Population Risk Estimation From Fluoride Exposure Through Drinking Water in Puruliya District, West Bengal (India)

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Submitted: 24 July 2021, Accepted: 1 April 2022, Published: 28 June 2022
Volume 30, 2022. pp. 834–850. http://doi.org/10.25133/JPSSv302022.046

Abstract

The menace of fluorosis is quite anticipatable for the people of the Puruliya district because of the excessive fluoride level in the groundwater. More than 80% of the population is rural, and 85% depend on groundwater as their single means of drinking water. Therefore, the current paper aims to determine the block-wise distribution of villages and populations based on the fluoride level of groundwater and associated health risk in the Puruliya district. The study is based on the report on village-level fluoride concentration from the National Rural Drinking Water Mission Survey. Blocks of Puruliya District are categorized according to the World Health Organization's classes of different fluoride concentrations and related health impacts. For each category, the population is calculated based on the census of India 2011 data. The mapping of the severity of fluoride-exposed villages and populations is prepared using Arc. GIS 10.5. Our study found that 35.39% of the population is in danger of getting fluorosis through ingesting fluoride-rich water. Applying a geospatial approach to study the fluoride distribution is very significant in identifying the endemic fluoride region and safe areas for the entire district, which will help to take proper management remedies regarding prevention and control of fluorosis in the concerned district.

Keywords

Fluoride; fluorosis; health; population; risk

Introduction

The primary health risks resulting from excess fluoride consumption are collectively termed fluorosis (Subba Rao et al., 2020; World Health Organization, 2004). Fluorosis is a disease that develops in the human body due to fluoride deposition from consuming water or foods containing too much fluoride or breathing hazardous fluoride fumes (Doig, 1963; Subba Rao et al., 2021). The symptoms of fluorosis range from deformation of tooth enamel to skeletal distortion to neural impairment, dependent upon the level and period of fluoride exposure (Doig, 1963; Fan et al., 2003). Fluorosis has become an endemic disease in more than 50 nations worldwide, with a higher predominance in the water-scarce regions of the tropical climate (Chen et al., 1993; Subba Rao, 2011; World Health Organization, 2008). Approximately 411.4 million population across 201 districts are affected by fluorosis through fluoride contamination in India (Chakraborti et al., 2011). The subsurface geology of igneous and metamorphic rocks that contains fluoride-bearing minerals causes high fluoride levels in groundwater (Bailey et al., 2006; Subba Rao et al., 2016). Fluorosis is a serious health concern, particularly in rural India, where more than 85% of residents drink groundwater from tube wells (Susheela, 1984; World Health Organization, 2008).

Several recent investigations, primarily conducted in China and India, have discovered a link between drinking fluoridated water and the development of fluorosis in people. More than half of drinking water samples obtained from groundwater sources in India's Telangana and Andhra Pradesh states contain fluoride levels exceeding the regulatory limits of 1.5 mg/L, posing a severe health risk to the people. Rainwater harvesting and the use of contaminated filters are suggested for controlling the impact fluoride contaminated water in the concerned area (Adimalla & Li, 2019; Subba Rao et al., 2020). Fluoride is naturally found in India and China's subsurface water due to the semi-arid environment and hard rock lithology with fluoride-containing minerals, where a high rate of evaporation raises fluoride enrichment of the groundwater. Children are suffering more due to the harmful impacts of fluoride in these regions (He et al., 2021).

The fluoride concentration is higher in groundwater because water dissolves the fluoride-bearing mineral while percolating and flowing in the subsurface aquifer through rock-water interaction (Falvey, 1999; Marghade et al., 2020; Rango et al., 2009). Fluoride-rich groundwaters are closely associated with fractured crystalline basement aquifers containing many fluoride-bearing minerals at a certain depth (Edmunds & Smedley, 2013; Jacks et al., 2005; Rukah & Alsokhny, 2004; Subba Rao, 2003, 2017). Fluoride levels in groundwater can range from 0 to 35 mg/L in nature (World Health Organization, 1994). The continents of Asia, Africa, and South America are more likely to have high fluoride concentrations (International Programme on Chemical Safety, 2002). Fluoride levels in India's groundwater range from 48 mg/L in 276 districts across 20 states (Central Ground Water Board, 2019; Subba Rao et al., 2017; Susheela, 2002). People in rural India are compelled to consume fluoride-contaminated groundwater due to a lack of centralized piped water (Bretzler & Johnson, 2015). As a result, groundwater becomes the primary medium for spreading fluoride-related disorders (Chen et al., 2012; Dissanayake & Chandrajith, 2009; Subba Rao et al., 2013).

Dental cavities are more likely to form when fluoride levels are less than 0.5 mg/L. Fluoride levels between 0.5 and 1.5 mg/L are recommended for avoiding dental cavities. As a result, the maximum amount of fluoride allowed in drinking water is 1.5 mg/L (Bo et al., 2003; Harrison, 2005; Irigoyen-Camacho et al., 2016; Ozsvath, 2009; Subba Rao, 2009; World Health

Organization, 2004). According to studies, fluoride intake ranging from 1.5 to 4 mg/L causes dental fluorosis in children (Goodarzi et al., 2017). Dental fluorosis in children is characterized by enamel deformation caused by fluoride exposure during tooth development (Yadawe et al., 2010). White to dark brown stains, mottling, and tooth enamel pitting are indications of dental fluorosis (Dean, 1942; Larsen et al., 1987). Fluoride concentrations of 4 to 10 mg/L in drinking water have been associated with human skeletal abnormalities (Yeung, 2008). Due to extended exposure to fluoride polluted water in India, skeletal fluorosis is more common in older people (Choubisa & Choubisa, 2015). In India, there are two forms of skeletal fluorosis: deformity in the knees and bow-leggedness, which may be detected by the symptoms of a significant gap between the knees. Genu varum (crippling fluorosis) is more common in malnourished children who eat a calcium-deficient diet (Jha et al., 2011).

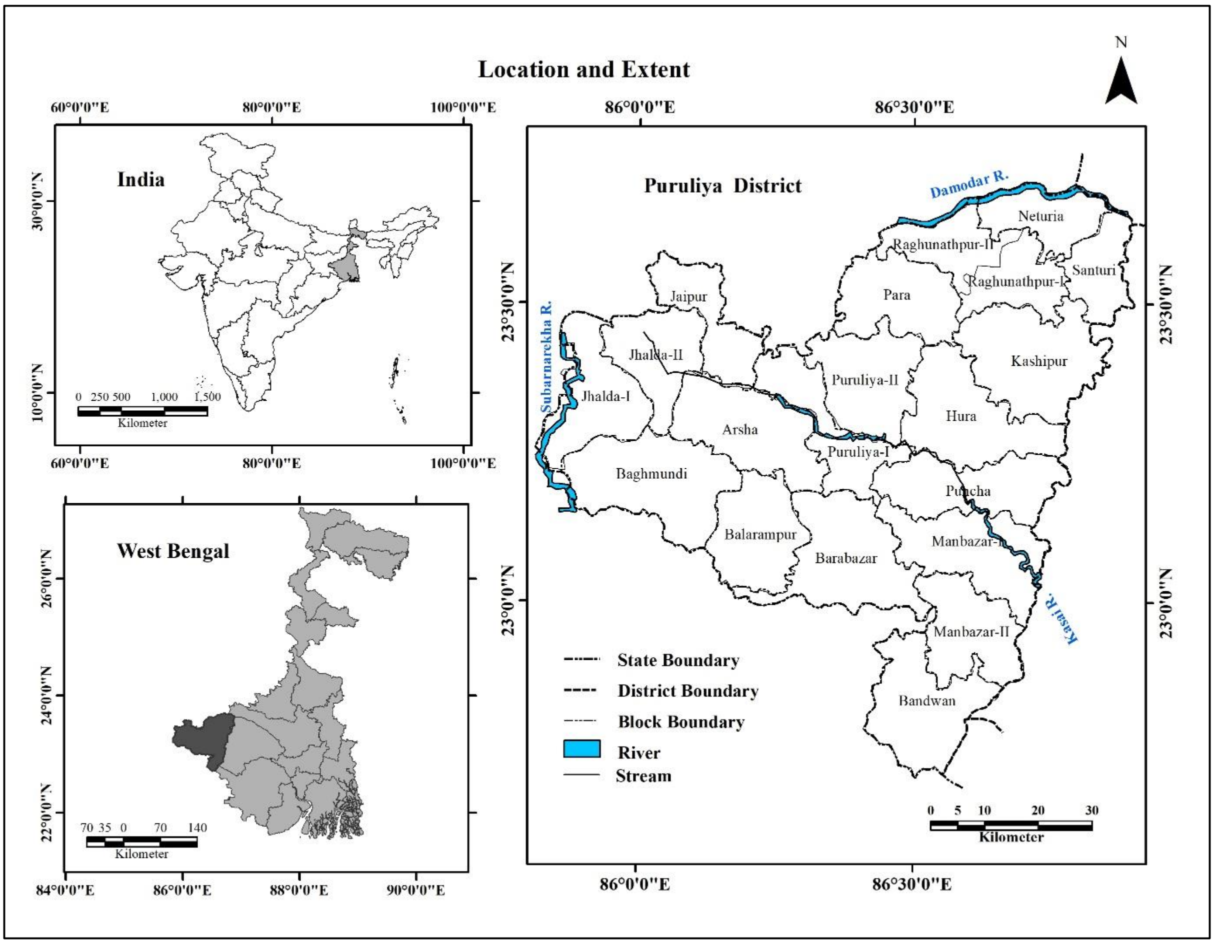
Puruliya is one of West Bengal's seven fluorosis-endemic districts. The subsurface water in each of the 20 blocks is contaminated with fluoride. The extent of fluoride concentration of groundwater in Puruliya ranges between 0.126 to 8.28 mg/L (National Rural Drinking Water Programme, 2020). In different parts of the Puruliya district, excessive fluoride concentrations and incidences of dental and skeletal fluorosis have been reported in several studies (Chatterjee et al., 2008). This research aims to divide the blocks into distinct health risk zones based on the fluoride content in each village's groundwater and to assess the population at risk of acquiring fluoride-related disorders at various concentrations. The severity of fluoride exposure in the district is computed using the population of fluoride-contaminated villages. The current study will provide a comprehensive picture of fluoride exposure and associated health hazards for the entire population of the area. The study of population risk estimation through fluoride exposure from a geographical viewpoint, will assist in making appropriate decisions for preventive and mitigation facilities to manage fluorosis in the district.

Material and methods

Study region

As shown in Figure 1, the geographical extent of the Puruliya district is amid 22°43′ to 23°42′ north latitudes and 85°49′ to 88°54′ east longitudes characterized by semi-arid tropical climate (Mandal & Sanyal, 2019). The district covers 6,259 square kilometers, and in 2011 had a population of 2,930,115 people (Office of the Registrar General & Census Commissioner India, 2021). There are 20 administrative blocks and 2,649 villages. Fluorides are found naturally in the district’s groundwater because of its pre-Cambrian metamorphic subsurface basement, which dissolves abundant fluoride-bearing minerals into the water (Central Ground Water Board, 1989). The arid climate with droughts has increased the fluoride concentration of the groundwater through a higher rate of evaporation. In the scorching summer, most surface water sources dry up, leaving people with little choice but to rely on groundwater as a supply for drinking purposes. The area receives more than 100 cm of rainfall in the monsoon, but a larger part of that runoff through undulating hilly topography. On the other hand, the groundwater recharge rate is also meager due to its hard base rock composition (Jha et al., 2013; Rudra, 2012).

Figure 1: Location and Extent of Puruliya District (By Authors)



The hydrogeochemical qualities of the groundwater in the affected district are substantially controlled by fluoride-containing minerals, particularly in fractured and shear zones with joints, where water dissolution facilitates fluoride enrichment**.** The extended contact period between the sub-surface bedrock and water in the deeper aquifers is the core cause behind the higher fluoride level found in the deep tube wells (30–60 feet) in the district (Bhattacharya & Chakrabarti, 2011; Mandal & Sanyal, 2019). The shallow and medium-depth unconfined aquifers contain low fluoride but are more prone to biological contagions. The confined aquifer source becomes a key source of drinking water with elevated fluoride levels (Mandal & Sanyal, 2019). Puruliya is one of the poorest districts in the country in terms of social and economic conditions, with a low literacy rate that has aggravated the situation.

Methodology

The database of fluoride levels for each village is prepared from the data collected from 2005 to 2006 West Bengal Public Health Engineering Department (2006), Summary of Test Results of Public Hand Pump Tube wells Under the Joint Plan of Action with UNICEF, and National Rural Drinking Water Programme (NRDWP) (2020) water quality reports from 2012 to 2013 to 2019 to 2020 of Ministry of Drinking Water and Sanitation, and the 2011 Census data from the Office of the Registrar General & Census Commissioner India (2021). Blocks are classified into different fluoride concentration zones based on the villages' fluoride levels under every block. The classification is based on the summarization of the health effects of fluoride studied by Dissanayake (1991) based on the standard drinking water quality report of Adler and World Health Organization, 1970 (Table 1).

Table 1: Fluoride Level and Related Health Impacts

Range of Fluoride Concentration (mg/L)	Associated Health Effect
< 0.5	This leads to dental caries and the formation of cavities
0.5 – 1.5	Ideal limit beneficial to preventing dental caries
1.5 – 4.0	This leads to enamel deformation and discoloration
4.0 – 10.0	Deformities of teeth and skeleton both are common (sporadic ache, stiffness of joint)
> 10.0	Crippling fluorosis (fracture of bone to damage in the nervous system, sometimes can lead to death)

Note: Dissanayake (1991) based on Adler and World Health Organization (1970)

As the highest fluoride concentration of the district is 8.28 mg/L, we have taken the first four categories of Table 1. By summarizing the population of the total number of villages in each block, the population number for different fluoride concentrations is calculated for the entire district.

After that, to identify the severity of fluoride contamination, blocks are categorized based on contaminated villages (Fluoride level > 1.5 mg/L) and population under risk into categories mentioned below:

1. Below 20% (low risk)
2. 20 to 40% (moderate risk)
3. Above 40% (high risk)

The study area was mapped using choropleth techniques using ArcGIS 10.5 software based on the categories mentioned above. Microsoft Excel was used for categorizing, calculating, analyzing, and visualizing data.

Results

The range of fluoride is 0.126 to 8.28 mg/L in sub-surface water in the region (National Rural Drinking Water Programme, 2020). As the maximum level of fluoride is reported as 8.28 mg/L, the classification is limited to the four categories of fluoride-health risk zones (Table 1) and based on the fluoride concentration of villages of the Puruliya District, categorized into different health risk zones as per World Health Organization norms for 2019–2020. The total number of villages in the Puruliya district is 2,649, and the total population is 2,930,115 (Office of the Registrar General & Census Commissioner India, 2021), among which fluoride concentration report was available for 2,417 villages consisting of 2,567,487 people. With respect to different ranges of fluoride content, the villages and their corresponding populations are divided into four zones: the zone of dental caries, the safe zone, the zone of dental fluorosis, and finally, the zone of dental and skeletal fluorosis (Table 2).

Table 2: Distribution of Villages and Population for Different Health Risk Zone in Puruliya District, 2019–2020

Fluoride Level (mg/L)	Population	Villages	[1] Health Risk Zone
Below 0.5	645,480 (22.03)	1,008 (38.05)	Dental Caries
0.5 – 1.5	884,702 (30.19)	793 (29.93)	Safe Zone
1.5 – 4.0	925,470 (31.58)	564 (21.29)	Dental Fluorosis
Above 4.0	111,835 (3.81)	52 (1.96)	Dental & Skeletal Fluorosis
Total	**2,567,487**	**2,417**	

Note: Own calculation based on Census 2011 and NRDWP, 2020 reports.
[1]Health risk zones are taken from the summarization made by Dissanayake (1991) based on Adler and World Health Organization (1970)

For healthy tooth formation, a fluoride level of 0.5 mg/L is recommended; fluoride doses below this level cause dental cavities in children. In Puruliya district, there are 1008 villages comprising 38.05% of the total villages under this category. In these 1008 villages, 22.03% population are under threat of getting dental caries due to the deficiency of the minimum fluoride amount. Fluoride concentrations between 0.5 mg/L and 1.5 mg/L are safe for preventing cavities and promoting dental health. The fluoride safe zone includes 793 villages (29.93%), which account for 30.19% of the district's population and are excluded from the danger of acquiring fluorosis.

Villages having fluoride concentrations over this limit are in danger of acquiring fluorosis. The symptoms of Dental fluorosis among the people can be identified by a white striking to brown pitting to mottling of teeth in villages with fluoride levels ranging from 1.5 to 4.0 mg/L. Five hundred sixty-four villages are in this zone of dental fluorosis, which is 21.29% of the total villages having 31.58% of the area’s population. Both skeletal and dental fluorosis develop when fluoride levels surpass 4.0 mg/L. Fifty-two villages belong to this high fluoride contamination zone containing 3.81% population under the menace of dental and skeletal fluorosis (Table 2). The highest fluoride limit in the Puruliya District is 8.16 mg/L, so we did not consider the range above 10 mg/L fluoride concentration responsible for crippling fluorosis and sometimes death (Table 1).

Fluoride health risk zones and block-level distribution of villages

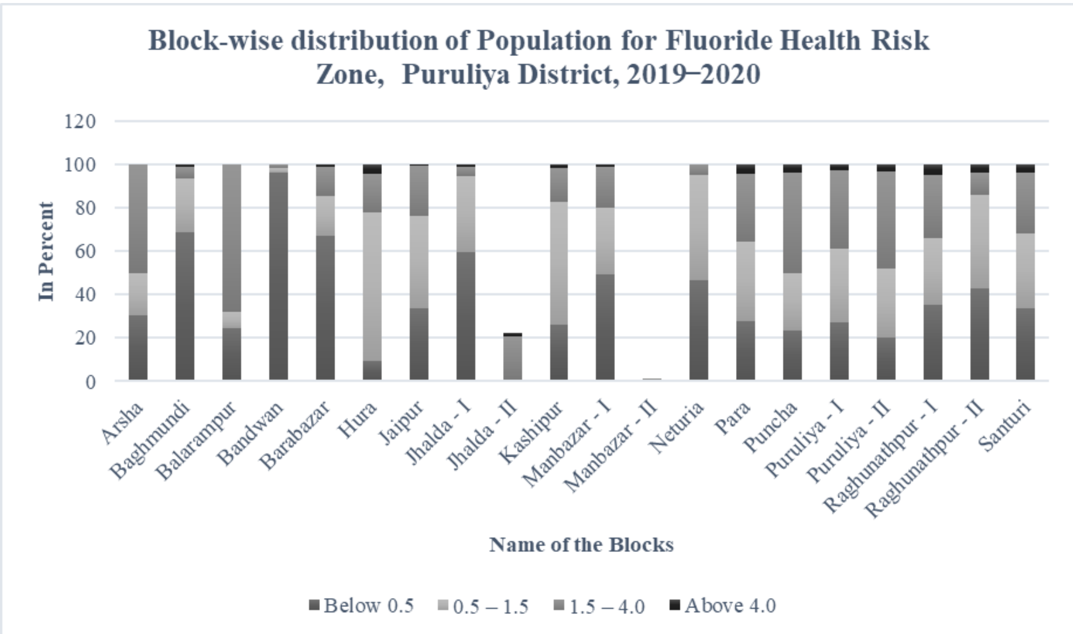
There are 20 administrative blocks in the Puruliya district with 2,649 villages. All 20 blocks have villages with fluoride levels in the groundwater exceeding the 1.5 mg/L limit (National Rural Drinking Water Programme, 2020). Fluoride concentrations are underneath 0.5 mg/L in 38.05% of the villages, placing them at risk for dental cavities. Bandwan has the highest percentage (96.27) of villages in the zone of dental caries. Except for Bandwan, Barabazar, Baghmundi, and Jhalda-I, more than 50% of their villages are in this zone of dental caries. Data for Jhalda-II and Manbazar-II was unavailable for this range, so we must exclude them for this interpretation. Hura is the least affected block in terms of the percentage of villages belonging to this dental caries zone which is 9.48%. Other than Hura, Balarampur, Kashipur, Para, Puncha, and Puruliya-I, Puruliya-II has less than 30% of the villages in this zone. Furthermore, fluoride content from 0.5 to 1.5 mg/L is found in 29.93% of villages. For the safe zone, the Hura block has the highest percentage (68.10) of villages, and Kashipur comes in the second position having 56.59% of the villages. Arsha (19.79), Balarampur (7.78), and Bandwan (2.24) have below 20% of villages in this safe zone. 21.29% have fluoride concentrations ranging between1.5 to 4.0 mg/L and are mostly affected by dental fluorosis.

Table 3: Block-Wise Distribution of Villages for Each Range of Fluoride Concentration, Puruliya, 2019–2020

Block	Total villages	[1]Fluoride Health Risk Zone (mg/L)							
		Below 0.5 (Dental Caries)		0.5 – 1.5 (Safe Zone)		1.5 – 4.0 (Dental Fluorosis)		Above 4.0 (Dental & Skeletal fluorosis)	
		In no.	(%)	In no.	(%)	In no.	(%)	In no.	(%)
Arsha	96	29	30.21	19	19.79	48	50	0	0
Baghmundi	141	97	68.79	35	24.82	7	4.96	2	1.42
Balarampur	90	22	24.44	7	7.78	61	67.78	0	0
Bandwan	134	129	96.27	3	2.24	2	1.49	0	0
Barabazar	208	139	66.83	39	18.75	27	12.98	3	1.44
Hura	116	11	9.48	79	68.10	21	18.10	5	4.31
Jaipur	110	37	33.64	47	42.73	25	22.73	1	0.91
Jhalda-I	141	84	59.57	49	34.75	6	4.26	2	1.42
Jhalda-II	130	N/A		N/A		27	20.77	2	1.54
Kashipur	205	53	25.85	116	56.59	32	15.61	4	1.95
Manbazar-I	237	117	49.37	72	30.38	45	18.99	3	1.27
Manbazar-II	133	N/A		N/A		2	1.50	0	0
Neturia	125	58	46.4	61	48.8	6	4.8	0	0
Para	134	37	27.61	49	36.57	42	31.34	6	4.48
Puncha	108	25	23.15	29	26.85	50	46.30	4	3.70
Puruliya-I	115	31	26.96	39	33.91	42	36.52	3	2.61
Puruliya-II	115	23	20	37	32.17	51	44.35	4	3.48
Raghunathpur-I	102	36	35.29	31	30.39	30	29.41	5	4.90
Raghunathpur-II	105	45	42.86	45	42.86	11	10.48	4	3.81
Santuri	104	35	33.65	36	34.62	29	27.88	4	3.85
Total	2,649	1,008	38.05	793	29.93	564	21.29	52	1.96

Note: Own computation based on Census 2011 and NRDWP, 2020 reports.
[1]Health risk zones are taken from the summarization made by Dissanayake (1991) based on Adler and World Health Organization (1970)

Figure 2: Fluoride Health Risk Zones and Block-Level Distribution of Villages, Puruliya District, 2019–2020



Balarampur has 68.78% of the villages in the dental fluorosis zone. Arsha, Puncha, and Puruliya-II have above 40% of the villages in the dental fluorosis zone. Bandwan and Manbazar-II have below 2% villages in this zone, which are the lowest. Other least affected blocks are Baghmundi, Jhalda-II, and Neturia, with less than 5% of villages in this zone. For the zone of skeletal fluorosis, Raghunathpur-I has the highest percentage (4.9%) of villages in this zone. Barabazar and Para also have more than 4% of villages in this zone. Arsha, Balarampur, Bandwan, Manbazar-II, and Neturia are blocks with zero villages in this skeletal fluorosis zone. The district's dental and skeletal fluorosis zone covers 1.96% of the villages (Table 3 & Figure 2).

Block-wise distribution of population with respect to fluoride health risk zones

The distribution pattern of villages and populations for each fluoride zone slightly varies as the number of populations for each village/municipality or census town differs. Some villages are found to be uninhabited. Other than that, similar patterns have been found in the villages and population-wise distribution of blocks of the Puruliya district for fluoride health risk zones (Table 4 & Figure 3).

Table 4: Block-Wise Distribution of Population with Respect to Fluoride Health Risk Zones, Puruliya, 2019-2020

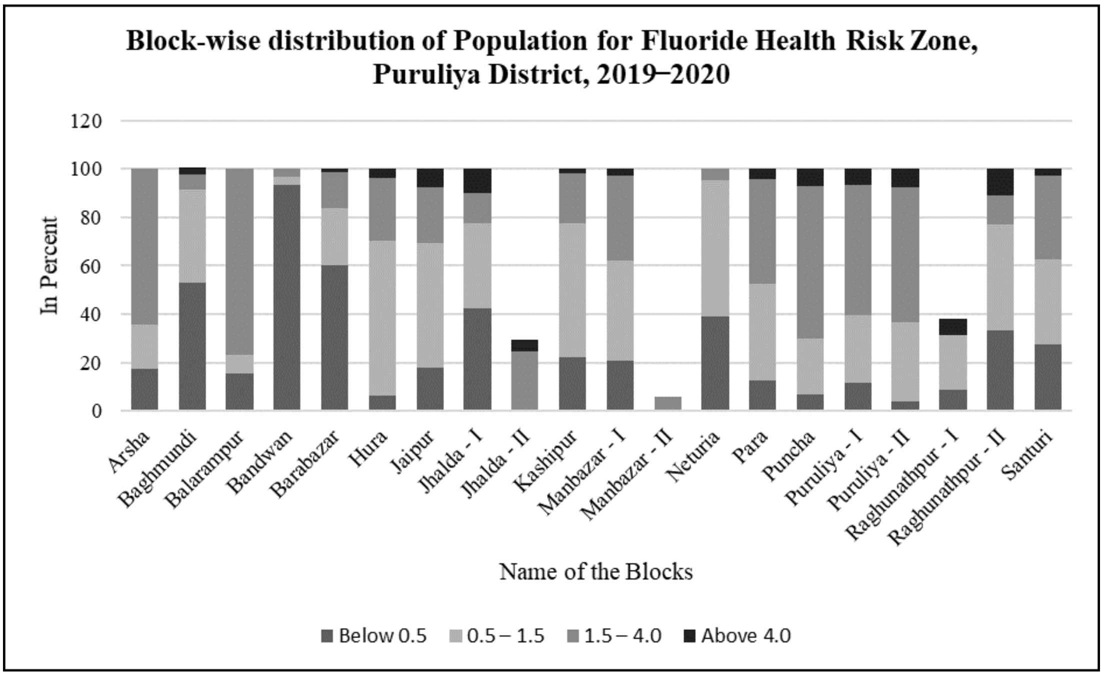
Block	Total Population	Population Exposed to different Fluoride Health Risk Zones							
		Below 0.5 mg/L		0.5–1.5 mg/L		1.5–4.0 mg/L		Above 4.0 mg/L	
		(Dental caries)		(Safe Zone)		(Dental fluorosis)		(Dental & Skeletal Fluorosis)	
		In no.	(%)	In no.	(%)	In no.	(%)	In no.	(%)
Arsha	154,736	27,024	17.51	28,415	18.36	99,237	64.13	0	0
Baghmundi	135,579	70,752	52.75	52,265	38.54	8,576	6.32	3,986	2.93
Balarampur	137,950	21,533	15.60	10,157	7.36	106,260	77.04	0	0
Bandwan	94,929	88,582	93.31	3,283	3.46	3,064	3.23	0	0
Barabazar	170,564	102,769	60.25	40,055	23.48	25,370	14.87	2,370	1.39
Hura	143,575	9,101	6.34	92,001	64.08	37,213	25.92	5,260	3.66
Jaipur	133,349	23,702	17.77	68,926	51.68	30,462	22.84	10,259	7.69
Jhalda-I	137,143	58,135	42.39	48,248	35.18	17,293	12.61	13,467	9.82
Jhalda-II	148,156		N/A		N/A	36,349	24.53	6,905	4.66
Kashipur	200,083	44,307	22.14	110,408	55.18	41,904	20.94	3,464	1.74
Manbazar-I	154,071	31,590	20.51	64,423	41.81	53,477	34.71	4,581	2.97
Manbazar-II	97,164		N/A		N/A	5,670	5.84	0	0
Neturia	101,427	39,539	38.98	57,122	56.32	4,766	4.70	0	0
Para	200,621	25,566	12.74	79,657	39.71	87,448	43.59	7,950	3.96
Puncha	123,855	8,554	6.91	28,420	22.95	78,326	63.24	8,555	6.91
Puruliya-I	151,188	17,837	11.8	42,039	27.8	81,594	53.97	9,718	6.43
Puruliya-II	169,488	6,960	4.11	55,296	32.63	94,008	55.46	13,224	7.80
Raghunathpur-I	117,760	10,022	8.51	27,022	22.95	73,058	62.04	7,658	6.50
Raghunathpur-II	113,790	37,872	33.28	49,541	43.54	14,157	12.44	12,220	10.74
Santuri	78,515	21,635	27.56	27,424	34.93	27,238	34.69	2,218	2.82
Total	2,930,115	645,480	22.03	884,702	30.19	925,470	31.58	111,835	3.81

Note: Own computation based on Census 2011 and National Rural Drinking Water Programme, 2020 reports. [1]Health risk zones are taken from the summarization made by Dissanayake (1991) based on Adler and World Health Organization (1970); Fluoride concentration in mg/L.

As shown in Table 4, 22.03% of the total population belongs to the dental caries zone. Bandwan has the highest with 93.31% of the population in the dental caries zone. Baghmundi and Barabazar also have more than 50% of their population in this first zone. Puruliya-II block has 4.11% of villages in this zone, which is the least. Hura, Puncha, and Raghunathpur-I are the blocks with less than 10% of villages in the zone of Dental caries. Moreover, 30.19 % belongs to the safe zone with a desirable fluoride limit. The data for Jhalda-II and Manbazar-II was unavailable for this and the safe zone. Hura has the highest percentage (64.08%) of the population in the safe zone, and other than that, Jaipur, Kashipur, and Neturia have more than 50% of their population in the safe zone. Bandwan (3.46%) and Balarampur (7.36%) have the least percentage of villages in this safe zone. Also, 31.58% are in the dental fluorosis zone. Arsha, Balrampur, Puncha, and Raghunathpur-I have more than 60% of the villages for this range of fluoride concentration for the dental fluorosis zone. Baghmundi, Bandwan, Neturia, and Manbazar-II are the blocks with less than 10% of the population and belong to the least affected blocks.

Likewise, as shown in Table 4, 3.81% of the total population of the district are in the skeletal fluorosis zone. In this zone of above 4.0 mg/L fluoride concentration, Arsha, Balarampur, Bandwan, Manbazar-II, and Neturia have no population at risk of having skeletal fluorosis. Raghunathpur-II has the highest skeletal fluorosis risk population, which is 10.74%; after that comes Jhalda-I with 9.82%. Barabazar is at the least with 1.39% of the risk population. More than 6% of their population is at risk of having skeletal fluorosis in Puruliya I and II, Puncha, Jaipur, and Raghunathpur-I blocks. The remaining blocks have less than a 6% risk population in this zone (Table 4 & Figure 3).

Figure 3: Block-Wise Distribution of Population Exposed to Fluoride Health Risk Zones, Puruliya District, 2019–2020



Fluoride contaminated villages and populations at risk

The block-level distribution of villages above the recommended drinking water margin, as well as the related risk population for developing dental and skeletal fluorosis, will be discussed here (Table 5). Six hundred sixteen villages (23.25% of the total villages) of Puruliya district have groundwater polluted with high fluoride. Because the majority of people still rely on groundwater as their main source of drinking water, 35.40% of the entire population living in these contaminated villages is at risk of developing dental and skeletal fluorosis.

Based on the percentage of fluoride polluted villages and related risk population, the blocks are divided into three groups: low risk, moderate risk, and high risk and shown using a choropleth map (Figure 4). The low-risk blocks are Baghmundi, Bandwan, Jhalda-I, Manbazar-II, Neturia, and Raghunathpur-II, with less than 20% fluoride contaminated villages (Mandal & Sanyal, 2019). Barabazar, Hura, Jaipur, Jhalda-II, Kashipur, Raghunathpur-I, and Santuri, with 20% to 40% fluoride-contaminated villages, are under moderate risk. The blocks with more than 40% fluoride contaminated villages are Arsha, Balarampur, Manbazar-I, Para, Puncha, Puruliya-I, and Puruliya-II belong to the high-risk class (Table 6 & Figure 4). Blocks are also classed together in terms of the population at risk from the high fluoride levels in the groundwater. Here, the least affected blocks with less than 20% risk population are Baghmundi, Barabazar, Baghmundi, Barabazar, Bandwan, Manbazar-II, and Neturia. Moderately affected blocks with a 20 to 40% risk population are Hura, Jaipur, Jhalda-I, Jhalda-II, Kashipur, Manbazar-I, Raghunathpur-II, and Santuri. Highly affected blocks with more than 40% risk population are Arsha, Balarampur, Para, Puncha, Puruliya-I, Puruliya-II, and Raghunathpur-I (Table 6 & Figure 4) (Mandal & Sanyal, 2019).

Table 5: No. of Fluoride-Affected Villages and Population, Puruliya District, 2019−2020

Block	Total villages in number	*Affected villages	Total population in number	*Population in high-risk area in 2011
Arsha	96	48 (50.00)	154,736	99,237 (64.13)
Baghmundi	141	9 (6.38)	135,579	12,562 (9.25)
Balarampur	90	61 (67.77)	137,950	106,260 (77.04)
Bandwan	134	2 (1.49)	94,929	3,064 (3.23)
Barabazar	208	30 (14.42)	170,564	27,740 (16.26)
Hura	116	26 (22.41)	143,575	42,473 (29.58)
Jaipur	110	26 (23.63)	133,349	40,721 (30.53)
Jhalda-I	141	8 (5.67)	137,143	30,760 (22.43)
Jhalda-II	130	29 (22.31)	148,156	43,254 (29.19)
Kashipur	205	36 (17.56)	200,083	45,368 (22.68)
Manbazar-I	237	48 (20.25)	154,071	58,058 (37.68)
Manbazar-II	133	2 (1.50)	97,164	5,670 (5.84)
Neturia	125	6 (4.80)	101,427	4,766 (4.70)
Para	134	48 (35.82)	200,621	95,398 (47.55)
Puncha	108	54 (50.00)	123,855	86,881 (70.15)
Puruliya-I	115	45 (39.13)	151,188	91,312 (60.40)
Puruliya-II	115	55 (47.83)	169,488	107,232 (63.26)
Raghunathpur-I	102	35 (34.31)	117,760	80,716 (68.54)
Raghunathpur-II	105	15 (14.29)	113,790	26,377 (23.18)
Santuri	104	33 (31.73)	78,515	29,456 (37.51)
Total	**2,649**	**616 (23.25)**	**2,930,115**	**1,037,305 (35.40)**

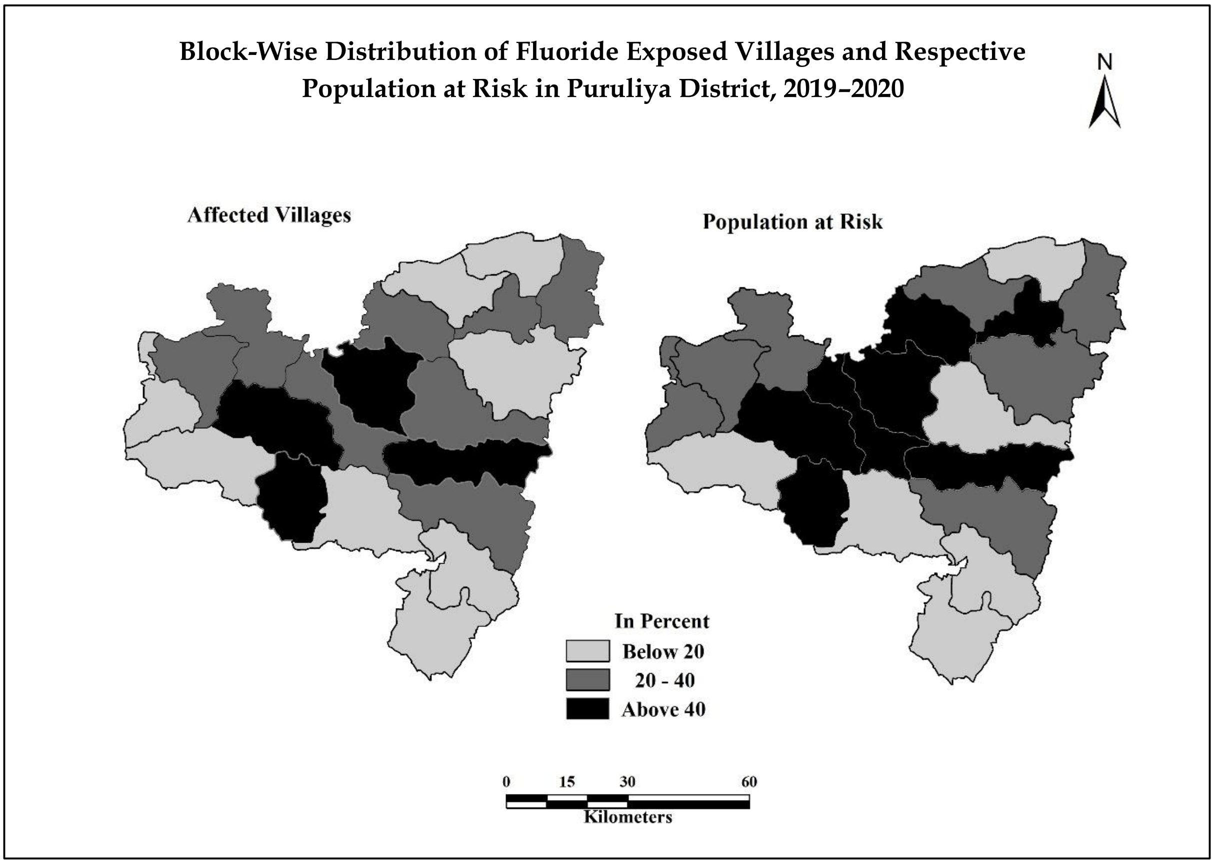
*Note: Own computation based on Census 2011 and NRDWP, 2020 reports. *Affected, meaning fluoride level above 1.5 mg/L (World Health Organization, 2008)*

Table 6: Severity of Fluoride Exposure Concerning Fluoride Contaminated Villages and Risk Population, Puruliya District, 2019–2020

Category	Blocks with risk villages	Total	Block with risk population	Total
Low Risk (< 20 %)	Baghmundi, Bandwan, Jhalda-I, Manbazar-II, Neturia, and Raghunathpur-II.	6	Baghmundi, Barabazar, Bandwan, Manbazar-II, and Neturia	5
Moderate Risk (20 – 40 %)	Barabazar, Hura, Jaipur, Jhalda-II, Kashipur, Manbazar-I, Raghunathpur-I, and Santuri.	7	Hura, Jaipur, Jhalda-I, Jhalda-II, Kashipur, Manbazar-I, Raghunathpur-II, and Santuri.	8
High Risk (> 40 %)	Arsha, Balarampur, Para, Puncha, Puruliya-I, and Puruliya-II	7	Arsha, Balarampur, Para, Puncha, Puruliya-I, Puruliya-II, and Raghunathpur-I.	7

Note: Own Computation based on Table 5

Figure 4: Block-Wise Distribution Fluoride Affected Villages and Population under Risk, Puruliya, 2019–2020



Discussion

Fluoride has both desirable and undesirable health implications (Hamilton, 1992; Subba Rao & John Devadas, 2003). Our study is based on Dissanayake's (1991) categorized health impacts of fluoride levels in drinking (Table 1). Consumption of fluoride in high quantities can cause dental and skeletal deformities termed fluorosis (Subba Rao, 2021; World Health Organization, 1994). The quantity and duration of fluoride consumption influence the severity of the health impacts (Ozsvath, 2009). Fluoride-contaminated (> 1.5 mg/L) drinking water has been linked to various kinds of dental and skeletal deformities among children and adults in several studies throughout the world (Choubisa, 2001; Marghade et al., 2021; Gopalakrishnan et al., 1999; Narayanamurthy & Santhuram, 2013). Skeletal fluorosis is primarily observed among older people due to prolonged ingestion of fluoride-contaminated water (Chen et al., 2012; Choubisa, 2012; Gautam et al., 2011). In India, many states have reported several skeletal fluorosis cases, including the symptoms of genu-valgum (Chakma et al., 1997; Choubisa et al., 2001; Mondal et al., 2016; Sivakumar & Krishnamachari, 1976). Although skeletal fluorosis symptoms are also detected below the fluoride tolerance limit in India, for example, the prevalence of skeletal fluorosis among the elderly increased from 4.4% to 63.0% when fluoride concentrations climbed from 1.4 to 6.0 mg/L in several villages in Rajasthan (World Health Organization, 2004).

In Puruliya, some studies have reported dental and skeletal fluorosis in some villages among people. Bhattyacharya (2009) estimated that 47,358 and 53,961 people of Purulia's I and II blocks are experiencing health issues as a result of fluoride pollution in the water. The tribal community of the district is more vulnerable to the chronic implication of fluoride-contaminated water because of their poor diet with a lack of essential vitamins (Choubisa et al., 2009; Jha et al., 2013). In the past, no study or report is available regarding the district's block-wise distribution of fluoride-contaminated populations. Our study tries to give a holistic view of the overall condition of fluoride concentration associated with health impact for the entire district, which will take proper management remedies regarding prevention and control of fluorosis in the concerned district.

Several studies have suggested various measures to control the fluoride problem in drinking water and remediation the people with the danger of fluorosis. Provision of defluorinated drinking water, alternate safe drinking water supply, and establishment of centrally treated drinking water facilities, health education and awareness programs in schools and villages of affected areas are some of the crucial measures mentioned by various authors in their studies (Choubisa, 2001; Jha et al., 2013; Viswanathana et al., 2009; Yadawe et al., 2010). Geo-climatic settings, high water consumption, lack of clean drinking water, the incidence of drought, impoverished nutritional status, illiteracy, and unsanitary circumstances should all be considered when establishing policies and programs for emerging nations like India (Susheela, 2002). Ingestion of calcium and vitamin c is also suggested to lessen the ill effect of fluoride among children (Athavale & Das, 1999; Bhagavan & Raghu, 2005). Since most defluoridation procedures are expensive, biological remediation must be used to keep the issue under control. Furthermore, rainwater harvesting seems to be a more effective method of providing clean drinking water to the afflicted population (Arveti et al., 2011). Because of their accessibility and cost-effectiveness, native and herbal techniques for fluoride-rich water defluoridation are suited for Indian settings (Bose et al., 2019). All the aforementioned suggestions can be implemented in the Puruliya District to manage the existing situation.

Conclusion

Puruliya is the worst fluoride-affected district in West Bengal state, India. Our study has found that in Puruliya District, 20 out of 20 blocks have villages with fluoride-contaminated groundwater. The permissible margin of 1.5 mg/L has been exceeded in groundwater in 23.25% of villages. Highly affected blocks with more than 40% fluoride contaminated villages are Arsha, Balarampur, Manbazar-I, Para, Puncha, Puruliya-I, and Puruliya-II. More than 35% of the population in the area is in great danger of having both dental and skeletal fluorosis. Highly affected blocks with more than 40% risk population are Arsha, Balarampur, Para, Puncha, Puruliya-I, Puruliya-II, and Raghunathpur-I.

The use of a geospatial technique to study fluoride distribution is helpful in identifying fluoride endemic areas and fluoride safe zones. Because the district covers a large physical region with a considerable population, it is critical to identify the high-risk areas that require immediate attention from government and non-government organizations. To safeguard people from the fluoride threat in the area, alternative sources with low fluoride levels, rainwater conservation, and defluoridation of fluoride-contaminated drinking water sources are required. Our findings will guide policymakers and planners in identifying high-risk locations with the most vulnerable population and developing appropriate mitigation measures, such as installing defluoridation facilities in the study area.

Acknowledgments

The authors are grateful to the University Grants Commission (New Delhi, India) for providing a research fellowship and two anonymous reviewers for their insightful remarks.

References

Adimalla, N., & Li, P. (2019). Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. *Human and Ecological Risk Assessment: An International Journal, 25*(1–2), 81–103. https://doi.org/10.1080/10807039.2018.1480353

Adler, P., & World Health Organization. (1970). *Fluorides and human health*. World Health Organization. https://apps.who.int/iris/handle/10665/41784

ArcGIS. (2015). [GIS software]. Version 10.5. Environmental Systems Research Institute, Inc.

Arveti, N., Sarma, M. R. S., Aitkenhead-Peterson, J. A., & Sunil, K. (2011). Fluoride incidence in groundwater: a case study from Talupula, Andhra Pradesh, India. *Environmental Monitoring and Assessment, 172*(1–4), 427–443. https://doi.org/10.1007/s10661-010-1345-3

Athavale, R. N., & Das, R. K. (1999). Beware! Fluorosis is zeroing in on you. *Down to Earth*, *8*(6), 24–25.

Bailey, K., Chilton, J., Dahi, E., Fewtrell, L., Magara, Y., & Fawell, J. (2006). *Fluoride in drinking-water*. World Health Organization; IWA Publishing.

Bhagavan, S. V. B. K., & Raghu, V. (2005). Utility of check dams in dilution of fluoride concentration in ground water and the resultant analysis of blood serum and urine of villagers, Anantapur District, Andhra Pradesh, India. *Environmental Geochemistry and Health, 27*(1), 97–108. https://doi.org/10.1007/s10653-004-0786-4

Bhattacharya, H. N., & Chakrabarti, S. (2011). Incidence of fluoride in the groundwater of Purulia District, West Bengal: A geo-environmental appraisal. *Current Science, 101(2)*, 152–155. https://www.currentscience.ac.in/Volumes/101/02/0152.pdf

Bhattyacharya, D. (2009). Pachimbanger bhugarvastha jole fluoride sankraman o tar pratikar [Fluoride contamination and remediation in West Bengal's ground water]. *Amit Bari, 5*, 8–11.

Bo, Z., Mei, H., Yongsheng, Z., Xueyu, L., Xuelin, Z., & Jun, D. (2003). Distribution and risk assessment of fluoride in drinking water in the west plain region of Jilin province, China. *Environmental Geochemistry and Health*, *25*(4), 421–431. https://doi.org/10.1023/b:egah.0000004560.47697.91

Bose, S., Yashoda, R., & Puranik, M. P. (2019). Novel materials for defluoridation in India: A systematic review. *Journal of Dental Research and Review*, *6*(1), 3–8. https://doi.org/10.4103/jdrr.jdrr_55_18

Bretzler, A., & Johnson, C. A. (2015). The geogenic contamination handbook: Addressing arsenic and fluoride in drinking water. *Applied Geochemistry*, *63*, 642–646. https://doi.org/10.1016/j.apgeochem.2015.08.016

Central Ground Water Board. (1989). *Groundwater resource development plan for the drought-prone Puruliya*. Ministry of Water Resources, West Bengal.

Central Ground Water Board. (2019). *States Wise Details of Partly Affected Districts with Select Contaminants in Ground Water of India*. http://cgwb.gov.in/contaminated-areas.html

Chakma, T., Singh, S. B., Godbole, S., & Tiwary, R. S. (1997). Endemic fluorosis with genu valgum syndrome in a village of district Mandla, Madhya Pradesh. *Indian Pediatrics*, *34*, 232–236. https://www.indianpediatrics.net/mar1997/232.pdf

Chakraborti, D., Das, B., & Murrill, M. T. (2011). Examining India's groundwater quality management. *Environmental Science and Technology*, *45*(1), 27–33. https://pubs.acs.org/doi/full/10.1021/es101695d

Chatterjee, A., Roy, R. K., Ghosh, U. C., Pramanik, T., Kabi, S. P., & Biswas, K. (2008). Fluoride in water in parts of Raniganj Coalfield, West Bengal. *Current Science*, *94*(3), 309–311. http://www.indiaenvironmentportal.org.in/files/cs1.pdf

Chen, L., He, B. Y., He, S., Wang, T. J., Su, C. L., & Jin, Y. (2012). Fe—Ti oxide nano-adsorbent synthesized by co-precipitation for fluoride removal from drinking water and its adsorption mechanism. *Powder Technology*, *227*, 3–8. https://doi.org/10.1016/j.powtec.2011.11.030

Chen, W., Xu, R., Chen, G., Zao, J., & Chen, T. (1993). Changes of the prevalence of endemic fluorosis after changing water sources in two villages in Guangdong, China. *Bulletin of Environmental Contamination and Toxicology*, *51*(4), 479–482. https://doi.org/10.1007/BF00192160

Choubisa, S. L. (2001). Endemic fluorosis in southern Rajasthan, India. *Fluoride*, *34*(1), 61–70. http://fluoridealert.org/wp-content/uploads/choubisa-2001.pdf

Choubisa, S. L. (2012). Fluoride in drinking water and its toxicosis in tribals of Rajasthan, India. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *82*(2), 325–330. https://doi.org/10.1007/s40011-012-0047-8

Choubisa, S. L., & Choubisa, D. (2015). Neighbourhood fluorosis in people residing in the vicinity of superphosphate fertilizer plants near Udaipur city of Rajasthan (India). *Environmental Monitoring and Assessment*, *187*(8), Article 497. https://doi.org/10.1007/s10661-015-4723-z

Choubisa, S. L., Choubisa, L., & Choubisa, D. (2009). Osteo-dental fluorosis in relation to nutritional status, living habits, and occupation in rural tribal areas of Rajasthan, India. *Fluoride*, *42*(3), 210–215. http://fluoridealert.org/wp-content/uploads/choubisa-2009.pdf

Choubisa, S. L., Choubisa, L., & Choubisa, D. K. (2001). Endemic fluorosis in Rajasthan. *Indian Journal of Environmental Health*, *43*(4), 177–189. https://europepmc.org/article/med/12395525

Dean, H. T. (1942). The investigation of physiological effects by the epidemiological method. *American Association for the Advancement of Science, 19*, 23–33.

Dissanayake, C. B. (1991). The fluoride problem in the ground water of Sri Lanka—environmental management and health. *International Journal of Environmental Studies*, *38*(2-3), 137–155. https://doi.org/10.1080/00207239108710658

Dissanayake, C. B., & Chandrajith, R. (2009). Introduction. In *Introduction to medical geology* (pp. 1–18). Springer.

Doig, A. T. (1963). Fluorosis. *Practitioner*, *190*(1139), 622–627. https://doi.org/10.5005/jp/books/12869_28

Edmunds, W. M., & Smedley, P. L. (2013). Fluoride in Natural Waters. In O. Selinus (Ed.), *Essentials of medical geology* (pp. 311–336). Springer.

Falvey, D. A. (1999). Groundwater geochemistry. *Earthwise, 13*.

Fan, X., Parker, D. J., & Smith, M. D. (2003). Adsorption kinetics of fluoride on low cost materials. *Water Research, 37*(20), 4929–4937. https://doi.org/10.1016/j.watres.2003.08.014

Gautam, R., Bhardwaj, N., & Saini, Y. (2011). Dental fluorosis—a case study from Nawa tehsil in Nagaur district, Rajasthan (India). *The Environmentalist*, *31*(4), 401–406. https://doi.org/10.1007/s10669-011-9354-5

Goodarzi, F., Mahvi, A. H., Hosseini, M., Nodehi, R. N., Kharazifard, M. J., & Parvizishad, M. (2017). Prevalence of dental caries and fluoride concentration of drinking water: A systematic review. *Dental Research Journal*, *14*(3), 163–168. https://doi.org/10.4103/1735-3327.208765

Gopalakrishnan, P., Vasan, R. S., Sarma, P. S., Ravindran Nair, K. S., & Thankappan, K. R. (1999). Prevalence of dental fluorosis and associated risk factors in Allappuzha district, Kerala. *National Medical Journal of India*, *12*(3), 99–102. http://archive.nmji.in/archives/Volume-12/issue-3/original-articles-1.pdf

Hamilton, M. (1992). Water fluoridation: A risk assessment perspective. *Journal of Environmental Health, 54*(6), 27–32. https://www.jstor.org/stable/44534047

Harrison, P. T. C. (2005). Fluoride in water: A UK perspective. *Journal of Fluorine Chemistry*, *126*(11-12), 1448–1456. https://doi.org/10.1016/j.jfluchem.2005.09.009

He, X., Li, P., Wu, J., Wei, M., Ren, X., & Wang, D. (2021). Poor groundwater quality and high potential health risks in the Datong Basin, northern China: research from published data. *Environmental Geochemistry and Health*, *43*(2), 791–812. https://doi.org/10.1007/s10653-020-00520-7

International Programme on Chemical Safety. (2002). *Fluorides*. World Health Organization. https://apps.who.int/iris/handle/10665/42415

Irigoyen-Camacho, M. E., Pérez, A. G., González, A. M., & Alvarez, R. H. (2016). Nutritional status and dental fluorosis among schoolchildren in communities with different drinking water fluoride concentrations in a central region in Mexico. *Science of the Total Environment*, *541*, 512–519. https://doi.org/10.1016/j.scitotenv.2015.09.085

Jacks, G., Bhattacharya, P., Chaudhary, V., & Singh, K. P. (2005). Controls on the genesis of some high-fluoride groundwaters in India. *Applied Geochemistry*, *20*(2), 221–228. https://doi.org/10.1016/j.apgeochem.2004.07.002

Jha, S. K., Mishra, V. K., Sharma, D. K., & Damodaran, T. (2011). Fluoride in the environment and its metabolism in humans. In D. Whitacre (Ed.), *Reviews of environmental contamination and toxicology* (pp. 121–142). Springer.

Jha, S. K., Singh, R. K., Damodaran, T., Mishra, V. K., Sharma, D. K., & Rai, D. (2013). Fluoride in groundwater: toxicological exposure and remedies. *Journal of Toxicology and Environmental Health, Part B*, *16*(1), 52–66. https://doi.org/10.1080/10937404.2013.769420

Larsen, M. J., Kirkegaard, E., & Poulsen, S. (1987). Patterns of dental fluorosis in a European country in relation to the fluoride concentration of drinking water. *Journal of Dental Research*, *66*(1), 10–12. https://doi.org/10.1177/00220345870660010101

Li, P., He, X., Li, Y., & Xiang, G. (2019). Occurrence and health implication of fluoride in groundwater of loess aquifer in the Chinese Loess Plateau: A case study of Tongchuan, Northwest China. *Exposure and Health*, *11*(2), 95–107. https://doi.org/10.1007/s12403-018-0278-x

Mandal, J., & Sanyal, S. (2019). Geospatial analysis of fluoride concentration in groundwater in Puruliya district, West Bengal. *Space and Culture, India*, *6*(5), 71–86. https://doi.org/10.20896/saci.v6i5.369

Marghade, D., Malpe, D. B., & Subba Rao, N. (2021). Applications of geochemical and multivariate statistical approaches for the evaluation of groundwater quality and human health risks in a semi-arid region of eastern Maharashtra, India. *Environmental Geochemistry and Health, 43*(2), 683–703. https://doi.org/10.1007/s10653-019-00478-1

Marghade, D., Malpe, D. B., Subba Rao, N., & Sunitha, B. (2020). Geochemical assessment of fluoride enriched groundwater and health implications from a part of Yavtmal District, India. *Human and Ecological Risk Assessment: An International Journal, 26*(3), 673–694. https://doi.org/10.1080/10807039.2018.1528862

Mondal, D., Dutta, G., & Gupta, S. (2016). Inferring the fluoride hydrogeochemistry and effect of consuming fluoride-contaminated drinking water on human health in some endemic areas of Birbhum district, West Bengal. *Environmental Geochemistry and Health*, *38*(2), 557–576. https://doi.org/10.1007/s10653-015-9743-7

Narayanamurthy, S., & Santhuram, A. N. (2013). Prevalence of dental fluorosis in school children of Bangarpet taluk, Kolar district. *Journal of Orofacial Sciences*, *5*(2), 105–108. https://doi.org/10.4103/0975-8844.124253

National Rural Drinking Water Programme (NRDWP). (2020). *Contamination area wise report, Ministry of Drinking Water and Sanitation, Government of India*. https://ejalshakti.gov.in/IMISReports/NRDWP_MIS_NationalRuralDrinkingWaterProgramme.html

Office of the Registrar General & Census Commissioner India. (2021). *Population Finder – Census 2011 (Puruliya)*. https://censusindia.gov.in/census.website/data/population-finder

Ozsvath, D. L. (2009). Fluoride and environmental health: A review. *Reviews in Environmental Science and Bio/Technology*, *8*(1), 59–79. https://doi.org/10.1007/s11157-008-9136-9

Rango, T., Bianchini, G., Beccaluva, L., Ayenew, T., & Colombani, N. (2009). A hydrogeochemical study in the Main Ethiopian Rift: New insights into the source and enrichment mechanism of fluoride. *Environmental Geology*, 58, 109–118. https://doi.org/10.1007/s00254-008-1498-3

Rudra, S. (2012). Fluoride contamination of ground water: A geographical analysis Purulia Block-1 of Purulia District, West Bengal, India. *Analyst*, *2*(1), 1–6. http://dx.doi.org/10.13140/RG.2.2.14537.95840

Rukah, Y. A., & Alsokhny, K. (2004). Geochemical assessment of groundwater contamination with special emphasis on fluoride concentration, North Jordan. *Geochemistry*, *64*(2), 171–181. https://doi.org/10.1016/j.chemer.2003.11.003

Sivakumar, B., & Krishnamachari, K. A. V. R. (1976). Circulating levels of immunoreactive parathyroid hormone in endemic genu valgum. *Hormone and Metabolic Research*, *8*(4), 317–319. https://doi.org/10.1055/s-0028-1093624

Subba Rao, N. (2003). Groundwater quality: Focus on fluoride concentration in rural parts of Guntur district, Andhra Pradesh, India. *Hydrological Sciences Journal*, *48*(5), 835–847. https://doi.org/10.1623/hysj.48.5.835.51449

Subba Rao, N. (2009). Fluoride in groundwater, Varaha River Basin, Visakhapatnam District, Andhra Pradesh, India. *Environmental Monitoring and Assessment, 152*, Article 47. https://doi.org/10.1007/s10661-008-0295-5

Subba Rao, N. (2011). High-fluoride groundwater. *Environmental Monitoring and Assessment, 176*, 637–645. https://doi.org/10.1007/s10661-010-1609-y

Subba Rao, N. (2017). Controlling factors of fluoride in groundwater in a part of South India. *Arabian Journal of Geosciences, 10,* Article 524. https://doi.org/10.1007/s12517-017-3291-7

Subba Rao, N. (2021). Spatial distribution of quality of groundwater and probabilistic non-carcinogenic risk from a rural dry climatic region of South India. *Environmental Geochemistry and Health, 43*, 971–993. https://doi.org/10.1007/s10653-020-00621-3

Subba Rao, N., & John Devadas, D. (2003). Fluoride incidence in groundwater in an area of Peninsular India. *Environmental Geology, 45*, 243–253. https://doi.org/10.1007/s00254-003-0873-3

Subba Rao, N., Dinakar, A., & Karuna Kumari, B. (2021). Appraisal of vulnerable zones of non-cancer-causing health risks associated with exposure of nitrate and fluoride in groundwater from a rural part of India. *Environmental Research, 202*, Article 111674, https://doi.org/10.1016/j.envres.2021.111674

Subba Rao, N., Dinakar, A., Surya Rao, P., Rao, P. N., Madhnure, P., Prasad, K. M., & Sudarshan, G. (2016). Geochemical processes controlling fluoride-bearing groundwater in the granitic aquifer of a semi-arid region. *Journal of the Geological Society of India, 88*, 350–356. https://doi.org/10.1007/s12594-016-0497-3

Subba Rao, N., Ravindra, B., & Wu, J. (2020). Geochemical and health risk evaluation of fluoride rich groundwater in Sattenapalle Region, Guntur district, Andhra Pradesh, India. *Human and Ecological Risk Assessment, 26*(9), 2316–2348. https://doi.org/10.1080/10807039.2020.1741338

Subba Rao, N., Subrahmanyam, A., & Babu Rao, G. (2013). Fluoride-bearing groundwater in Gummanampadu Sub-basin, Guntur District, Andhra Pradesh, India. *Environmental Earth Sciences, 70*, 575–586. https://doi.org/10.1007/s12665-012-2142-9.

Subba Rao, N., Surya Rao, P., Dinakar, A., Nageswara Rao, P. V., & Marghade, D. (2017) Fluoride occurrence in the groundwater in a coastal region of Andhra Pradesh, India. *Applied Water Sciences, 7*, 1467–1478. https://doi.org/10.1007/s13201-015-0338-3

Susheela, A. K. (1984). Epidemiology and control of fluorosis in India. *Journal of Nutrition Foundation of India*, 1–3.

Susheela, A. K. (2002). Fluorosis in developing countries: Remedial measures and approaches. *Proceedings-Indian National Science Academy Part B*, *68*(5), 389–400.

Viswanathana, G., Jaswantha, A., Gopalakrishnanb, S., Siva ilangoc, S. (2009). Mapping of fluoride endemic areas and assessment of fluoride exposure. *Science of The Total Environment, 407*(5), 1579–1589. https://doi.org/10.1016/j.scitotenv.2008.10.020

West Bengal Public Health and Engineering Department. (2006). *Summary of Test Results of Public Hand Pump Tube Wells Under the Joint Plan of Action with UNICEF*. Public Health Engineering Department, Govt. of West Bengal.

World Health Organization. (1994). *Fluoride and Oral Health*. https://apps.who.int/iris/bitstream/handle/10665/39746/WHO_TRS_846.pdf?sequence=1

World Health Organization. (2004). *Guidelines for drinking-water quality: Volume 1 - Recommendations* (3rd ed.). https://apps.who.int/iris/handle/10665/42852

World Health Organization. (2008). *Guidelines for drinking-water quality: Volume 1 - Recommendations* incorporating the first and second addenda (3rd ed.). https://www.who.int/publications/i/item/9789241547611

Yadawe, M. S., Hiremath, SMT D. M., & Patil, S. A. (2010). Assessment of fluoride content in ground and surface water and its environmental impacts at Basavan-Bagewadi and Muddebihal Taluka of Bijapur District, Karnataka, India. *Journal of Chemistry, 7*, Article ID 120909. https://doi.org/10.1155/2010/120909

Yeung, C. A. (2008). A systematic review of the efficacy and safety of fluoridation. *Evidence-Based Dentistry*, *9*(2), 39–43. https://doi.org/10.1038/sj.ebd.6400578