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Geographical analysis of fluoride distribution pattern in groundwater and related health effects in Puruliya District of West Bengal, India

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Abstract

An overwhelming 90 percent of the population in the Puruliya district is rural and significantly dependent on groundwater as the only source of drinking water. However, the groundwater of all the 20 blocks of this district is contaminated with high-level fluoride. The geographical pattern of fluoride distribution in this study is assessed using Moran's Index, and hotspot analysis on fluoride contamination reports of 2019-20. Fluoride distribution shows a random pattern, and the hotspot zones are spread in blocks, namely Puruliya- I, Puruliya-II, Raghunathpur-I, Raghunathpur-II, Puncha, Balarampur, Para, Hura, Jaipur, Manbazar-I. This study will help to identify the areas with chronic and acute problems that need immediate measures.

Keywords: *Fluoride, groundwater, hotspot, contamination, fluorosis.*

Introduction

World Health Organisation (2004) reported that more than 85 per cent of people living in India are primarily dependent on groundwater for drinking purposes. Thus, human health status is largely dependent on the quality of groundwater. The potability of groundwater is subject to the quantity of various ions dissolved in it (Wood, 1974). Aquifers with crystalline subsurface are usually enriched with high fluoride groundwater (Edmunds and Smedley, 2005; Jacks *et al.*, 2205). Leaching of minerals like granites, monzonites, quartz with high fluorite content from the crystalline basement through rock-water interaction is the primary factor behind fluoride-rich groundwater (Handa, 1975; Hyndman, 1985 and Ozsvath, 2009). Rocks of alkaline nature are higher in fluoride concentration (Dey, Goswami and Ghosh, 2004).

Arid parts of the world are most often found to be enriched with high fluoride groundwater because of evapotranspiration in the soil and water, which elevate the residual alkalinity in the groundwater (Jacks *et al.*, 2005). The disintegration of fluoride bearing rocks becomes much easier due to the higher temperature in these regions (Ali *et al.*, 2006; Saxena and Ahmad, 2003). High fluoride level is usually found in the deeper part of groundwater where the rock-water contact period is prolonged, and groundwater infiltration and flow rate are low (Raju, 2017).

Ingestion of fluoride-rich groundwater via drinking water is the primary source of fluoride toxicity in the human body and its consequent assimilation through food items.

Fluoride consumption below 0.5 mg/L results in dental caries, distortion of dental enamel, and demineralisation of bones, particularly in children, whereas excessive ingestion (>1.5 mg /L) may lead to dental and skeletal fluorosis (WHO, 1994). Dental fluorosis can be identified with staining and pitting of teeth, while skeletal fluorosis leads to hardening and bending of bone due to the deposition of calcium fluoride in the joints, which elevates the fracture frequency (Jacks *et al.*, 2005; Turner, Binning and Stipp, 2005). Fluoride in water can be considered an imperceptible poison as it does not contain any distinguishable taste, odour or colour (Edmunds and Smedley, 2005).

High fluoride ground water is a major geogenic issue worldwide, but the inhabitants of the tropical region are suffering more due to the climate and its close proximity with their surrounding environment (Dissanayake and Chandrajith, 2009). India, a tropical country, has its major consequences due to fluoride-rich drinking water (Agrawal, Vaish and Vaish, 1997; Solanki *et al.*, 2022). It is reported that 18,700 people in India have shown various skeletal fluorosis symptoms, including the development of kidney stones (Singh *et al.*, 2001; Mukherjee and Singh, 2018). In India, the fluoride level in groundwater fluctuates from 0.1 to 48 mg/l (Susheela, 2002). According to Central Ground Water Control Board report 276 districts spread over the 20 states in India have fluoride in their groundwater above the tolerable limit. Rajasthan, Gujarat, Andhra Pradesh, Punjab, Haryana are central fluorosis endemic states of India (CGWB, 2013; Adimalla and Venkatayogi, 2017; Mandal and Sanyal, 2019).

In West Bengal, 60 blocks in eight districts, namely Bankura, Bardhaman, Birbhum, Purulia, Midnapur, Malda and West Dinajpur have been known for their fluoride contaminated groundwater (Chatterjee *et al.*, 2008; Gupta, Mondal and Bardhan, 2012). Among these eight-fluoride contaminated districts, Puruliya is the worst affected, where all 20 blocks have fluoride concentration beyond the acceptable level of 1.5 mg/l as per the norms (WHO, 2006; BIS, 2012; NRDWP, 2020). Here the range of fluoride concentration in groundwater ranges between 0.126 to 8.16 mg/l. Severely distressed blocks of the district are Balarampur, Hura, Kashipur, Puruliya-I, Puruliya-II, Raghunathpur- I. Severity of the situation has reached a frightening stage, but people under risk is still unidentified due to deficit of organized study and demarcation of fluoride contaminated zones (Chakrabarti, and Ray, 2013; Jha et el., 2013; Mandal and Sanyal, 2019). Therefore, it is essential to develop a health surveillance system for continuous monitoring. This involves delineating and mapping fluoride-hotspot areas, assessing the intensity of the effect, and analysing the fluoride concentration pattern in groundwater. An effort is made in this research to map the geographical pattern of fluoride distribution in Puruliya district using geo-statistical and geospatial techniques considering WHO's guideline.

Study area

Puruliya district lies at 22°43' N to 23°42' N latitude and 85°49' E to 88°54' E longitude comprising an area of 6259 Km^2 spread over 20 constituent development blocks (Fig. 1). Geomorphologically, the district is part of the Chotanagpur plateau characterised by undulating topography with isolated hills and

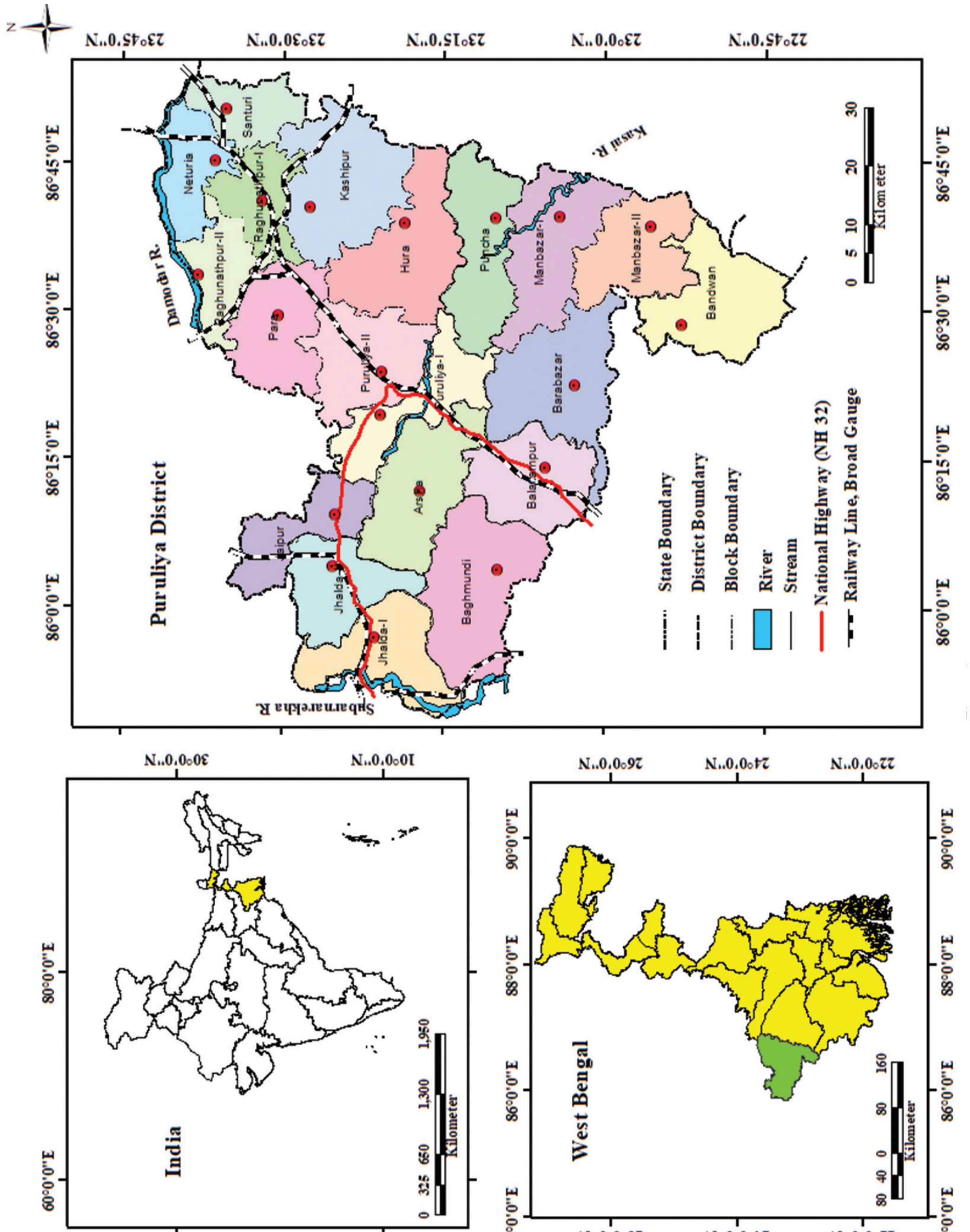

Fig. 1: Location and extent of the Puruliya District

mounts (Mandal and Sanyal, 2019; CGWB, Puruliya, 1989). The underlain geology of the area mainly consists of pre-Cambrian rocks, e.g. granite and gneiss, except a small part in the north-east where sediments of Gondwana age predominates. These granite rocks release a high fluoride in groundwater (Ozsvath, 2009). The district's climate is dry tropical with scorching summer and dry winter; maximum rainfall occurs during the monsoon (Gupta, Mondal and Bardhan, 2012; CGWB, Puruliya, 1989). The higher rate of evaporation in arid climatic settings results in alkaline fluoride-rich soil and underground water (Wang *et al.*, 2002; Young *et al.*, 2011).

Most rainwater flow as runoff and infiltration is difficult because of the hard rock sub-surface geology and undulating topography. This condition further aggravates when most surface water and shallow dug wells get dried up during summer, and people are forced to use fluoride-rich groundwater as drinking water due to absenteeism of centrally treated piped water in this region. The highest fluoride concentration is observed between 30 to 60 feet beneath the ground surface in the concerned area (Mandal and Sanyal, 2019; Chakrabarti, and Ray, 2013). The amount of water intake of people living in the area is higher because of the heat persisting throughout most of the months, which elevates fluoride ingestion in their body compared to cold climatic conditions (Manivannan *et al*, 2012; Chidambaram, 2013; Thivya, 2017).

The total population of Puruliya district is 2,930,115, of which 87.30 per cent in rural and ranks 3rd in terms of scheduled tribe population (Census of India, 2011). This tribal-dominated rural demography having an underprivileged socioeconomic background, low level of education, and geographical location makes the district most susceptible to fluoride exposure health hazards (Bhattacharya and Chakrabarti, 2011). Prior studies reported the evidence of villagers affected by dental and skeletal fluorosis by ingestion of fluoride enriched groundwater (Mondal and Nath, 2015).

Methods

Data collection, categorisation and mapping

The data is collected from Public Health and Engineering Department, West Bengal and National Rural Drinking Water Programme (NRDWP) reports related to fluoride concentration in groundwater for Puruliya district for 2018-19. The village-level shapefile is collected from Bhuvan, ISRO to superimpose the data of each village.

The development blocks of the district are classified into different fluoride concentration zones based on the villages' highest fluoride levels for each block. The classification is based on the summarisation of health effects related to fluoride level of drinking water made by Dissankaye in 1991 from the World Health Organization's drinking water guidelines in 1970. Here we have classified the data into four categories, e.g. below 0.5, 0.5 to 1.5, 1.5 to 4.0 and above 4.0 classes as in our study area, the highest fluoride concentration reported as 8.16 mg/l. So, we must exclude the above 10.0 mg/l fluoride concentration category in our study (Table 1). After that, we mapped the classes using the software Arc.GIS 10.5 (Fig. 2).

Geo-statistical analysis

To analyse the spatial pattern of fluoride concentration, the spatial autocorrelation method is applied based on the Tobler's first law of geography "everything is related to everything else, but nearby things are more related than distant things" (Foster, 2009).

Spatial Auto-correlation by Moran's Index

Moran's Index is used to understand the occurrence of fluoride concentration at a given location and assesses the extent and intensity of its effect on the surrounding. Auto-correlation coefficient lies between -1 to +1 (-1: negative autocorrelation indicating dispersion; 0: no autocorrelation indicating random pattern; +1: positive autocorrelation or clustered pattern).

Moran's I is an index to measure spatial auto-correlation developed by Patrick Alfred Pierce. Moran based on feature location and feature value. It assesses whether the spatial distribution pattern is clustered, dispersed, or random. We have used Moran's I to measure the spatial pattern of fluoride distribution in the Puruliya District for the year 2019-20 (Shan, 2015; Balyani, 2017). The formula is given below

$$I = \frac{N\sum_{i=I}^{n}\sum_{j=I}^{n} W_{ij}(X_i - \overline{X})(X_j - \overline{X})}{(\sum_{i=I}^{n}\sum_{j=I}^{i} W_{ij})\sum_{i=I}^{n}(X_i - \overline{X})^2}$$

The result of Moran's index for the spatial auto-correlation of distribution fluoride concentration of the Puruliya District is 0.22641, which is close to Zero (0), indicating a random pattern of distribution.

Further, it is also essential to distinguish between hotspot, e.g. higher values cluster together, and cold spot, e.g. low values cluster together. For this, Getis Ord GI* is performed, which is a Z score to identify the hotspot areas of fluoride concentration in the area (Getis and Ord, 1992).

Hotspot analysis

Z-score should be high and surrounded by a high Z-score to find a statistically significant hotspot. So, to identify hotspots of fluoride concentration in groundwater of Puruliya district where high fluoride values will surround high fluoride values, we have applied Getis Ord GI* in ArcGIS.

GI* value is the Z score which tells about the clusters.

Low values surrounded by low value are termed as cold spots, and high values surrounded by high value are termed as a hotspot (Bardhan, Debnath, and Bandopadhyay, 2016). The formula is given below

$$G_i^* = \frac{\sum_{j=i}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

Where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features.

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$s = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\overline{X})^2}$$

The GI* statistic is a Z score, so no further calculation is required (Das, 2021).

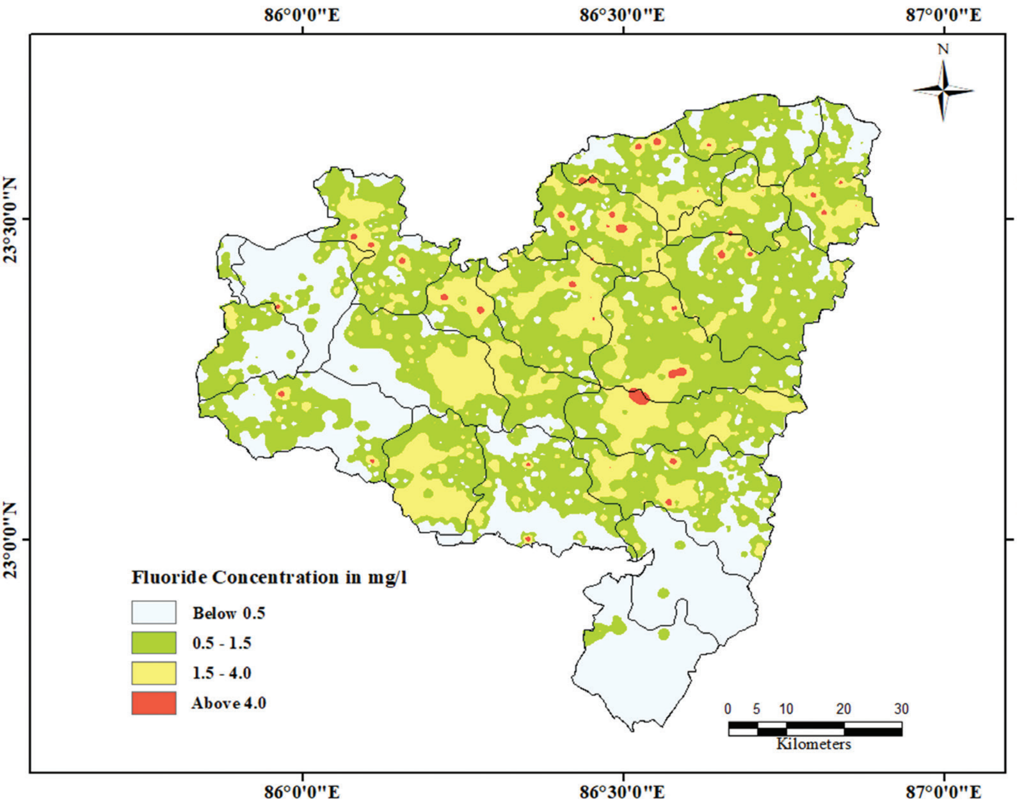

Fig. 2: Groundwater fluoride concentration zones of Puruliya District, 2018-19.

Examination and identification

Examination and identification of fluorosis affected people are conducted following the guidelines of WHO (1970) and NPPCF (2014). Fluorosis is a type of disease that results from excessive fluoride ingestion can be identified by teeth mottling in earlier stages to bone distortions to death in extreme cases (Fan, Parker and Smith, 2003). The incidence and prevalence of fluorosis can differ from place to place with the same level of fluoride concentration. During the field visit, a community-based survey of inhabitants having fluorosis of different stages is completed. Dean's Index is taken to measure the intensity and effect of dental fluorosis at different stages, and guidelines of the National Programme on Prevention and Control of Fluorosis, 2014 guidelines are followed to identify skeletal fluorosis affected people of the study area (NPPCF, 2014; Dean, 1942).

Photographic examinations of some observations on dental and skeletal fluorosis affected people are discussed below from the study area during the field visit. Digital images are taken with Canon 200 DSLR camera under indirect sunlight of the respondent with symptoms of dental and skeletal fluorosis. Photographs are taken with the consent of the participation.

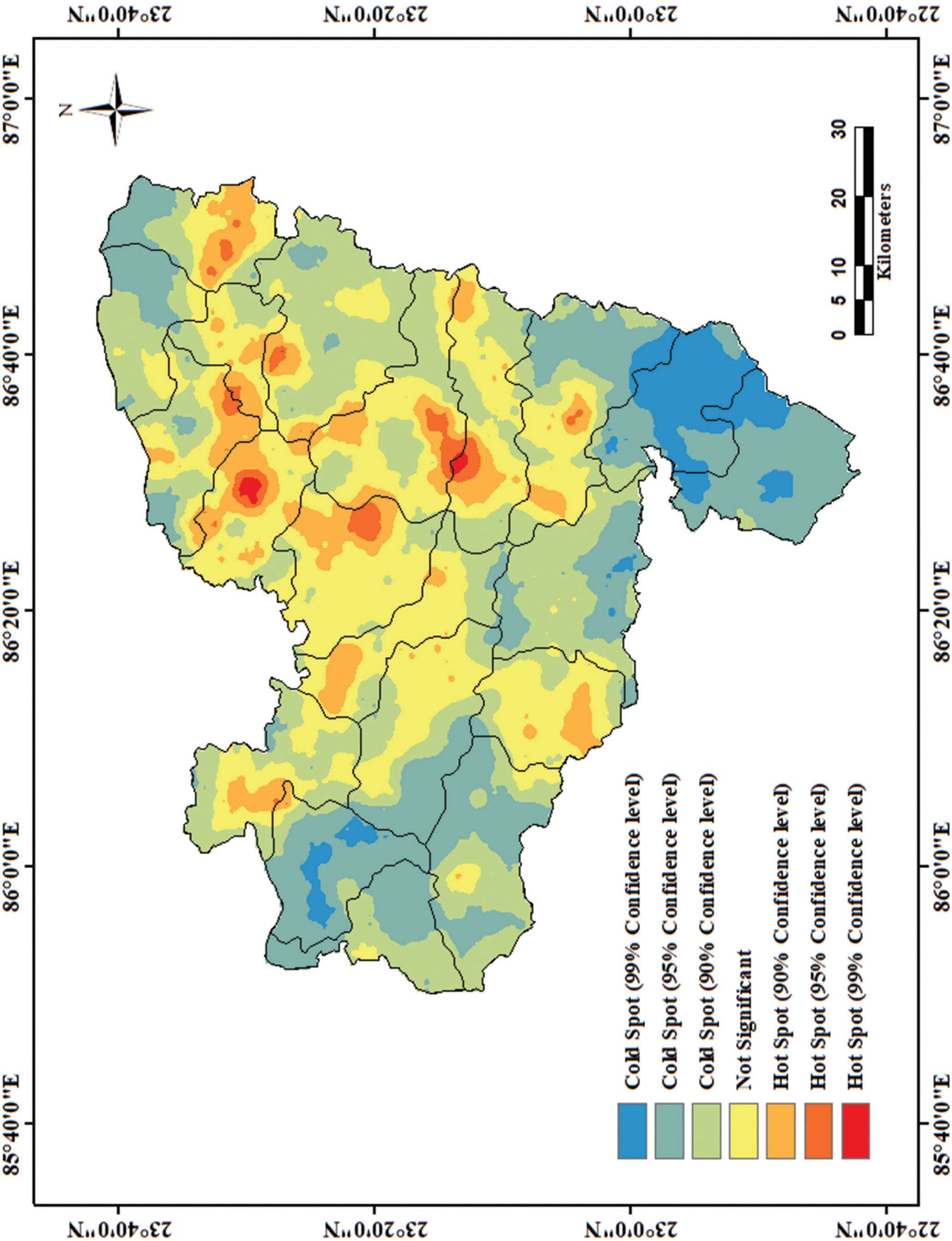

Fig. 3: Hotspot analysis of fluoride concentration of ground water in Puruliya District, 2018-19.

Table 1: Block-wise distribution of villages concerning fluoride concentration in ground water in Puruliya district, 2018-19

BLOCKS	No. of villages with different range of Fluoride concentration in mg/l				
	Total villages	Below 0.5	0.5 – 1.5	1.5 – 4.0	Above 4.0
Arsha	96	29	19	48	0
Baghmundi	141	97	35	5	4
Balarampur	90	22	7	61	0
Bandwan	134	129	3	2	0
Barabazar	208	139	39	27	3
Hura	116	11	79	21	5
Jaipur	110	37	47	25	1
Jhalda - I	141	84	49	4	2
Jhalda - II	130	N/A	N/A	27	2
Kashipur	205	53	116	32	4
Manbazar - I	237	117	72	45	3
Manbazar - II	133	N/A	N/A	2	0
Neturia	125	58	61	6	0
Para	134	37	49	42	5
Puncha	108	25	29	50	4
Puruliya - I	115	31	39	42	3
Puruliya - II	115	23	37	51	4
Raghunathpur - I	102	36	31	30	5
Raghunathpur - II	105	45	45	11	4
Santuri	104	35	36	29	3
Total	2649	1008	793	560	52

Source: Personal computation based on Census, 2011 and NRDWP, 2019 report; Classification by Dissankaye 1991 based on WHO, 1970

Result and discussion

Fluoride concentration zone of Puruliya District, 2018-19

The development blocks of Puruliya district are categorised into four classes according to WHO's classification (Table 1) e.g. below 0.5 mg/l, 0.5 to 1.5 mg/l, 1.5 to 4.0 and above 4.0 mg/l fluoride concentration. There are 5 classes in WHO's classification, but here we have only taken 4 classes because the highest limit of fluoride concentration of Puruliya district is reported as 8.16 mg/l (WBPHED, 2006). A level below 0.5 mg/l fluoride for the human body is regarded as a deficiency which leads to dental caries, the ideal limit of fluoride in drinking water is between 0.5 to 1.5 mg/l which is considered as safe and required for better dental health, the level between 1.5 to 4.0 mg/l fluoride in water leads to dental fluorosis e.g. mottling of teeth and finally the above 4.0 mg/l fluoride in drinking water leads several bone deformities collectively called as skeletal fluorosis (Table 1).

Among 2649 total villages 1008 villages has fluoride level under 0.5 mg/l, 793 villages between 0.5 to 1.5 mg/l, 564 village between 1.5 to 4.0 mg/l and 52 villages are in above 4.0 mg/l fluoride concentration zone. So, as per the current scenario, 38.05 per cent of villages are at risk of having dental caries (> 0.5 mg/l fluoride concentration), 29.93 per cent of villages in the safe zone (0.5 to 1.5 mg/l fluoride level), 21.29 per cent villages at the risk of having dental fluorosis (1.5 to 4.0 mg/l fluoride level), and 1.96 per cent of villages at risk having both dental and skeletal fluorosis (> 4.0 mg/l fluoride concentration). Bandwan, Barabazar, Manbazar - I have more than a hundred villages below 0.5 mg/l fluoride level class, while Balarampur, Hura and Puruliya - II has less than thirty villages in the same category. (Fig. 2 and Table 1). Hura, Kashipur and Neturia have a maximum number of villages in the safe limit of 0.5 to 1.5 mg/l category, while Arsha, Balarampur and Bandwan have less than 20 villages in this class. In the class of fluoride range between 1.5 to 4.0 mg/l, which is the zone of fluoride contamination for dental fluorosis Balarampur, Puncha, Puruliya - II has 50 and more villages under the risk while Baghmundi, Bandwan, Jhalda - I, Manbazar - II, Neturia has less than 10 villages. Para has the highest number of villages, e.g. 6 in the last category above 4.0 mg/l fluoride range, whereas Arsha, Balarampur, Bandwan, Manbazar - II and Neturia do not have any villages in this range. So, the highly fluoride affected blocks have more villages in both 1.5 to 4.0 mg/l and above 4.0 mg/l category, e.g. Kashipur, Para, Puncha, Puruliya – I and Puruliya – II, Raghunathpur - I. Bandwan, Manbazar – II and Neturia are the least affected blocks in terms of fluoride contamination (Table 1 and Fig. 2).

Hotspot analysis for fluoride concentration

GI* statistic is used to study the spatial association of phenomena and identify statistically significant hotspots or cold spots (Getis and Ord, 1992). A hotspot is a zone where the maximum concentration of events occurred, which is detected through the study of points distribution of a particular phenomenon (Chakravorty, 1995). Thus, it helps to understand the density of points and the spatial pattern of points (Getis, 2010; Baddeley *et al.*, 2010).

The result of hotspot analysis by GI* statistic is represented in the map of Puruliya district for the fluoride distribution level pattern in groundwater at village level through block-wise distribution (Fig. 3). The resulting clusters of hotspots and cold spots at 90 to 99 percent confidence levels show significant areas where the fluoride concentration occurs at a higher rate and a lower rate and insignificant distribution area. The hotspot zones are spread in Puruliya- I, Puruliya-II, Raghunathpur-I, Raghunathpur-II, Puncha, Balarampur, Para, Hura, Jaipur, Manbazar-I, where high-value fluoride concentration is surrounded by high-value concentration. The clusters of cold spots are spread on the blocks of lower fluoride concentration of groundwater. Bandwan and Manbazar- II have the maximum cold spot of fluoride concentration where low values surround low fluoride concentration, considered the least affected blocks (Fig. 2 and 3).

Fig. 4: Some observations on Dental Fluorosis during field survey (Mandal and Sanyal, 2020)

Compared to figure 2, which is the zonal distribution of groundwater fluoride concentration, figure 3 gives us a clearer picture of the actual pattern of the distribution to detect the significant hotspot and cold spots of the phenomena in the study region. This will help to delineate the areas where the problem is chronic and acute and need immediate measures.

This also will help in the application of proper mitigation measures, e.g. establishment of fluoride removal plant location, providing centrally treated piped water system, health survey for locating and identifying fluorosis affected people, providing healthcare facilities. The cold spot areas are co-related, with the blocks having more villages less than 0.5 mg/l categories, e.g. Bandwan, Manbazar – II and Jhalda - II, where we can identify people with fluoride deficiency leads dental caries. The clusters of hotspots are identified in the blocks like Hura, Para, Puncha, Puruliya – I and II, Raghunathpur – I and II, where a higher proportion of villages beyond 1.5 mg/l limits are found. So, here in these areas, we can easily find people with dental and skeletal fluorosis symptoms where the whole area are contaminated with high fluoride water. Fluoride removal plants and supply of filtered drinking water and proper medical help should reach these places more urgently. The insignificant areas fall under the areas between the ranges of 0.5 to 1.5 mg/l fluoride concentration, which is considered

Fig. 5: Some observations on skeletal fluorosis (Mandal and Sanyal, 2020, field survey)

the safe zone, where the contamination is low and needs less attention.

Dental fluorosis

Dental fluorosis is a disorder that occurs from the consumption of excess fluoride throughout tooth formation, generally from birth to nearly 6 to 8 years of age (Hussain, Sharma and Hussain, 2004). Dental fluorosis can be distinguished as horizontal lines or bands on the teeth' surface. The staining will typically appear in pairs based on formation patterns and not occur on a single tooth. The staining of the teeth can vary from chalky white abrasions to yellow-brown streaks to mottling pitting and distortion enamels in severe forms. There are other factors of staining of teeth, e.g., infected teeth, smoking, tobacco eating, coffee or tea stains which can occur along the gums and margin of the teeth. During the survey, these factors are taken under consideration for exclusion criteria. The digital images of different cases of dental fluorosis of Puruliya District are taken during the survey are given in figure 4. It is found that children are primarily identified with various symptoms of dental fluorosis in the study area. Many villages with high fluoride drinking water have school-going children affected by various grades of dental fluorosis from mild to severe. It is already reported that nearly 45 percent of children in elementary public schools in this district are affected with various fluorosis types (NPPCF, 2014; Mandal and Sanyal, 2019). Most villages do not have any centrally treated piped water and depend on tube wells, so people are forced to consume fluoride-rich groundwater as the only source of drinking water which results in a significant health hazard in the concerned area.

Children are also malnourished, come from poor economic backgrounds, and cannot afford a nutritious diet. Mid-day meal of the schools is inferior in nutrition and not sufficient to prevent the disease. Vitamin C and calcium deficiency in the diet is also major factor in prevailing dental fluorosis among children. There are many other consequences children affected with dental fluorosis have to face, like fear of laughter, humiliation, and isolation, which can also impact their mental health (WHO, 2006).

Skeletal fluorosis

Skeletal fluorosis is distinguished by skeletal changes due to increased bone density leading to bending and fracturing of bones, mainly in adults (Yıldız, 2003). Due to the prolonged exposure to fluoride-rich water, the occurrence of skeletal fluorosis is higher in old age people (Choubisa and Choubisa, 2015). Two chief kinds of skeletal fluorosis detected in India are termed genu valgum can be identified by knock-knees and genu varum, detected by bow legs (WHO, 2004; Gupta and Ayoob, 2016). In Puruliya District, we have also found that people of old age are more affected by skeletal fluorosis due to the extended exposure to high fluoride water. People suffer from harrowing experiences of genu valgum and genu varum. They are primarily agricultural labourers and belong to a poor, backward tribal community. They are complaining that they cannot go to work every day because of the disease and cannot function properly due to severe pain; some are unable to walk (Fig. 5). Thus, skeletal fluorosis affects their source of income and ultimately the economy of the village.

Conclusion

The study reveals that although the spatial pattern of fluoride concentration of groundwater is random, being a natural occurrence, there are clusters of hotspots where the intensity of the problem is much concentrated and needs quick and serious attention for proper planning and management. For this purpose, geographical locations of dental and skeletal fluorosis zone are also demarcated in the study based on the fluoride concentration level to facilitate a better health surveillance system. Very few fluoride removal plants have been established, and most of them are not in working mode and lack proper monitoring. In many parts, no piped water facility has been provided, and if there is piped water facility, duration of water supply is significantly less and mostly remain damaged. There is an urgent need for local and federal government to take the initiative to build proper means and capacity to control the current situation.

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