An Overview of the Impact of Fluoride in India: A Pervasive Public Health Challenge

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ABSTRACT

Fluoride contamination in groundwater has emerged as a significant public health issue in various regions of India, including the state of Jharkhand. Fluoride contamination of groundwater in India has become a pressing public health issue. This contamination, stemming from natural and anthropogenic sources, has led to widespread fluorosis, affecting millions of individuals, particularly children. This paper provides an overview of the problem of fluoride contamination mainly in Jharkhand, India, highlighting its causes, consequences, and potential mitigation strategies. Fluoride contamination in Jharkhand primarily results from the geological composition of the region, where naturally occurring fluoride-rich rocks and minerals contribute to elevated levels of fluoride in groundwater. Consequently, many communities in the state are exposed to unsafe levels of fluoride through their drinking water sources, leading to adverse health effects such as dental fluorosis, skeletal fluorosis, and other related health problems. his paper also addresses the development of various methods for removing fluoride contamination.

Keywords: Jharkhand, Groundwater, fluoride, contamination, fluorosis

1. **Introduction**: India has two major public-health problems induced by the use of groundwater as a source of drinking water, having excess fluoride and arsenic[1-3]. Due to a variety of natural and human influences, groundwater resources are under threat in a few parts of the country[4-5]. Fluorine is widely distributed in the earth's crust and exists in the form of fluorides[6]. It also plays a significant role in dental health and bone development[7]. A small quantity of fluoride is an essential component for normal mineralization of bones and the formation of dental enamel[8]. Low concentrations of fluoride cause dental caries, both in children and adults[9]. However, an excess concentration may result in a slow, progressive scourge known as fluorosis[10]. Fluoride is completely absorbed by the gastrointestinal tract, and the absorbed fluoride is rapidly distributed throughout the body[11]. Since fluorine is a highly electronegative element, it has a strong tendency to get attracted by

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positively charged calcium ions in teeth and bones, and excessive intake results in pathological changes in teeth and bones, such as mottling of teeth or dental fluorosis followed by skeletal fluorosis[12]. Thus, a large amount of fluoride gets bound in these tissues, and only a small amount is excreted via urine, faces, and sweat[11]. Skeletal fluorosis is observed when drinking water contains 3-6 mg of fluoride per liter and develops as crippling skeletal fluorosis when drinking water contains over 10 mg of fluoride per liter[13]. Other sources of fluoride poisoning are food[14], industrial exposure[15], drugs[16], cosmetics[17], etc. WHO has stated that India and China are the most affected countries by fluoride exposure[18]. BIS (Bureau of Indian Standards) permissible limit for fluoride is 0.6-0.12 mg/l, and WHO (International Std.) 0.8-1.5 mg/l[19]. The general guideline for fluoride concentration in drinking water (expressed in parts per million or ppm) corresponds to different levels of dental fluorosis[20]

Table 1 Guidelines for required fluoride concentration in drinking water.

Dental Fluorosis Severity	Fluoride Concentration in Drinking Water (ppm)
None (No Fluorosis)	< 0.7 ppm
Very Mild (Questionable)	0.7 - 1.2 ppm
Mild (Mild)	1.3 - 2.0 ppm
Moderate (Moderate)	2.1 - 4.0 ppm
Severe (Severe)	> 4.0 ppm

Fluoride in drinking water was first reported in India at Nellore district of Andhra Pradesh in 1937, and since then, considerable work has been done in different parts of India[20]. More than 66 million people are estimated to be suffering from fluorosis, among whom 6 million are children below 14 years of age in India alone[21]. Dipankar et al. reported that 20 out of 28 Indian states have some degree of groundwater fluoride contamination, impacting 85-97% of districts[21]. At present, it has been estimated that fluorosis is widespread in seventeen states of India, indicating that endemic fluorosis is one of the most acute public health problems in the country[22-23]. More than 20 developed and developing nations are suffering from fluorosis[24]

Table 2 State-wise fluoride contamination (Source: Ministry of Jal Shakti Ministry of Jal Shakti, Ministry of Jal Shakti)[25]

State/UT	Fluoride (above 1.5 mg/l)
Andhra Pradesh	Visakhapatnam, West-Godavari, Krishna, Guntur, Prakasam, Nellore, Chittoor Kadapa, Kurnool, Ananthapur, Sirkakulam, Vizianagaram
Telangana	Adilabad, Karimnagar, Khammam, Warangal, Mahabubnagar, Medak,

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	Nalgonda, Rangareddy, Nizamabad, Hyderabad.
Assam	Goalpara, Kamrup, KarbiAnglong, Naugaon, Golaghat, Karimganj, Bangiagaon, Sibasagar, Jorhat
Bihar	Aurangabad, Banka, Bhagalpur, Gaya, Jamui, Kaimur(Bhabua), Munger, Nawada, Rohtas, Jahanabd, Lakhisarai, Sheikhpura, Nalanda
Chhattisgarh	Bastar, Balod ,Balrampur, Bemetra, Bijapur , Durg, Kanker, Kondagaon, Korba, Koriya, Raigarh, Surajpur, Surguja, Jashpur, Dhamtari, Mahasamund, Rajnandgaon, Bilaspur, Raipur
Delhi	East Delhi, New Delhi, North West Delhi, South Delhi, South West Delhi, North Delhi, West Delhi
Gujarat	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Gandhinagar, Jamnagar, Junagadh, Kachchh, Mehesana, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surendranagar, Vadodara, Kheda, Navsari, Surat
Haryana	Ambali, Bhiwani, Fatehabad, Faridabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendergarh, Panchkula, Palwal,Panipat, Rewari, Rohtak, Sirsa, Sonepat, Yamuna Nagar, Mewat
Jammu & Kashmir	Jammu, Kathua
Jharkhand	Bokaro, Dhanbad, Garhwa,Giridih, Godda, Gumla, Koderma, Pakur, Palamu, Ranchi, , Sahebganj, Khunti
Karnataka	Bagalkot, Bangalore-Rural, Bangalore-Urban, Belgaum, Bellary, Bidar, Bijapur, Chikaballapur Chamarajanagar, Chikmagalur, Chitradurga, Davanagere, Dharwad, Dakshina Kannada, Gadag, Gulburga, Hassan, Haveri, Kolar, Koppal, Mandya, Mysore, Raichur, Ramnagara , Shimoga, Tumkur, Yadgir, Uttara Kannada, Udupi, Kodagu
Kerala	Palakkad, Alappuzha, Idukki, Ernakulum, Thiruvananthpuram
Madhya Pradesh	Alirajpur, Balaghat, Barwani, Betul, Bhind, Bhopal,Chhatarpur, Chhindwara, Datia, Dewas, Dhar, Dindori, Guna, Gwalior, Harda, Jabalpur, Jhabua, Khargon, Mandla, Mandsaur, Morena, Narsinhpur, Neemuch, Panna, Raisen, Rajgarh, Ratlam, Sagar, Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Sidhi, Shivpuri, Singrauli, Uajjain, Vidisha, Anuppur, Indore, Khandwa, Tikkamgarh

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Maharashtra	Ahmednagar, Beed, Chandrapur, Bhandara, Dhule, Gadchiroli, Gondia, Jalna, Nagpur, Nanded, Ratnagiri, Sangli, Satara, Sindhudurg, Solapur, Wardha,Yavatmal
Manipur	Thoubal
Meghalaya	Ri Bhoi
Nagaland	Dimapur
Odisha	Angul, Balasore, Bhadrak, Bargarh Bolangir, Boudh, Cuttack, Deogarh Dhenkanal, Jajpur, Kandhamal ,Keonjhar, Khurda, Mayurbhanj, Nayagarh, Nuapada, Ganjam, Jagatsinghpur, Kalahandi, Koraput, Puri, Rayagada, Sambalpur, Sonepur, Sundargarh, Gajapati
Punjab	Amritsar, Barnala, Bhatinda, Fazilka, Faridkot, Fatehgarh Sahib, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Pathankot, Patiala, Ropar, Sangrur, SAS Nagar (Mohali), Tarn-Taran
Rajasthan	Ajmer, Alwar, Banswara, Barmer, Bharatpur, Baran, Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhalawar Jhunjhunu, Jodhpur, Karauli, Kota, Nagaur, Pali, Pratapgarh, Rajsamand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur
Tamil Nadu	Coimbatore, Dharmapuri, Dindigul, Erode, Karur, Kancheepuram, Krishnagiri, Namakkal, Madurai, Puddukotai, Ramanathanpuram, Salem, Sivagangai, Theni, Thiruvannamalai, Tiruchirapally, Thirunelveli, Tirupur Vellore,Cuddalore, Perambalur, Thanjavur, Thiruvarur, Tuticorin, Virudhunagar
Uttar Pradesh	Agra, Aligarh, Allahabad ,Auraiya, Banda ,Bulandshahar ,Etah,Etawah,, Farrukhabad, Fatehpur, , Firozabad, G B Nagar, Ghaziabad, Hathras,Jaunpur, Kannauj , Kanpur Nagar, Kasganj (Kashiram Nagar), Lalitpur, Mahoba, Mainpuri, Mathura, MaunathBhanjan,Pratapgarh, Rai Bareli, Shajahanpur, Sonbhadra, Sultanpur, Varanasi and Unnao,Chandauli, Gonda, Hardoi, Sitapur
West Bengal	Bankura, Birbhum, Dakshindinajpur, Malda, Purulia, Uttardinajpur, South 24 Praganas, Nadia

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Occurrence of fluoride in Jharkhand: Fluoride contamination in groundwater has affect various areas in Jharkhand, as it has in many parts of India have been reported by several authors[26-30]. Fluoride occurrence in Jharkhand, like in many other regions, depends on the geological and hydrogeological characteristics of the area[31]. Fluoride is a naturally occurring element found in the Earth's crust[32]. The Chainpur, Pandu and Daltonganj blocks are affected with high concentration of fluoride as (1.57, 1.84 and 1.86 mg L-1, respectively)[33]. Whereas, Bishrampur block with lower concentration of fluoride (1.25 mg L-1)[33]. The higher concentration of fluoride may be due to the presence of fluoride-bearing minerals in groundwater as the majority of the area in fluoride affected blocks are underlain by granitic rocks[34]. The affected areas of Jharkhand with the contamination ranges have been incorporated in Table 2.

Table 3 Affected areas of Jharkhand [35-37]

District	Blocks or Areas Affected	Fluoride Concentration Range (ppm)
Bokaro	Chas, Chandankiyari	1.5 - 2.5
Chatra	Itkhori, Simaria	1.8 - 2.8
Deoghar	Sarath, Devipur	1.7 - 2.4
Dumka	Gopikandar, Jama	1.6 - 2.2
Giridih	Bengabad, Dumri	1.6 - 2.3
Hazaribagh	Keredari, Barkagaon	1.4 - 2.0
Jamtara	Narayanpur	1.7 - 2.6
Koderma	Domchanch, Jainagar	1.5 - 2.3
Latehar	Balumath, Manika	1.7 - 2.4
Lohardaga	Kisko, Senha	1.6 - 2.5
Palamu	Haidernagar, Naudiha	1.6 - 2.2
Ranchi	Nagri, Silli	1.8 - 2.7
Sahibganj	Borio, Taljhari	1.5 - 2.6
Simdega	Thethaitangar, Bolwa	1.8 - 2.8

Fluoride is a naturally occurring chemical element found in various minerals and compounds[38]. It is abundantly found in the Earth's crust, and it can be present in rocks, soil, water, and various natural substances[39]. The natural concentration of fluoride in groundwater depends on the geological, chemical, and physical characteristics of resources, as well as the types of soil and rocks[40]. Fluoride contamination typically arises from natural geological processes where fluoride-rich minerals and rocks, such as fluorite or mica, dissolve into groundwater[40]. Human activities, such as industrial

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processes and the excessive use of certain fertilizers and pesticides, can also contribute to fluoride contamination in water sources[41].

Some of the fluoride-bearing rocks have been represented in Table 1.

Table 4 Sources of fluoride from fluoride bearing rocks[42-46]

Mineral or Ore	Chemical Composition	Primary Use
Fluorite	Calcium Fluoride (CaF_2)	Flux in steelmaking, aluminum production
Apatite Group	Various phosphate minerals with fluorine	Phosphate fertilizers, industrial applications
Topaz	Aluminum silicate (Al2SiO4)(F,OH)2	Gemstone (imperial topaz)
Cryolite	Sodium Aluminum Fluoride (Na3AlF6)	Historical aluminum smelting
Beryllium Minerals	Bertrandite, Beryl, etc.	Beryllium production, gemstones
Phosphorite	Phosphate-rich rocks with fluorine	Phosphate fertilizer production
Spodumene	Lithium Aluminum Silicate (LiAlSi2O6)	Lithium production, ceramics
Amblygonite	Lithium Aluminum Phosphate (LiAlPO4[F,OH])	Lithium production, ceramics
Zircon	Zirconium Silicate (ZrSiO4)	Zirconium compounds, gemstones

Several methods for removing fluoride from drinking water have been reported, broadly categorized into membrane and adsorption techniques. Membrane techniques include reverse osmosis, nanofiltration, dialysis, and electrodialysis[47-50]. Adsorption techniques involve various adsorbents such as alumina/aluminium-based materials, clays, calcium-based minerals, synthetic compounds, and carbon-based materials. Layered double oxides have also gained interest as fluoride adsorbents[51-54].

Table 5 Various techniques used for the removal of fluoride.

Technique	Description	Advantages	Disadvantages	Ref
Coagulation-Flocculation	Chemicals like aluminum sulfate or calcium carbonate are added to water to form flocs that trap fluoride.	Effective at fluoride removal.	High operational and maintenance costs.	55
Precipitation	Chemicals like calcium or magnesium salts are added to water to form insoluble precipitates with fluoride.	Relatively simple and cost-effective.	Requires careful chemical dosing and monitoring.	56
Adsorption	Adsorbent materials like activated alumina, bone char, or activated carbon are used to capture fluoride.	High removal efficiency.	Regular replacement of adsorbent material.	57

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Ion Exchange	Resin beads with exchangeable anions are used to replace fluoride ions with other ions, like chloride.	Efficient removal and regeneration.	Requires periodic regeneration of resin.	58
Reverse Osmosis	A semi-permeable membrane is used to filter out fluoride and other contaminants from the water.	Effective at removing multiple contaminants.	High energy consumption and maintenance costs.	59
Electrodialysis	A membrane-based separation process using an electric field to transport ions, separating fluoride.	Efficient for ionic separation.	Requires electricity and regular maintenance.	60
Defluoridation Plants	Large-scale facilities that combine various techniques, such as precipitation and coagulation, for fluoride removal.	Suitable for community water supply.	High initial investment and operating costs.	61
Activated Alumina Adsorption	Activated alumina is a specialized adsorbent that traps fluoride ions.	Effective fluoride removal.	Requires periodic regeneration or replacement.	62
Bone Char Adsorption	Bone char is a carbonaceous adsorbent made from animal bones and is effective at removing fluoride.	Natural and sustainable adsorbent.	Limited regeneration potential.	63
Calcium Hydroxide Precipitation	Adding calcium hydroxide to water raises the pH and precipitates fluoride as calcium fluoride.	Low-cost and simple method.	Requires careful pH control.	64
Solar Defluoridation	Sunlight is used to facilitate the precipitation of fluoride, which settles as calcium fluoride.	Environmentally friendly and low cost.	Slower removal rates compared to some methods.	65
Nanofiltration	A type of membrane filtration that effectively removes fluoride by size exclusion.	High removal efficiency and less energy-intensive.	Requires maintenance and membrane replacement.	66
Electrocoagulation	Electric current is used to destabilize and aggregate fluoride ions, which are then removed by coagulation.	Effective at fluoride removal.	Energy consumption and electrode maintenance.	67
Electrochemical Defluoridation	Electrochemical processes can selectively remove fluoride ions through electrode reactions.	Efficient fluoride removal.	Requires electrical setup and maintenance.	68
Electrocoagulation	Electric current is used to form coagulants that trap fluoride, which can then be removed.	Effective fluoride removal.	Energy consumption and electrode maintenance.	69

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Sorption with Clay	Natural clay minerals like bentonite or kaolinite can be used to adsorb fluoride ions.	Readily available and cost-effective.	Limited sorption capacity, may require pretreatment.	70
Magnesium-Based Adsorption	Adsorbents containing magnesium compounds are used to capture fluoride ions.	High removal efficiency.	Requires regeneration or replacement.	71
Membrane Filtration	Various types of membranes, like ultrafiltration or nanofiltration, are used to physically block fluoride.	Effective for small molecules like fluoride.	Membrane replacement and maintenance.	72
Hybrid Methods	Combination of multiple techniques, e.g., adsorption followed by ion exchange, to enhance fluoride removal.	Increased removal efficiency and flexibility.	More complex and potentially higher costs.	73
Photochemical Methods	Ultraviolet (UV) or photocatalytic processes are employed to degrade or remove fluoride from water.	Can effectively break down fluoride compounds.	May require energy for UV lamps or catalysts.	74

Considerable work on defluorination has been conducted worldwide[75-77] .Popular fluoride removal technologies include coagulation followed by precipitation, membrane processes, ion exchange, and adsorption[78]. Coagulation may leave trace fluoride ions in solution, resulting in high pH and bulky sludge[79]. The Nalgonda technique, based on precipitation, has limitations like daily chemical addition, sludge production, and low effectiveness for water with high total dissolved solids and hardness[80]. Membrane processes are effective but demineralize water and involve high costs[81]. Ion exchange is efficient but requires complex resin preparation and is costly.[81]
Adsorption techniques have gained popularity due to their simplicity and the availability of various low-cost adsorbents, including clays, industrial wastes, activated alumina, carbonaceous materials, bone charcoal, and natural/synthetic zeolites[82]. Components of red mud from Alcoa's Kwinana bauxite refinery, Western Australia [83] and drying red mud[84] . Adsorption of fluoride with different oxides have been presented in Table6.

Table6. Adsorption of fluoride with different oxides

Chemical	Formula	% w/w
Aluminium oxide	Al2O3	17–22
Calcium oxide	CaO	4–5
Iron oxide	Fe2O3	25–35
Silicon dioxide	SiO_2	25–30
Sodium carbonate	Na_2CO_3	2.8

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Sodium oxide	Na_2O	2–3
Titanium oxide	TiO_2	2–4

It's important to emphasize that the health effects of fluoride are dose-dependent, meaning that the severity of these effects varies with the level and duration of exposure. Regulatory standards for fluoride in drinking water are established to protect public health by ensuring that fluoride concentrations remain within safe limits, balancing dental health benefits and minimizing potential health risks.

Table 7. Potential health risks of fluoride

Health Effect	Description	Ref.
Impaired Reproductive Health	Some studies suggest a link between high fluoride exposure and reproductive health issues, including reduced fertility and altered hormonal balance.	85
Cardiovascular Effects	There is ongoing research into potential cardiovascular effects of chronic fluoride exposure, such as hypertension and atherosclerosis, but the evidence is not yet conclusive.	86
Increased Risk of Hypothyroidism	Excessive fluoride intake may disrupt thyroid function and contribute to the development of hypothyroidism, a condition characterized by an underactive thyroid gland.	87
Gastrointestinal Disorders	Chronic exposure to high fluoride levels can lead to gastrointestinal issues, including stomach pain, ulcers, and increased risk of gastrointestinal diseases.	88
Kidney Damage	High levels of fluoride in drinking water may contribute to kidney dysfunction and have been associated with an increased risk of kidney stones.	89
Impaired Bone Health	While moderate fluoride exposure is beneficial for bone health, excessive and prolonged exposure can lead to poor bone health, increasing the risk of fractures.	90
Endocrine System Disruption	Some research suggests that high fluoride exposure may disrupt the endocrine system, affecting hormone regulation, but more studies are needed for a clear understanding.	91
Immune System Effects	Elevated fluoride intake may have immunosuppressive effects, potentially making individuals more susceptible to infections and diseases.	92
Developmental Delays in Children	There is emerging evidence that children exposed to high fluoride levels may experience developmental delays, impacting growth and cognitive development.	93
Osteoarthritis	Long-term exposure to high fluoride levels has been associated with an increased risk of osteoarthritis, leading to joint pain and stiffness.	94

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Conclusion: Fluoride is a double-edged element, offering substantial benefits to dental health when managed appropriately but posing potential health risks with excessive exposure. A comprehensive understanding of its sources, uses, and health implications is crucial for ensuring the safe and effective utilization of fluoride in our daily lives. Fluoride contamination is a widespread environmental concern, primarily linked to the presence of elevated fluoride levels in natural water sources. While controlled fluoride intake can have dental health benefits, excessive concentrations in drinking water and the environment can result in adverse health and environmental consequences. It is imperative to strike a balance in managing fluoride to harness its positive attributes while safeguarding against its adverse effects

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