# High fluoride in groundwater and fluorosis related health hazard in Rarh Bengal, India: a socio-environmental study

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**More than 600,000 people in the three districts in Rarh Bengal, namely Purulia, Bankura and Birbhum live in fluoride endemic area where dental, skeletal and non-skeletal fluorosis is wide spread. Rarh Bengal is in an extended part of Chotanagpur Plateau in Eastern India. Fluoride content in 727 water samples of drinking water and petrography of 34 rock chip samples from these districts have been studied to understand fluoride in the drinking water. About 1753 households (in 410 villages) were surveyed using stratified random and quota sampling techniques to assess the number of people affected by fluorosis. Fluoride risk analysis was performed by applying the standard fluoride hazard index and fluoride vulnerability index. Results showed that granite gneiss and pegmatite are responsible for release of fluoride ions into the soils and groundwater. About 118 villages in 14 blocks of Purulia, 15 villages in 7 blocks in Bankura and 9 villages in 5 blocks in Birbhum are found to be affected by severe fluorosis.**

**Keywords:** Fluoride, hazard, host rocks, Rarh Bengal, risk, vulnerability.

FOR strong teeth and bones in human beings, fluoride is a requisite micronutrient. In 1984, World Health Organization (WHO) prescribed the desirable fluoride limit between 0.6 and 1.5 mg/l in drinking water. Bureau of India Standard (BIS) has fixed the range between 0.6 and 1.2 mg/l whereas Indian Council of Medical Research (ICMR) has standardized the limit as 0.5–1.5 mg/l. Beyond the given standard range, fluoride concentration in drinking water is detrimental to human health[1,2].

Fluoride contamination in groundwater is a socio-environmental jeopardy. Nearly 261 million people in the world are found to be consuming groundwater with high fluoride content. More than 29 nations are suffering from severe dental and skeletal fluorosis resulting in health hazard and societal vulnerability[3–5]. Tropical countries with hot and humid climate exhibit higher incidence of fluorosis owing to excessive intake of fluoride rich water[6]. According to Central Ground Water Board (CGWB)[7], more than 95 million people including 6.5 million children are suffering from dental, skeletal and non-skeletal fluorosis in India. The CGWB report also highlights that 223 districts in 23 states are under the impact of high to severe fluoride contamination in groundwater.

Figure 1 *a* shows district map of West Bengal. In 2017–2018, fluoride contamination in groundwater was noticed (ranging from 1 to 10 mg/l) in 43 blocks of 7 districts in West Bengal, India. The district includes Purulia, Bankura, Birbhum, Malda, North Dinajpur, South Dinajpur, and 24 Parganas (S). In three districts, namely Purulia (17 Blocks), Bankura (10 Blocks) and Birbhum (7 Blocks) of Rarh Bengal, the groundwater is moderately to highly contaminated by fluoride ion. But fluorosis related health hazard like dental and skeletal fluorosis are mostly found in the districts of Purulia and Birbhum[8]. In 2017–2018, worst affected blocks under Purulia district were Purulia I (10.75 mg/l and 11,400 mg/kg), Purulia II (6.25 mg/l and 9,000 mg/kg) and Hura (6.25 mg/l and 10,200 mg/kg). Similarly, the present study (in the year 2017–2018) revealed that 4 blocks (Bankura-II, Indpur, Khatra and Simlapal) of Bankura district and 1 block (Khoyrasole) of Birbhum district of Rarh Bengal were also highly affected. In recent years, groundwater contamination by fluoride and fluorosis related health hazard has become a serious health cum societal issue in the Rarh Bengal[9,10]. People suffer from yellow cracked teeth, joint pains, crippled limbs and quick ageing[11]. The spectrum of fluorosis related health hazard that leads to current status, health challenges and mitigation measures have been studied by many scientists[12]. Young boys and girls are mostly affected by dental fluorosis, whereas adults are affected more by skeletal and non-skeletal fluorosis[13].

Rarh Bengal (Figure 1 *a*) is located on an extended part of the Singbhum Craton and lies between Chota Nagpur plateau and the Ganges Delta. It is characterized by undulating terrain in the west and alluvial tract in the east. Purulia, Bankura, Birbhum, Murshidabad, Jhargram, Purba Barddhaman, Paschim Barddhaman, Purba Medinipur, Paschim Medinipur, Hooghly and Howrah districts comprise Rarh Bengal. Groundwater of three districts, viz. Purulia, Bankura and Birbhum are found to be highly contaminated by fluoride. The main objective of this work is to find out: (i) the reasons for fluoride contamination in groundwater through petrological and hydrogeomorphological studies of Rarh Bengal and (ii) identify the high-risk blocks with magnitude of fluorosis.

To understand the geology and structure of Rarh Bengal, lineament map has been prepared using module edge filtering technique (performed using PCI Geomatica V 9.1.0 software) using ETM and ASTER imageries. ETM imagery is composed of six VNIR bands and has 30 m

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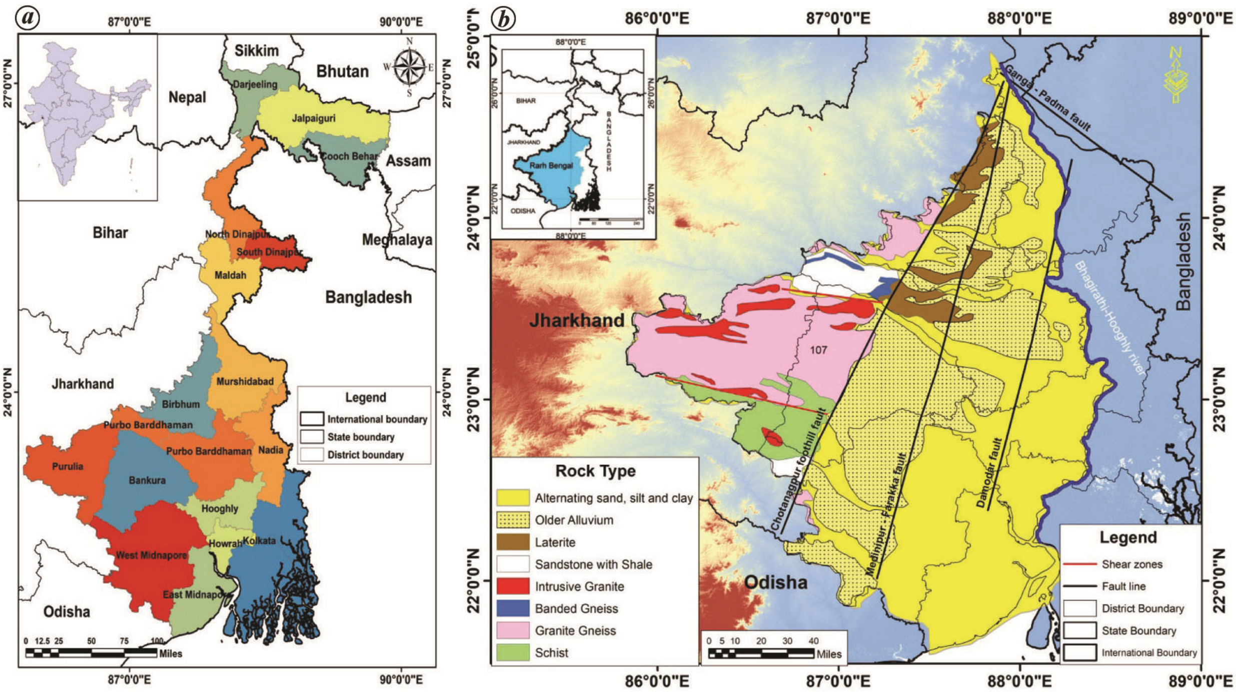


**Figure 1.** ***a***, District map of West Bengal; ***b***, Simplified geological map of Rarh Bengal.

resolution and 8 SWIR band having 15 m resolution. On the other hand, ASTER imagery consists of 3 VNIR bands of 30 m resolution and SWIR band of 15 m resolution[14]. A lineament density index (LDI) is computed by taking into consideration total length of lineament per unit area (km/km$^2$) and expressed as

$$\text{LDI} = \sum_{i=1}^{N} xi \ \text{km/km}^2, \quad (1)$$

where LDI is the lineament density index (total length of lineament), $N$ denotes number of lineament and $xi$ is the length of lineament number $i$.

Total of 727 water samples were collected from Purulia, Bankura and Birbhum districts of Rarh Bengal and important parameters, viz. fluoride ($F^-$), pH, iron (Fe), potassium (Na), calcium (Ca), magnesium (mg), bicarbonate ($HCO_3$), etc. were determined. LKB UV-visible spectrophotometer model 4054 attached with an automatic cell driver, 1 cm quartz cell and spectrum recorder has been used for the measurement of fluoride (mg/l) concentration in the water samples. Thin sections of 34 rock chip samples have been collected from the three districts and these were examined under the petrological microscope and the mineralogy was determined by X-ray powder diffractometry in the laboratory of the Geological Survey of India. In order to analyse the magnitude of fluorosis, a total of 1753 households (410 villages) were surveyed applying stratified random and quota sampling technique. To determine the degree of risk due to fluoride related health issues, fluoride hazard and vulnerability have been calculated as[6]

$$\text{FHI} = (\text{\% of geographical areas affected by fluoride} + tfhev)/100, \quad (2)$$

where FHI is the fluoride hazard index and *tfhev* is the total fluoride hazard evaluation value.

$$\text{FVI} = \text{ratings of } mtf + ef + adwa + sa, \quad (3)$$

where FVI means fluoride vulnerability index, *mtf*, medical treatment facilities within 5 km radius, *ef*, education facilities, *adwa*, alternate drinking water availability and *sa* is the social awareness. Thus on the basis of FHI and FVI, fluoride risk is computed as

$$R = H + V, \quad (4)$$

where $R$, Risk, $H$, Hazard and $V$, Vulnerability.

Figure 1 *b* shows simplified geological map of Rarh Bengal. The rock formations principally belong to the Precambrian Chotanagpur gneissic complex (CGC) exposed to the north of Singbhum Craton[15,16]. The study shows that the predominant Precambrian metamorphic rocks constituting Chotanagpur granitic gneiss complex are granite gneiss, cal-granulites and meta-basic rocks. The banded gneisses of this region are similar to other basement rocks of the Indian Shield. Amphibolites, hornblende gneiss and diorite gneisses are exposed as bands occasionally amidst the gneisses[17]. Gneissic rocks

**Table 1.** Affected villages with high fluoride content in different blocks under the three districts of Rarh Bengal (2019)

| Districts | Blocks | Total no. of affected villages | Average fluoride (mg/l) | Villages with highest fluoride concentration | Highest fluoride value (mg/l) | Highest fluoride (rock chip) (mg/kg) | Fluoride bearing minerals |
|---|---|---|---|---|---|---|---|
| Purulia | Arsha | 17 | 0.71 | Kishanpur | 1.59 | 5,110 | Apatite |
| | Baghmundi | 43 | 0.25 | Burda | 0.65 | 4,507 | Fluorite |
| | Balarampur | 25 | 0.77 | Biramdih | 1.63 | 5,202 | Apatite |
| | Bandwan | 8 | 0.33 | Gurur | 0.85 | 4,700 | Biotite mica |
| | Barabazar | 21 | 0.68 | Ladiha | 1.87 | 5,330 | Fluorite |
| | Hura | 17 | 0.89 | Palgan | 1.85 | 5,324 | Biotite mica |
| | Jhalda I | 18 | 0.68 | Ichag | 2.58 | 5,500 | Apatite |
| | Jhalda II | 21 | 0.75 | Sarjumatu | 1.88 | 5,338 | Hornblende |
| | Joypur | 19 | 0.53 | Karkara | 1.96 | 5,400 | Hornblende |
| | Kashipur | 19 | 0.38 | Rambani | 8.01 | 12,400 | Fluorite |
| | Manbazar I | 45 | 1.40 | Daha | 6.77 | 9,900 | Fluorite |
| | Manbazar II | 21 | 0.55 | Sankura | 1.52 | 4,995 | Biotite mica |
| | Neturia | 44 | 0.58 | Gunyara | 3.65 | 6,300 | Apatite |
| | Para | 20 | 0.64 | Kaluhar | 1.83 | 5,315 | Hornblende |
| | Puncha | 48 | 1.10 | Kenda | 2.92 | 5,822 | Biotite mica |
| | Purulia I | 43 | 0.72 | Dimdiha & Bhul | 1.96 | 5,337 | Fluorite |
| | Purulia II | 78 | 1.43 | Bhangra | 5.56 | 8,500 | Apatite |
| | Raghunathpur I | 20 | 0.70 | Shanka | 2.18 | 5,445 | Hornblende |
| | Raghunathpur II | 35 | 0.91 | Barrah | 1.98 | 5,430 | Fluorite |
| | Santuri | 18 | 0.71 | Talberya | 1.81 | 5,310 | Biotite mica |
| Bankura | Bankura II | 6 | 3.35 | Kanchanpur | 7.30 | 10,000 | Apatite |
| | Indpur | 1 | – | Kamlabad | 6.85 | 9,400 | Hornblende |
| | Khatra | 3 | 4.86 | Jasara | 7.80 | 10,200 | Biotite mica |
| | Mejhia | 3 | 1.86 | Banjora | 2.10 | 5,442 | Fluorite |
| | Ranibundh | 1 | – | Suritari | 2.70 | 5,600 | Biotite mica |
| | Simlapal | 5 | 3.58 | Bhaduldoba | 6.92 | 9,555 | Hornblende |
| | Taldangra | 1 | – | Kadamara | 1.64 | 5,207 | Apatite |
| Birbhum | Dubrajpur | 1 | – | Dedaha | 1.54 | 5,198 | Biotite mica |
| | Khoyrasole | 6 | 4.55 | Kendgore | 10.42 | 9,000 | Hornblende |
| | Mayureswar I | 2 | 2.35 | Sekhpur | 2.71 | 5,605 | Fluorite |
| | Nalhati I | 2 | 2.38 | Lakshminarayanpur | 2.95 | 5,826 | Hornblende |
| | Rajnagar | 7 | 2.16 | Bhabanipur | 3.07 | 5,850 | Apatite |

are mylonitized at places giving rise to mylonite gneiss[18] which show strong planar fabric and straight bands. Such mylonite gneisses occur in the vicinity of outcrops of Bengal Anorthosite[18]. Numerous granites occur as isolated plutons in the CGC and largely these granite plutons have been detected in the Ranchi–Purulia Belt. The granites of CGC are classified into pink and grey granites[19]. The youngest-pink type, intrudes the gneissic complex. The grey granites are mostly porphyritic and coarse-grained seen in the form of dome-like bosses and tors[20–22]. Some granites show migmatitic character. The supracrustal metasedimentary and metavolcanic rocks appear in the gneissic rocks as enclaves in different pockets in Rarh Bengal. These are mainly mica schist, quartzite, banded iron formation and marble along with ultramafic and mafic rocks. Geologically, the most important attribute of CGC is the incidence of elliptical or lenticular bodies of anorthosite which are locally associated with thin lenses of syenite[22]. The largest mass of anorthosite is Bengal Anorthosite which is an approximately 40 km long elongated ‘tadpole-shaped’ body[23]. This ‘tadpole-shaped’ intrusive body is associated with felsic gneisses and metapelitic granulites[24].

In Purulia district, two prominent east-west shear zones are seen[6]. Prominent vertical joints are exposed in the granite gneiss having north-south, east-west, east-southeast strike. Well-developed bedding and indistinct bedding planes have also been found in the sedimentary rocks such as sandstone and shale formations of the Gondwana Group. In the northeastern part of the Singbhum craton, carboniferous shale is predominant that is highly jointed, but compact in nature.

Petrographic studies revealed that granite gneiss, biotite granite gneiss, biotite gneiss, hornblende schist and pegmatite are the fluoride bearing host rocks along with the fluoride bearing minerals hornblende, biotite, apatite and fluorite in this area (Table 1).

The favourable primary and secondary geological structures such as shear or fracture zones, joints, schistosity, foliation, etc. accelerate the weathering processes[25,26].

**Table 2.** Physico-chemical properties of various water samples collected from three districts of Rarh Bengal, 2019

| Block | Location | pH | Ca | Mg | Na | Cl | $SO_4$ | $HCO_3$ |
|---|---|---|---|---|---|---|---|---|
| Purulia | Manbazar | 7.23 | 24 | 7.3 | 50 | 32 | 41 | 214 |
| | Hura | 7.51 | 30 | 27 | 46 | 32 | 45 | 220 |
| | Kotshila | 8.12 | 82 | 17 | 96 | 132 | 97 | 238 |
| | Arsa | 8.96 | 140 | 39 | 240 | 462 | 93 | 390 |
| | Bagmundi | 6.16 | 66 | 27 | 430 | 604 | 5 | 177 |
| | Raghunathpur | 5.96 | 138 | 40 | 407 | 296 | 193 | 91 |
| | Gauandih B | 6.77 | 70 | 9.7 | 125 | 156 | 97 | 207 |
| | Kenda | 8.04 | 78 | 22 | 105 | 164 | 51 | 250 |
| | Takaria | 7.11 | 34 | 16 | 49 | 107 | – | 195 |
| | Sindri | 8.41 | 84 | 34 | 19 | 28 | 29 | 323 |
| | Dangardi | 6.34 | 54 | 71 | 20 | 132 | – | 146 |
| | Narayanpur | 7.09 | 84 | 21 | 29 | 139 | 3 | 189 |
| | Jhargo | 6.79 | 180 | 23 | 62 | 270 | 47 | 205 |
| | Keshargarh | 6.09 | 26 | 24 | 27 | 32 | – | 134 |
| | Baraurma | 5.97 | 12 | 15 | 15 | 249 | – | 61 |
| | Ludurka | 7.84 | 98 | 4.8 | 118 | 341 | 9 | 262 |
| | Tamna | 7.52 | 82 | 40 | 82 | 231 | 56 | 232 |
| | Kantadihi | 6.74 | 80 | 39 | 25 | 117 | 40 | 195 |
| | Bero | 7.79 | 44 | 30 | 26 | 32 | 8 | 290 |
| | Kustur | 8.10 | 140 | 16 | 117 | 181 | 142 | 445 |
| | Para | 8.96 | 140 | 43 | 483 | 427 | 432 | 763 |
| | Dubra | 7.33 | 50 | 61 | 76 | 89 | | 232 |
| | Mathbura | 7.61 | 112 | 16 | 303 | 370 | 145 | 555 |
| | Joypur | 7.42 | 82 | 32 | 139 | 196 | – | 397 |
| | Bishpuria | 6.56 | 52 | 26 | 97 | 124 | – | 256 |
| | Simla | 5.96 | 94 | 17 | 28 | 43 | – | 79 |
| | Korenge | 6.14 | 66 | 6 | 26 | 135 | – | 159 |
| | Balitora | 8.32 | 110 | 24 | 115 | 178 | 9 | 531 |
| | Chakaltore | 7.46 | 70 | 40 | 65 | 107 | 13 | 342 |
| | Jhapra | 6.51 | 60 | 8.5 | 26 | 89 | 11 | 189 |
| | Naduara | 6.49 | 76 | 18 | 23 | 149 | – | 177 |
| | Barabazar | 8.52 | 162 | 34 | 185 | 334 | 12 | 616 |
| | Chinpina | 6.77 | 100 | 40 | 330 | 494 | 27 | 348 |
| | Podalroad | 8.69 | 117 | 18 | 253 | 430 | 23 | 726 |
| | Hariharpur A | 6.10 | 46 | 58 | 72 | 107 | 50 | 183 |
| | Babugram | 6.04 | 36 | 15 | 19 | 21 | – | 134 |
| | Kapasitha | 6.49 | 80 | 8.5 | 32 | 156 | – | 281 |
| | Napara | 6.35 | 44 | 32 | 23 | 50 | 15 | 194 |
| | Deuli | 6.21 | 30 | 24 | 68 | 85 | 21 | 159 |
| | Gobag | 6.85 | 38 | 17 | 93 | 124 | 56 | 201 |
| | Bararola | 6.94 | 54 | 13 | 71 | 78 | 19 | 238 |
| | Dhabani | 7.23 | 82 | 7.3 | 96 | 85 | 93 | 275 |
| | Ankro | 7.05 | 70 | 15 | 115 | 124 | 77 | 207 |
| | Nituria | 7.01 | 86 | 16 | 67 | 17 | 51 | 226 |
| | Katagora | 6.19 | 36 | 11 | 29 | 28 | 46 | 165 |
| | Imundi | 7.34 | 118 | 146 | 225 | 298 | 234 | 214 |
| | Bagmundiha | 7.46 | 30 | 18 | 95 | 67 | 49 | 299 |
| | Rangini | 6.09 | 96 | 17 | 234 | 373 | 175 | 104 |
| | Panipathar | 7.39 | 102 | 26 | 119 | 174 | 100 | 354 |
| | Tulin | 6.01 | 12 | 73.6 | 21 | 21 | 15 | 61 |
| Bankura | Barjora | 7.28 | 42 | 27 | 15 | 39 | 2.7 | 238 |
| | Radhanagar | 6.03 | 26 | 8.5 | 17 | 32 | – | 98 |
| | Mejia | 6.66 | 42 | 13 | 14 | 39 | 2.9 | 220 |
| | Bankura | 6.73 | 66 | 35 | 113 | 107 | 192 | 244 |
| | Chhatna | 8.16 | 104 | 45 | 69 | 110 | 43 | 470 |
| | Ranibandh | 6.29 | 82 | 55 | 515 | 231 | 201 | 146 |
| | Beduasol | 6.35 | 162 | 77 | 302 | 629 | 244 | 262 |
| | Simlipal | 6.02 | 10 | 7.3 | 18 | 21 | 1.9 | 61 |
| | Patrasayer I | 5.96 | 24 | 17 | 16 | 39 | 29 | 49 |
| | Patrasayer II | 6.09 | 34 | 6 | 26 | 46 | – | 92 |
| | Patrasayer II | 6.18 | 58 | 15 | 29 | 82 | 3 | 104 |

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**Table 2.** (*Contd*)

| Block | Location | pH | Ca | Mg | Na | Cl | $SO_4$ | $HCO_3$ |
|---|---|---|---|---|---|---|---|---|
| | Jhilimili | 6.25 | 18 | 7.3 | 16 | 46 | 34 | 250 |
| | Ratanpur | 5.99 | 16 | 8.5 | 13 | 25 | 99 | 43 |
| | Gangajolhati | 6.21 | 40 | 18 | 90 | 75 | 141 | 153 |
| | Gholkunda | 6.24 | 150 | 49 | 237 | 405 | 337 | 159 |
| | Kharkasuli | 5.97 | 18 | 6 | 50 | 36 | – | 55 |
| | Rautkanda | 8.41 | 16 | 13 | 209 | 160 | – | 409 |
| | Benajira | 8.75 | 100 | 57 | 231 | 284 | 8.6 | 756 |
| | Dhabon | 8.59 | 140 | 53 | 161 | 288 | 5 | 494 |
| | Barjora | 6.34 | 84 | 27 | 276 | 306 | 7 | 549 |
| | Kusthalia | 6.13 | 98 | 40 | 185 | 224 | 19 | 226 |
| | Murulu | 6.09 | 42 | 26 | 89 | 96 | 100 | 183 |
| | Tarasinsh bridge | 7.22 | 48 | 18 | 65 | 53 | 145 | 262 |
| | Susunia | 6.03 | 310 | 97 | 286 | 427 | 16 | 116 |
| | Kenjakura | 7.01 | 58 | 50 | 41 | 107 | 25 | 153 |
| | Gouripur | 7.37 | 350 | 403 | 368 | 1013 | 20 | 244 |
| | Lakhanpur | 7.43 | 60 | 43 | 148 | 284 | 19 | 256 |
| | Narula | 6.06 | 26 | 9.7 | 16 | 78 | 5 | 153 |
| | Sahabdi | 5.97 | 18 | 15 | 35 | 89 | 7 | 67 |
| | Basudevpur | 6.88 | 50 | 18 | 69 | 128 | 24 | 171 |
| | Jaadavnagar | 5.96 | 8 | 3.6 | 51 | 36 | 49 | 12 |
| | AIMA | 6.08 | 12 | 7.3 | 16 | 32 | 34 | 55 |
| | Basudevpur | 7.59 | 17 | 18 | 138 | 235 | – | 354 |
| | Chunpara | 8.14 | 128 | 46 | 9.5 | 327 | 17 | 580 |
| | Jadavnagar | 7.54 | 108 | 33 | 140 | 213 | | 366 |
| | Chandai | 6.29 | 150 | 49 | 230 | 356 | 24 | 110 |
| | Ganganidanga | 6.44 | 26 | 17 | 30 | 50 | – | 134 |
| | Junsura | 6.31 | 30 | 9.7 | 27 | 39 | 24 | 110 |
| | Moyra | 5.97 | 12 | 4.9 | 12 | 36 | – | 31 |
| | Tantibandh | 5.99 | 16 | 2.4 | 24 | 18 | 98 | 61 |
| | Fakirdanga | 6.01 | 42 | 6 | 32 | 50 | 288 | 61 |
| | Tuldaria | 5.96 | 14 | 3.6 | 15 | 61 | 49 | 31 |
| | Ghugimorai | 6.05 | 18 | 8.5 | 30 | 62 | 97 | 73 |
| | BasudevpurAnchal | 6.02 | 6 | 2.4 | 34 | 18 | 98 | 74 |
| | Besula | 6.00 | 14 | 7.3 | 7.3 | 28 | 91 | 43 |
| | Bongali | 6.05 | 14 | 3.6 | 14 | 25 | 194 | 61 |
| | Prasadpur | 8.24 | 64 | 39 | 26 | 64 | – | 305 |
| | Padampur | 8.61 | 78 | 33 | 190 | 288 | 93 | 372 |
| | Sonamukhi | 6.42 | 30 | 24 | 24 | 64 | 336 | 122 |
| Birbhum | Bolpur | 7.94 | 60 | 32 | 62 | 89 | 6.3 | 336 |
| | Baidanathpur | 7.99 | 78 | 24 | 56 | 36 | 2.1 | 372 |
| | Muluk | 6.35 | 42 | 39 | 51 | 103 | 4.5 | 189 |
| | Kakuria | 7.38 | 50 | 39 | 258 | 430 | 4.1 | 262 |
| | Logata | 6.25 | 44 | 12 | 29 | 53 | 9.2 | 171 |
| | Labpur | 6.27 | 110 | 30 | 45 | 231 | 8.1 | 171 |
| | Sambati | 6.90 | 46 | 18 | 50 | 36 | 2.3 | 299 |
| | Santiniketan | 6.03 | 10 | 2.4 | 18 | 21 | 3.5 | 49 |
| | Bolpur D | 7.97 | 68 | 43 | 141 | 231 | 2.2 | 354 |
| | Jamboni | 6.05 | 22 | 12.1 | 20 | 57 | 1.9 | 98 |
| | Ballavpur | 6.07 | 24 | 6 | 68 | 103 | 2.2 | 98 |
| | Ballavpur I | 6.62 | 36 | 15 | 27 | 14 | 1.1 | 195 |
| | Ballavpur II | 6.54 | 46 | 12.1 | 42 | 60 | 1 | 177 |
| | Ruppur | 7.22 | 32 | 16 | 46 | 68 | 1.2 | 220 |
| | Illambazar | 8.55 | 62 | 27 | 251 | 217 | 141 | 415 |
| | Bondanda | 6.13 | 30 | 61 | 82 | 117 | – | 140 |
| | Kopai | 6.08 | 30 | 61 | 28 | 71 | – | 85 |
| | Ahemedpur | 8.92 | 72 | 24 | 185 | 210 | 95 | 630 |
| | Paikpara | 7.50 | 42 | 15 | 44 | 14 | – | 262 |
| | Sainthia | 7.64 | 56 | 6 | 31 | 36 | – | 220 |
| | Sainthia C | 7.81 | 78 | 9.7 | 31 | 43 | 6.4 | 275 |
| | Nimpur | 7.51 | 15 | 38 | 19 | 57 | 5.8 | 232 |
| | Kotasur | 7.92 | 18 | 3.6 | 9.2 | 18 | 1.2 | 287 |

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**Table 2.** (*Contd*)

| Block | Location | pH | Ca | Mg | Na | Cl | $SO_4$ | $HCO_3$ |
|---|---|---|---|---|---|---|---|---|
| | Maureswar | 7.96 | 36 | 15 | 75 | 18 | – | 293 |
| | Tarapur | 7.39 | 64 | 19 | 79 | 11 | – | 226 |
| | Nagora | 7.35 | 50 | 15 | 22 | 7.1 | – | 220 |
| | Nidhia | 6.73 | 42 | 17 | 6.3 | 50 | – | 134 |
| | Mitrapur | 7.36 | 12 | 27 | 53 | 11 | – | 232 |
| | Panchahar | 6.70 | 32 | 17 | 58 | 43 | – | 177 |
| | Murarai | 7.44 | 78 | 61 | 34 | 53 | – | 244 |
| | Ratanpur | 7.16 | 32 | 49 | 19 | 14 | – | 214 |
| | Palsa | 7.41 | 58 | 26 | 45 | 53 | 0.11 | 244 |
| | Abdullapur | 6.34 | 62 | 18 | 35 | 82 | 0.06 | 146 |
| | Chara | 7.55 | 70 | 6 | 34 | 64 | 0.24 | 268 |
| | Margram | 6.79 | 62 | 11 | 33 | 36 | 0.25 | 183 |
| | Chandpara | 6.83 | 30 | 9.7 | 24 | 142 | 0.06 | 189 |
| | Shardha | 6.80 | 36 | 23 | 22 | 284 | 0.05 | 183 |
| | Kurugram | 6.80 | 26 | 15 | 11 | 106 | – | 189 |
| | Nasipur | 6.75 | 30 | 7.3 | 17 | 14 | 0.27 | 159 |
| | Amlai | 7.89 | 62 | 35 | 87 | 82 | – | 305 |
| | Nalhati | 8.36 | 164 | 102 | 239 | 525 | 0.22 | 433 |
| | Rampurhat I | 7.22 | 84 | 27 | 112 | 213 | 0.14 | 244 |
| | Rampurhat II | 7.38 | 40 | 26 | 172 | 107 | 0.25 | 262 |
| | Dhanmara | 7.34 | 32 | 36 | 41 | 57 | 0.41 | 250 |
| | Chakmandola | 6.02 | 10 | 15 | 21 | 46 | 0.08 | 73 |
| | Tumboni | 7.14 | 36 | 28 | 20 | 28 | 0.06 | 226 |
| | Naraynpur | 6.07 | 16 | 2.4 | 2.3 | 286 | 0.11 | 43 |
| | Kukurdighi | 6.82 | 34 | 24 | 2.8 | 46 | 0.37 | 134 |
| | Borjlbelpahari I | 6.10 | 76 | 9.7 | 28 | 57 | 0.41 | 85 |
| | Borjlbelpahari II | 6.17 | 24 | 9.7 | 9.2 | 18 | 0.21 | 98 |

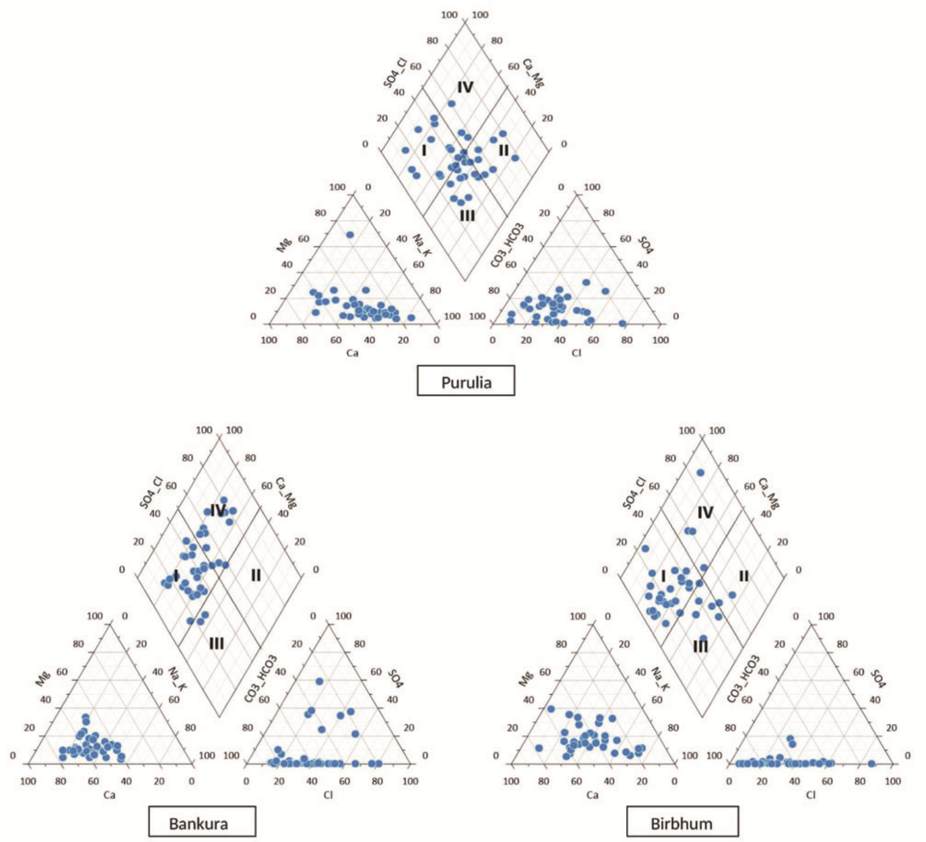


**Figure 2.** Piper diagram showing the hydro-geochemical properties of groundwater of three districts of Rarh Bengal (I, Ca–Mg–$HCO_3$ type; II, NA–Cl type; III, Na–$HCO_3$ type; IV, Ca–Mg–$SO_4$–Cl type).

**Table 3.** Magnitude of hazard, vulnerability and risk prone blocks of the three districts of Rarh Bengal with different types of dental and skeletal fluorosis

| Fluoride affected districts of Rarh Bengal | Affected blocks | | | Impact on human health or magnitude of fluorosis | |
|---|---|---|---|---|---|
| | Very high/high fluoride hazard | Very high/high fluoride vulnerability | Very high/high fluoride risk | Dental fluorosis (very mild, mild, moderate and severe) | Skeletal and non-skeletal fluorosis |
| Purulia | Purulia I, Neturia, Puncha, Manbazar I and Purulia II | Jhalda I, Jhalda II, Arsha, Balarampur, Hura, Santuri, Puncha, Kashipur and Manbazar II | Purulia II and Puncha | Small opaque, 'paper white' areas scattered irregularly over the tooth, mottled patches, brown stains, cavities, corroded like appearance | Knee, hip, neck, pelvic joints pain, unable to work, bow legs, lumber spines, etc. |
| Bankura | Bankura-II, Indpur, Khatra and Simlapal | Khatra and Indpur | Khatra, Indpur and Simlapal | Small opaque, 'paper white', mottled patches, brown stains, etc. | Hip joints pain, neck joints pain, shoulder joints pain, cannot do sit up, cannot bent forward, lumber spines, etc. |
| Birbhum | Mayureswar-I, Nalhati-I and Rajnagar | Khoyrasole and Nalhati-I | Khoyrasole | Small opaque, 'paper white', brown discolouration and discrete or confluent pitting, cavities, corroded like appearance | Knee joints pain, hip joints pain, neck joints pain, shoulder joints pain, pelvic joints pain, cannot do sit up, cannot bent forward easily, unable to work, bow legs, lumber spines, etc. |

Similarly rock water interaction, rapid draw down of groundwater table and prominent meteorological and hydrological drought have accelerated the removal of fluoride and added it into the soils and water. The high alkaline water assists in rapid dissolution of fluoride ions into the flowing water. The laboratory analysis of water samples (physico-chemical analysis) and plotting in Piper diagrams reveal that the hydro-geochemical facies of groundwater in these districts of Rarh Bengal are Ca–Mg–$HCO_3$ type which facilitates in the mobilization of fluoride ions in moving water under favourable alkaline pH condition (Table 2 and Figure 2).

The petrological study of rock chips revealed that the fluoride content varied in different host rocks in these three districts. The highest fluoride in the rock sample was found to be around 12,400 ppm in Purulia followed by 10,200 ppm in Bankura and 9000 ppm in Birbhum. The staggering figures indicate that most of the rock samples contain more than 5000 mg/kg fluoride (Table 1).

Results of the present study conducted during 2017–2019 showed that 134 villages of Rarh Bengal have high fluoride content in groundwater (Table 1). In Purulia district, out of 20 blocks, 14 are having groundwater with fluoride concentration above the permissible limit. Nearly 118 villages are prone to fluorosis related health hazards. Rambani (8.01 mg/l), Daha (6.77 mg/l), Bhangra (5.56 mg/l), Puncha (4.24 mg/l), Juhidi (3.81 mg/l), Mamurjor (2.77 mg/l), Chaupad (2.65 mg/l), etc. are the worst affected villages. More than 300,000 people are living in high fluoride areas. Out of 19 blocks, 5 blocks in Birbhum district and 9 villages are found to have high fluoride groundwater. Groundwater in some villages, namely Kendgore (10.42 mg/l), Purba Borkola (5.10 mg/l), Bhabanipur (3.07 mg/l), Lakshminarayanpur (2.95 mg/l), etc. have very high fluoride concentration. Nearly 100,000 people are found to be vulnerable to fluorosis. Similarly, Bankura district too, the situation is not very encouraging. Seven blocks out of 22 have high fluoride groundwater and 15 villages with very high fluoride contamination. Some of them are Jasara (7.80 mg/l), Kanchanpur (7.30 mg/l), Bhaduldoba (6.92 mg/l), Kamlabad (6.85 mg/l), Machatora (5.83 mg/l), Jagannathpur (4.40 mg/l), etc. More than 200,000 people are exposed to fluorosis. Therefore, in the three districts of Rarh Bengal – Purulia, Bankura and Birbhum, around 600,000 people are vulnerable to fluoride related health hazards.

The present study has found that Kendgore village and Purba Borkola of Khoyrasole block, and Bhabanipur village of Rajnagar block of Birbhum district are prone to high risk of fluorosis. On the other hand, in Bankura district, Jasara village in Khatra block, Kanchanpur in Bankura II, Bhaduldoba and Machatora in Simplapal, Kamlabad in Indpur block show considerably high to very high fluoride. Purulia district has the largest number of fluoride contaminated blocks and villages. Puncha village in Puncha block, Juhidi in Raghunathpur I, Mamurjor in Purulia II, Srijumkahna in Hura, Chaupad in Jhalda I, etc. are worst affected.

Over the years, due to prolonged intake of high fluoride water in Rarh Bengal, people are becoming more prone to high risk of fluorosis. Moderate to chronic dental, skeletal and non-skeletal fluorosis are found to be rampant. Various degrees of physical disability due to pain in knee joints, hip, neck, shoulder, pelvic joints have been observed. People who are unable to squat or bend forward easily, unable to walk, having bow legs, narrowing of vertebral foramen in lumbar spines or vertebrae, etc. are commonly seen in the region (Table 3).

The following strategies are suggested as holistic mitigation measures:

(i) Fluoride removal units should be attached with existing or new tube wells in all the fluoride affected blocks. Deep tube wells should be installed in uncontaminated aquifers.

(ii) Several dams or reservoirs still exist in the districts of Rarh Bengal region. Many suitable sites have been identified for the construction of new small dams or check dams across the rivers[27] without displacing human habitations and destruction of forest. Despite existing dams/reservoirs, new dams/reservoirs need to be constructed (without hampering the ecological stability or environmental norms of Ministry of Environment and Forest) for supplying fluoride free water to each and every household in the fluorosis affected blocks. Similarly, the existing area of reservoirs should also to be enlarged to accommodate the maximum storage of water for the benefit of local people who are not getting sufficient water during lean months.

(iii) In few cases, small check dams need to be constructed across Subarnarekha, Kumari and Kangsabati rivers to provide safe drinking water to the fluoride affected poor villagers.

(iv) More multi-annual and integrated support programmes for the use of bio-fertilizers in agricultural system and sustainable water use in dryland area should be encouraged[6].

(v) Human resource development programmes like development of medical facilities, human resource capabilities and skill profiles of firms, especially training programmes, need to be assessed.

(vi) The above discussed three districts of Rarh Bengal are dominated by tribal population. Finally, it is important to provide education facilities, arrange short-term training courses to educate people about dealing with fluoride related problems at the local level.


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# Full-parameter optimization to locate multi-passage-seepage in abutment using groundwater temperature

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**With groundwater temperature, hybrid-genetic algorithm is employed to locate multi-passage concentrated seepage underground to increase the probability of optimal global solutions, calculation efficiency and precision. The parameters of concentrated seepage passages (CSPs) indicated initially by the previous optimization and attraction basins of modified temperature residuals are evaluated again by the proposed full parameter optimization. The smaller CSP impacts on the stronger are eliminated, since all the parameters associated with all the CSPs are calculated by the last one-off optimization. In this case, three optimization steps are implemented with crossover fractions of 0.8, 0.5 and 0.45 (0.3), and the modified resultant residuals are 13.441, 2.27 and 0.7 individually. Results of this method are more effective compared to those from other methods and actual applications.**

**Keywords:** Abutment, dam safety, hybrid-genetic algorithm, geothermal temperature, seepage.

TO effectively repair abutments and dams which are scoured by concentrated seepage passages (CSPs), the seepage locations need to be identified. Using underground temperature for dam leakage detection is a relatively fast, more environment-friendly as well as practical approach[1]. Some studies indicate that this method is becoming fully independent and quantitative[2–8]. The lowest temperature method for location detection has been proposed and adopted earlier[9,10].

Based on the principle of heat conservation and thermal equilibrium, analytical solutions to flux and single CSP location in the field of initial homogeneous temperature are calculated numerically[6]. Parameters representing CSP characteristics are estimated following the temperature data calibration with vertical thermal gradient[11]. Theoretical models and objective functions are established for planar CSP detection[12]. The number and initial locations of the CSPs are obtained by analysing spline interpolation curves of the temperature data or their residuals, and an inverse technique is applied for multi-CSP location detection[1]. A global optimization, composed of simulated annealing (SA) or genetic algorithm (GA) and multi-start (MS), is employed to estimate

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