental, skeletal and non-skeletal fluorosis. Again, low fluoride less than 0.5 mg/l causes dental caries. Proper safeguards are, therefore, required to be taken to ensure safe fluoride level in drinking water. According to BIS[3] and ICMR[4], the highest desirable limit of fluoride is specified at 1.0 mg/l and the maximum permissible limit is 1.5 mg/l. In spite of this, fluoride contamination of groundwater is reported to be endemic in as many as 15 states in India.

In West Bengal, excess fluoride in groundwater has been detected so far in 43 blocks spread over seven districts, viz. Purulia, Birbhum, Bankura, Malda, South Dinajpur, North Dinajpur and South 24-Parganas[5]. As the problem spreads day by day, a scientific inquest to find out the source and cause of fluoride in groundwater of Purulia has become the need of the hour.

For example, in the Purulia District (the present study area), instances of fluorosis are on the rise. The rural population is the worst affected, because of the absence of centralized water-treatment system in these areas. Outbreak of media reports on this issue has become a matter of grave concern for the Government in view of the strategic location of Purulia, its poor socio-economic status and the tribal-dominated demography.

Geological and hydrogeological studies were carried out by drilling boreholes in 17 different locations of Purulia spread over the three worst-affected blocks, viz. Purulia I, Purulia II and Hura (Figure 1). A total of 401 samples from these blocks were collected in the post-monsoon (winter) period of 2009–2010, which included 242 rock-chip samples from boreholes and 159 water samples collected from three different sources: boreholes, dug wells and tube wells. These water and rock samples were analysed according to the standard procedures[3,6] and correlated to find out the plausible reason for fluoride enrichment. The results gave a dismal picture of contamination with fluoride above the prescribed limit detected in a majority of the rock and water samples.

For example, in Purulia I block, out of a total of 39 rock-chip and 30 borehole water samples, the maximum fluoride value in borehole water and the enclosed host rock was found to be 10.75 mg/l and 11,400 mg/kg respectively. In Purulia II block, out of 68 rock-chip and 34 borehole water samples, the maximum fluoride value was found to be 6.25 mg/l and 9000 mg/kg respectively. In Hura block, out of 135 rock-chip and 49 borehole water samples, the maximum fluoride value obtained was 6.25 mg/l and 10,200 mg/kg respectively (Table 1). A closer scrutiny of water quality results (of all boreholes, dug wells and tube wells taken together) of these analytical findings further reveals that nearly 54% of the water samples have fluoride content more than 1 mg/l, out of which over 17% is infested with fluoride over 1.5 mg/l (Table 2). In case of rock samples, more than 90% reported fluoride content more than 4000 mg/kg.

Study of the borehole rock-cutting samples has revealed that the area is principally underlain by Pre-Cambrian metamorphics represented by granite gneiss (Chotanagpur granite gneiss), biotite granite gneiss, calc-granulites, ultrabasic and meta-basic rocks, meta-sedimentaries, including crystalline limestone, hornblende schist, biotite gneiss, pegmatite and quartz-vein. Microscopic studies of drill cuttings of granite gneiss and pegmatite have revealed fluoride-bearing minerals, viz. apatite and fluorite. Two other fluoride-bearing minerals, biotite mica and hornblende, were also noted that might have added fluoride into the groundwater. Fluoride from the hydrothermal fluids usually gets adsorbed into the sheet structure of these silicate minerals and stays there until the conditions are congenial for leaching to take place. Abnormal level of fluoride is also observed within the pegmatite veins. Fluoride mineralization is found to have been favoured by the presence of structurally weak planes like shear/fracture zones, joints and contacts of host rock and vein quartz. Incidentally, all these conditions are prevalent in the present project area.

A review of the geological literature in Purulia has revealed that fluoride exists

Figure 1. Block map of Purulia District, West Bengal showing the extent of the study area (highlighted portion).

Table 1. Summarized table of fluoride concentration in borehole water and host-rock formation

Location of sampling sites	Nature of sample	Total samples analysed	Maximum (mg/l)	Average (mg/l)	Observed range of values in samples (mg/l)	Percentage of samples equal to or exceeding the standard*	Standard deviation**
Purulia I block							
Gandudih	Subsurface water	12	1.3	0.95	0.5–1.3	66.67	0.25
	Host-rock drill-chip	13	6900	5078	2440–6900	76.92	–
Sindri	Subsurface water	6	10.75	4.67	1.35–10.75	100	3.74
	Host-rock drill-chip	8	11,400	6248	2200–11400	75	–
Bashra	Subsurface water	7	1.125	0.8	0.20–l.125	42.86	0.35
	Host-rock drill-chip	9	5200	3891	2400–5200	55.56	–
Bhadsa	Subsurface water	5	1.25	1.13	1.00–1.25	100	0.11
	Host-rock drill-chip	9	8000	6911	6120–8000	100	–
Purulia II block							
Pindra	Subsurface water	9	4.25	1.54	0.725–4.25	88.89	1.04
	Host-rock drill-chip	10	8500	7210	6500–8500	100	–
Raghabpur	Subsurface water	Borewell dry	–	–	–	–	–
	Host-rock drill-chip	5	10,200	8600	7650–10200	100	–
Chepra	Subsurface water	6	5.50	2.24	1.20–5.50	100	1.63
	Host-rock drill-chip	8	BDL	7375	BDL–11000	75	–
Nodihatola	Subsurface water	9	6.25	1.92	1.00–6.25	100	1.66
	Host-rock drill-chip	17	8500	7004	5400–8500	100	–
Nodiha	Subsurface water	10	2.00	1.37	0.60–2.00	80	0.48
	Host-rock drill-chip	13	8600	7233	5800–8600	100	–
Chhoto Chanchra	Subsurface water	Borewell dry	–	–	–	–	–
	Host-rock drill-chip	15	9000	5146	BDL–9000	73.33	–
Hura block							
Chakalta	Subsurface water	4	0.90	0.65	0.41–0.90	Nil	0.21
	Host-rock drill-chip	12	6080	4590	3500–6080	83.33	–
Chatumadar	Subsurface water	4	1.14	0.83	0.57–1.14	25	0.25
	Host-rock drill-chip	16	3800	3346	2300–3800	Nil	–
Ladurka	Sub-surface water	7	2.15	0.72	0.125–2.15	14.29	0.66
	Host-rock drill-chip	8	5000	2963	1900–5000	12.50	–
Hatibari Upor Para	Subsurface water	Borewell dry	–	–	–	–	–
	Host-rock drill-chip	23	10,220	8636	5800–10220	100	–
Hatibari Nich Para	Subsurface water	Borewell dry	–	–	–	–	–
	Host-rock drill-chip	21	6900	4397	800–6900	61.90	–
Motipur	Subsurface water	10	2.15	1.26	0.325–2.15	70	0.58
	Host-rock drill-chip	17	4800	3986	3240–4800	66.67	–
Keshagora	Subsurface water	7	1.55	1.09	0.7–1.55	85.71	0.26
	Host-rock drill-chip	16	10200	4330.63	BDL–10200	56.25	–
Dungrigora	Subsurface water	9	2.00	1.56	0.9–2.00	77.78	0.43
	Host-rock drill-chip	13	10200	5211	800–10200	92.31	–
Dhabani	Subsurface water	8	1.65	1.11	0.6–1.65	62.50	0.34
	Host-rock drill-chip	9	7100	5233	4000–7100	100	–

*Standard of fluoride in water samples is taken as 1.0 mg/l according to the BIS and ICMR guidelines.

For host rock, a cut-off value of 4000 mg/l is taken as the standard in the present study. This cut-off value has been arrived at by taking the average of fluoride values as observed in all the drill holes sunk at different locations of the study area. Incidentally the average crustal abundance of fluoride is only 625 g/t. As evident from the table, the observed fluoride values in the host rock in the study area are much above the average crustal abundance.

**Standard deviations of fluoride values in rock samples are not shown as the samples have been collected from different formations and depths (geological age).

BDL, Below detection limit. For the procedure adopted, it is < 0.10 mg/l.

Table 2. Summarized break-up of fluoride level in sub-surface water (boreholes, tube wells and dug wells) of the study area

Block affected by fluoride concentration	*F* < 0.10 (mg/l)	*F* 0.10–<0.25 (mg/l)	*F* 0.25–< 0.50 (mg/l)	*F* 0.50–< 0.75 (mg/l)	F 0.75–< 1.00 (mg/l)	*F* 1.00–< 1.25 (mg/l)	*F* 1.25–< 1.50 (mg/l)	*F* 1.50–< 1.75 (mg/l)	*F* 1.75–< 2.00 (mg/l)	*F* 2.00–< 2.25 (mg/l)	*F* 2.25–< 2.50 (mg/l)	*F* 2.50–< 2.75 (mg/l)	*F* 2.75–< 3.00 (mg/l)	*F* 3.00–< 3.25 (mg/l)	*F* 3.25–< 3.50 (mg/l)	*F* > 3.50 (mg/l)	Total sites
Purulia I block																	
Gandudih	–	–	–	5	1	6	2	–	–	–	–	–	–	–	–	–	14
Sindri	–	–	–	–	–	2	1	–	–	–	1	–	–	–	–	3	7
Bashra	–	2	–	2	1	3	–	–	–	–	–	–	–	–	–	–	8
Bhadsa	–	–	3	1	–	4	1	–	–	–	–	–	–	–	–	–	9
Sub-total	–	2	3	8	2	15	4	–	–	–	1	–	–	–	–	3	38
Purulia II block																	
Pindra	–	–	–	2	–	3	4	–	–	–	–	–	–	–	–	1	10
Raghabpur	–	–	1	1	–	1	–	–	–	–	–	–	1	–	–	–	4
Chepra	–	–	–	–	–	2	2	–	–	2	–	–	–	–	–	1	7
Nodiha and Nodihatola	–	–	1	3	3	5	5	1	2	3	–	–	–	–	–	1	24
Chhoto Chanchra	–	–	–	1		1	–	–	–	–	–	1	–	–	–	–	3
Sub-total	–	–	2	7	3	12	11	1	2	5	–	1	1	–	–	3	48
Hura block																	
Chakalta	–	–	2	4	1	–	–	–	–	–	–	–	–	–	–	–	7
Chatumadar	–	–		4	2	1	–	–	–	–	–	–	–	–	–	–	7
Ladurka	–	1	3	3	2					1	–	–	–	–	–	–	10
Hatibari Upor and Nich Para	–	1	1	2	–	–	–	–	–	–	–	–	–	–	–	–	4
Motipur	1	–	2	1	1	1	3	1	–	2	–	–	–	–	–	–	12
Keshagora	–	–	1	2	1	5		1	–		–	–	–	–	–	–	10
Dungrigora	–	–	–	1	2	1	2	1	1	3	–	–	–	–	–	–	11
Dhabani	–	–	–	3	2	3	1	1	–	–	–	–	–	–	–	–	10
Bispuria	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Sub-total	2	2	10	20	11	11	6	4	1	6							73
Total of three blocks	2	4	15	35	16	38	21	5	3	11	1	1	1			6	159
Percentage distribution of fluoride	1.26	2.52	9.43	22.01	10.06	23.89	13.21	3.15	1.89	6.92	0.63	0.63	0.63			3.77	100

as a complex ion in a naturally occurring mineral called 'apatite', which is a fluorinated calcium phosphatic compound[7]. The rocks that contain apatite are of diverse petrological composition and geological age, and principally include composite gneisses, meta-sedimentaries, meta-basics and intrusive granites of Late Archean to Proterozoic age. The mineralization of apatite has taken place along two prominent linear zones – one located in the North Purulia region and referred to in the geological literature as the 'North Purulia Shear Zone' (covering the areas of Jhalda–Jaipur–Raghunathpur) and the other located in the South Purulia region and geologically referred to as the 'South Purulia Shear Zone' (covering the areas of Balarampur–Beldih–Barabhum).

From experiments conducted in the laboratory, it has been found that a wide array of physico-chemical factors operating under different hydrogeological regimes are responsible for fluoride enrichment to take place from the fluoride-bearing host (country) rock into the saturated zone of groundwater[8].

Physico-chemical analyses of water samples and their corresponding plots in the Piper's diagrams have revealed that the dominant hydrochemical facies of subsurface water in these fluoride-affected provinces of Purulia is Na–K–Ca–Mg–HCO_3-type, which has favoured continued leaching from the fluoride-rich host rock under alkaline pH condition of the circulating water[9,10].

Although rock–water interaction seems to play a major role behind the enrichment process, fast recession of the water table (due to excessive groundwater withdrawal) and long spells of drought (as a fallout of climate change) have triggered the gradual leaching of fluoride into the circulating water[11]. Prevalence of physical and chemical weathering under arid to semi-arid conditions in high-alkaline groundwater zones further favours quick dissolution of fluoride into the circulating water.

The villagers who thrive on this non-potable, fluoride-rich water bear the brunt of fluorosis and are clearly witnessed to suffer from yellow cracked teeth, joint pains, crippled limbs and quick ageing.

In order to mitigate the rising problem of fluorosis, one has to ensure fluoride-free, safe drinking water to the rural communities of Purulia. This will involve selection of area-specific appropriate technology for safe water supply and sustainability of the programme through active participation of the user community.

The following action plan is suggested as an holistic alternative to mitigate the rising fluorosis problem:

- Supply of fluoride-safe water.
- Extensive water quality monitoring.
- Diagnosis and treatment of fluorosis.
- Nutritional support.
- Awareness, motivation and training.

There could be various systems for the supply of fluoride-safe water to the community. However, such supply systems must be appropriate for the area-specific conditions. The option for fluoride-free safe water supply system could be the following:

- River or lake water-based piped water supply.
- Big diameter tube well-based piped water supply (selecting the fluoride-safe aquifers).
- Installation of deep tube wells attached with hand pumps (selecting fluoride-safe aquifers, if available).
- Hand pump-attached excess fluoride removal units.
- Fluoride removal units attached with big bore tube wells for piped water supply.
- Use of traditional water sources (lakes/ponds) after treatment.
- Rainwater harvesting.
- Household treatment for excess fluoride removal.

The situation has already reached an alarming level and calls for immediate intervention and attention of all stakeholders to understand and sensitize the issue to the society at large. A well-knit communication strategy must be developed for awareness sensitization and motivation of the local villagers and to generate knowledge–attitude–practice of using safe water amongst the end-users.

The final judgement is of course left to the decision of the environmental planners, policy makers and engineers to provide reprieve and respite to the poor villagers from the subtle ingress and influx of such a bizarre and deadly pollution phenomenon.

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