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ORIGINAL ARTICLE

A comprehensive and systematic study of fluoride and arsenic contamination and its impacts in India

Het Baboo[1] · Takshil Patel[1] · Rohan Faldu[1] · Manan Shah[2] · Harshad Shah[1]

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Abstract
Groundwater pollution of arsenic and fluoride is a serious issue; it has gained a serious amount of consideration in the previous few years and the researchers are working towards various ways to control the pollution. They have got such great attention because of their ability, aggregation in the human body and toxicity. Fluoride and arsenic enter the drinking water resources through different sources. These contaminants also have an ill effect on the agriculture sector of the country as they pollute the soil and the crops. Human body is sensitive to arsenic. Arsenic gets into the body through arsenic-contaminated . As per BIS Standards the acceptable limit of Arsenic is 0.01 mg/l (ppm) or 10 µg/L (ppb) for water. In crops of wheat and paddy root, stem, leaf and grain contamination of arsenic was present. In some crops like wheat and paddy their roots have the highest arsenic concentration of 4.82 mg/kg and 40.3 mg/kg, respectively. WHO allowable limit is 1.0 mg/kg. The allowable limit of arsenic in water used for agricultural purposes is 0.10 mg/l as given by FAO (Food and Agriculture Organization). Many technologies based on adsorption, membrane process, oxidation, ion exchange and co precipitation are developed and used for the expulsion of arsenic from polluted water; creative innovations for the expulsion of arsenic from groundwater like phytoremediation, biological treatment, permeable reactive barriers and electro kinetic treatment are likewise being utilized to treat arsenic-contaminated water. These advances might be applied at full scale to treat arsenic-defiled springs. For the case of Fluoride it was observed that the majority of the states in India have crossed the permissible limitExcess fluoride in the drinking resources leads to fluorosis which does not have a cure.

Keywords Groundwater · Contamination · Arsenic · Fluoride

Introduction

Water might just be the most important resource needed for survival of human beings, so the care we need or the importance given to it is totally understandable. Groundwater being the primary source of irrigation and drinking for most people, one of the main interests of many scientists out there has a main focus of improving the quality of the groundwater. A report from the World Bank in 2012 states that the amount of groundwater used by India is the largest around the world. Indians consider it a critical resource, but if a trend like this is continued for 20 years, more than 50% of aquifers in India will be in worse condition. Groundwater is cleaner than the surface water and its importance in providing and supplying water for agriculture and manufacturing processes is unrivalled (Patel et al. 2020; Ren et al. 2020). In this fast-paced world and the expansion of the human civilization we do not take environmental pollution into consideration and that also includes the groundwater pollution (Antony Ravindran and Selvam 2014; Manap et al. 2014; Neshat et al. 2014; Pradhan 2009; Selvam 2015; Selvam and Sivasubramanian 2012). This paper will also shed light on the factors responsible for the high level of contamination, It is not just industrialization that is the source of all problems; some contamination's are caused by natural phenomena like weathering of rocks. Source of water in coastal areas is provided by the groundwater (Galagan and Vermillion 1957; Mala 2013; Selvam, 2015). So, to control the growing need of our “most precious resource” we need a proper watershed

✉ Manan Shah
manan.shah@spt.pdpu.ac.in

[1] Chemical Engineering Program, School of Engineering and Applied Sciences, Ahmedabad University, Ahmedabad, Gujarat, India

[2] Department of Chemical Engineering, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

management team to monitor and treat the waters (Pradhan 2009).

In this review paper we wanted to highlight the high level of contamination of fluoride and arsenic found in various states of India and the harm that comes with it. The representation of data is done so that the readers will be able to examine and understand readily. From the review done we found mostly all the states in India are facing the problem of high contamination from fluoride and arsenic.

Fluoride is known to globally pollute freshwater supplies. For healthy bones and teeth, fluoride is a necessary component. But if taken in high concentrations, fluoride can be very harmful to the human system including the brain (Aravinthasamy et al. 2020; Choi et al. 2012). Following the prevalence of fluorosis in USA in 1930s many new research were carried out in the different parts of the world (Aravinthasamy et al. 2020). In Andhra Pradesh, India, a high level of fluoride contamination in groundwater was first recorded in 1937 (Narsimha and Sudarshan 2017a, b). The excessive concentration of fluorine in groundwater is the main reason for causing fluorosis and due to this many countries are affected. Fluorosis is mainly classified into three ways: fluorosis in soft tissues, muscles and ligaments (Jacks et al. 2005) In India, at least 1 M people are subject to excessive intake of fluorine. In southern India, dental fluorosis is seen when the concentration reaches 1.5–2 mg/l, whereas debilitating skeletal fluorosis can occur with a content of > 5 mg//l (Jacks et al. 1993). In India there are many states which are affected by high fluoride pollution is found in groundwater and around 62 million individuals are in danger of getting fluorosis from drinking this contaminated water. These issues are generally noticed in Uttar Pradesh, Punjab, Gujarat, Madhya Pradesh, Andhra Pradesh, Rajasthan, Bihar, Tamil Nadu and Gujarat. Dental fluorosis is now a serious issue in 14 states and 150,000 towns in India (Andezhath et al. 2000; Jacks et al. 2005; Pillai and Stanley 2002). Uttar Pradesh is one of the most fluoride-contaminated states of India and is also facing health-related issues like fluorosis. High fluoride concentration in groundwater has been recorded in Uttar Pradesh, especially Unnao district and is also severely affected by fluorosis (Ansari and Umar 2019; Jha et al. 2010; Kumar and Saxena 2011; Verma et al. 2018). Fluoride contamination in groundwater is natural and is affected not only by local, regional, geological and hydrological conditions, but also by the retention and leaching of soil fluoride. Fluoride contamination in groundwater is mainly due to the method of weathering and leaching and the occurrence of fluoride in groundwater is mainly due to water movement and percolation.

Arsenic is a natural element found in rocks and soil. Arsenic has been identified as a toxic ingredient and is known as a threat to human life. The main presence of arsenic contamination is found in aquifers of 100 m and the deeper aquifers are usually free of the contamination. When found in high concentrations in various drinking waters it is found that it can be very harmful to the human body and serious issues can be faced.

In India as of now the following seven states are facing the issue of high level of arsenic content in their groundwater: West Bengal, Uttar Pradesh, Assam, Jharkhand, and Chhattisgarh. In West Bengal the arsenic contamination in groundwater was first noticed in 1980 and studies indicate that eight districts have a well-water content above 0.050 mg/l with over 13.8 million people at risk, according to the United Nations Children's Fund (UNICEF). In Bangladesh, tube wells having arsenic contamination more than the acceptable limit of the World Health Organization (WHO) have been recorded (Dhar et al. 1997; Kumar 2019). Bihar has been careless with its management of arsenic contamination and 16 districts of the state have higher arsenic values than permitted (Kumar 2019).

Classification of contaminants and its general impacts

According to the data on the website of Unites States of Geological Contamination there are variety of inorganic and organic compounds which lead to the pollution and contamination of underground water, inorganic contaminants like aluminum, arsenic, barium, beryllium, cadmium, fluoride, etc. and for organic contaminants pesticides, plasticizers, chlorinated solvents, etc. A study by Datta et al. (1997) in Delhi observed that in the period from 1990 to 1993 the groundwater nitrate and potassium concentrations were far more higher than the general acceptance rate in the groundwater, the main possible cause being the regular application of fertilizers. High level of ions caused by regular discharge of wastes on lands and drains has also contributed to this contamination.. The amount of Fluoride in groundwater should not exceed 1.0–1.5 mg/l (Ojo 2012). "Emerging Organic Contaminants" (EOC's) is the new term used for newly developed compounds but mainly for the contaminants discovered, In the environment, often due to analytical developments, these, EOCs have a variety of different compounds like pharmaceutical and personal care products (PPCPs), pesticides, industrial products and by-products, food additives as well as engineered nanomaterials (Petrovic and Barceló 2006; Richardson and Ternes 2014; Lapworth et al. 2012; Lindsey et al. 2001). Phenol and carboxylic compounds(e.g., ibuprofen, triclosan) are not resistant to natural attenuation, whereas Amide EOCs (e.g., diethyltoluamide and carbamazepine) are a lot more resistant and better in comparison to phenols and carboxylic compounds (Alvarez-Cohen and Sedlak 2003; Moreau et al. 2019), The deciding factor whether a substance is polluting or non-polluting is to check their molecular properties. Anticoccidial veterinary drugs are one of the major upcoming groundwater contaminants which are of concern. Poultry activities are one of the main reasons for this. In a study by Mooney et al. (2020) in the republic of Ireland on various sites, detected seven different ionophores were detected at 24% of the groundwater monitoring points with the concentration range of 1.9–286 ng/L. Monesin was the most common ionophore present at the sites. As mentioned by Lapworth et al. (2012) if there are EOCs present, then it will pose a hazard for many decades due to their long residence times and persistence due to reducing chemistry (Fig. 1). In this paper we are going to go in deep for fluoride and arsenic but let us discuss other inorganic contaminants. (Table 1).

Fluoride contamination and its impact in agriculture

Fluoride contamination scenario in India

According to WHO (2011), 260 million people in the world are affected or suffer illness due to high fluoride concentration which is > 1.5 mg/L (Amini et al. 2008). Contamination of fluoride in groundwater is vastly seen and found in the following countries: India, Africa (Rift Valley Zone), China, Nigeria, Kenya, South America, Nigeria, Pakistan, and Northwest Iran (Asghari Moghaddam and Fijani 2008; Brunt et al. 2004; Chandrajith et al. 2012; Craig et al. 2015; Gaciri and Davies 1993; Rafique et al. 2009; Raj and

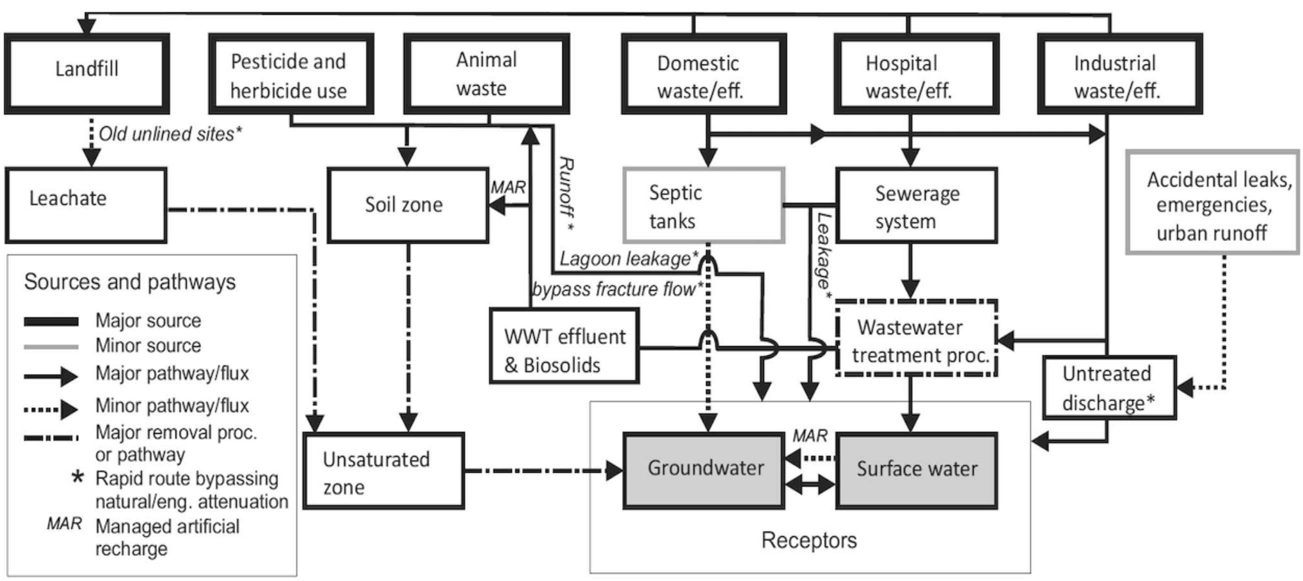

Fig. 1 Source pathway receptor approach for EOC's (Lapworth et al. 2012)

Table 1 Inorganic contaminants, sources and their side effects

Sr. no	Inorganic compound	Sources to groundwater	Potential health and other side effects	References
1	Aluminum	Leaching of aluminum from geochemical formations and soil particulates of aqueous environment	Al accumulation in Human body leads to diseases like Alzheimer's Disease	Popugaeva and Ajay (2019)
2	Barium	Barium is found naturally in some limestones and soils in the United States of America	Gastrointetinal, cardiac and neuromuscular effects on humans	Gilkeson et al. (1983) (usgs.gov)
3	Cadmium	Atmosphere (weathering of rocks, Airbone soil particles), Phosphate Fertilizers, Sewage Sludge and other Anthropogenic Cadmium Sources	Osteoporosis and Renal Tubular Dysfunction	Kubier et al. (2019)
4	Cyanide	Industrial contamination	Chronic effects on nervous systems and thyroid also creates deficiency of vitamin B12	Al-aizari et al. (2018)
5	Chromium	Unregulated disposal of pretanning industrial waste	Carcogenic Risks caused by Cr^{6+}	Bhattacharya et al. (2020), He and Wu (2019)

Shaji 2017). According to the CGWB (2018), in India, 19 states are facing fluoride contamination and also there is an increase in the fluoride concentration in the groundwater. High fluoride concentration is the main reason for the emergent epidemic diseases in the human health and also chronic diseases (Chouhan and Flora 2010; Mukherjee and Singh 2018; Nayak et al. 2008, 2009; Salve et al. 2008) Skeletal fluorosis (deformities in bone) and dental fluorosis(mottling in teeth) happen due to high concentration of fluoride in water.

Controlling mechanism and sources of fluoride

The main sources of fluoride in the geological sources are the weathering of the fluoride-rich materials (Edmunds and Smedley 2013; Mukherjee and Singh 2018; Tressaud 2006; Vithanage and Bhattacharya 2015).We can further split geological sources of fluoride into the following two categories: Fluoride-containing rocks and minerals and geothermal sources.

Fluoride is present in the earth's crust at 625 mg/kg, whereas various rocks contain floride in various amounts (Edmunds and Smedley 2013; Mukherjee and Singh 2018; Tressaud 2006; Vithanage and Bhattacharya 2015); for example, limestone contains around average of 220 ppm of fluoride concentration, sandstone contains around average of 180 ppm of fluoride concentration and phosphorite contains around average of 31,000 ppm of fluoride concentration(Jha et al. 2011a, b).Some examples of the many rocks contain fluoride concentrations (Fig. 2).

Taking the geothermal sources in consideration, a study by (Camargo 2003) states that the 60 to 60,000 kilotons of inorganic fluoride are contributed by the global releases of volcanoes.

This paper will be now discussing the different states of India in case study form and in tabular form about the various fluoride contamination. This paper has tried to cover majority of the Indian States and the researches done on their Fluoride contamination levels.

According to Shirke et al. (2020) their objective was to find out the variation of F^- ion and the need of taking preventive steps so health hazards caused by F^- ion can be prevented. Sixty samples were collected from the Ambadonagar area located in the South of the state Gujarat, India. Ambadongar (21°58′ 16″ N to 22° 03′ 30″ N and longitudinal extent 74° 05″ 51″ E to 74° 08′ 24″ E) is an area of 159 km^2 where there are 23 villages with a population of 26,241 where they use the groundwater. This is located in Chota Udaipur of Vadodara District in Gujarat. The plan to collect samples was designed in such a way that the sources of F^- distribution and occurrences in groundwater was measured. According to the lithological diversity of the area random sampling method was adopted. The sample analysis was triplicate and the accuracy was determined by the mean

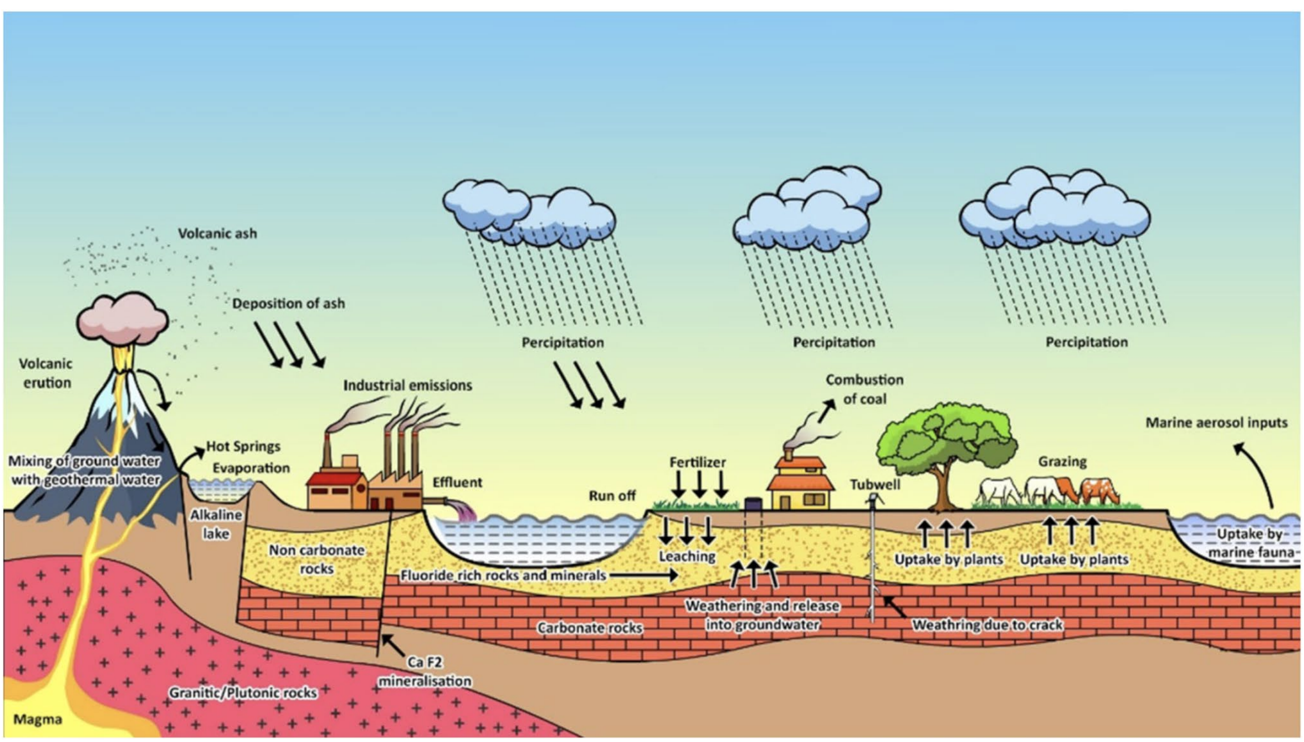

Fig. 2 Fluorine hydrogeochemical cycle (Edmunds and Smedley 2013)

value. The natural sources of F come mainly from Nephelinite, Limestone and Basalt. Due to the long residence time in aquifer the concentration of F is high in bore wells. Due to some extent of anthropogenic activity, rock–water interface has a role in increasing the content of F in the area.

In the study of Narsimha and Sudarshan (2017a, b) 34 samples were collected to identify the vulnerable areas of F contamination. The study of Narsimha and Sudarshan (2017a, b) covers a really stable part of the Dharwar Craton of the South Indian Shield. Which includes Dharwar Supergroup, Peninsular Gneissic Complex (PGC), and also the Deccan traps. The samples were collected from the Basara, Adilabad District, Telangana state. Using the standard EDTA measures the Electrical Conductivity (EC), pH, Total Hardness (TH). Ca^{2+} and Mg^{2+} were deducted Titrimetrically. The study above showed that groundwater is mildly acidic to alkaline. Also 20% of the samples were having concentration above 1.5 mg/L and hence unsuitable for drinking.

The study of (Hanse et al. 2019) focused on the health risk of consuming fluoride contamination. The study took place at eight different samples at Karbi Anglong District of Assam, India. The district is surrounded by hills and plains, and some rivers follow from the same district. The method used to analyse the samples was mainly followed according to the APHA (1998). Standard methods for the examination of water and wastewater analysis in the 20th edition were observed for pH, Electrical Conductivity (EC), Total Hardness (TH), Calcium Hardness, Total Alkalinity (TA), Chloride (Cl^-), Nitrate (NO_3^-) and Sulphate (SO_4^{2-}) by following standard practices of APHA (1998). Four out of eight blocks from the samples tested had fluoride contamination above the permissible level. In the area measured both adults and children will be exposed to non-carcinogenic risks.

The study conducted by Adimalla et al. (2019) collected a total of 123 groundwater samples in the rural part of Andhra Pradesh. As shown in the Gibbs Diagram, according to the data, the samples were collected from the groundwater. The primary cause of high fluoride is due to the nature of rocks present. The samples were having a pH of 8.36; the hydrogeochemical analysis turned out that the fluoride present in the groundwater was in range of 0.4 to 5.8 mg/L with an average of 1.98 mg/L. Western parts of Marakpur region was marked with higher concentration of fluorides. The concentration of fluoride was high in Na^+-HCO_3^- type groundwater and really low in Ca^{2+}-HCO_3^-.

For the study of Kumara (2020) collected a total of 90 samples of the groundwater from various taluks from the Yadgir districts (Karnataka), namely Yadgir, Shorapur, Shahpur. All samples were collected in post monsoon season. The main study area and angle for their research was to check the presence of the major anions and cations alongside fluoride in the samples collected. The fluoride samples were found in a range of 0.21–4.8 mg/l. The result also concluded that 31.18% of the groundwater samples were having fluoride concentration of more than the permissible level. The main reason for high fluoride concentration was due to longer residence time and interaction with minerals having high fluoride concentration.

As the study suggests by Farooq et al. (2018), the difference of fluoride concentration before and after the rainy season was drastic at Purilia District West Bengal. The team of Farooq et al. (2018) had taken 20 samples each for two batches (Pre monsoon and Post monsoon). The range of fluoride concentration in the Pre monsoon and in Post monsoon were 0.94–2.52 and 0.25–1.43 mg/l, respectively. As we see that the amount of fluoride was less in the Post-monsoon season and that was due to the dilution effect due to precolating rainwater, In post monsoon not only fluoride but also other contaminations were reduced. The study conducted also showed that the rocks consist of plagioclase, orthoclase and quartz with abundant biotite. The biotite controls fluoride concentration in the groundwater.

According to Tiwari et al. (2020), 34 groundwater samples were noted and experimented at Dausa District, Rajasthan, India. The fluoride concentration from the 34 groundwater samples were in a range of 0.48–3.64 mg/l and with an average of 1.66 mg/l. The fluoride concentration in about 82% of the samples was above the permissible level. The geological representation of the area consists of alluvium, quartzite and granite genesis, which contains minerals which bear fluoride like Biotite, Muscovite, Fluorite and Albite, where major contribution of fluoride comes from the weathering of the rocks. The high fluoride in groundwater is making it unfit for agriculture and drinking purposes.

Ahada and Suthar (2019) collected a total of 76 various samples from 14 districts in the Malwa region, Punjab. The results indicated that the fluoride range was from 0.67 to 5.07 mg/l. Majority percentage showed more than the allowed limit. The residents are subjected to a high risk of non-carcinogenic health disease.

Singaraja et al. (2014) collected a variety of 100 different samples collected during two different seasons at the Thoothukudi district, Tamil Nadu. In the pre-monsoon samples the highest was 3.3 mg/l and post-monsoon the maximum was 2.4 mg/l. The post-monsoon contamination was less due to rainwater. But the spatial diagram shows that the higher concentration was noted at North and Central part. It was shown and found out in the study that both the high concentration of F ion was due to weathering of rocks.

The research conducted by (Murkute and Badhan 2011) concluded that high fluoride concentration in the region Bhadravati Tehsil, Chandrapur District Maharashtra was the result of rock water interaction and the erosion of rocks. Out of 23 samples which were sampled and taken to the lab for further research it was observed that the concentration in

Table 2 Fluoride concentration in different states or areas of India

State	Study Area	Concentration of fluoride (mg/l)	References
Bihar	Extend of fluorosis in the three villages of Gaya	0.19–14.4	Yasmin et al. (2011)
Chhattisgarh	The Kourikasa area (≈ 500 km^2) around 20 samples pre and post monsoon, the groundwater was investigated using cluster and factor analysis	3.70–27.0	Patel et al. (2017a; b)
Delhi	Investigation to identify the groundwater depth and pollutant concentration levels in the National Capital Territory of Delhi	0.20–51.2	Dash et al. (2010)
Haryana	A total of 275 samples from deep aquifer-based hand-pumps along various villages/towns of Bhiwani Region	0.14–86.0	Garg et al. (2009)
Jharkhand	Chukru in the Palamau district of Jharkhand	0.77–10.3	Patel et al. (2014)
Kerala	Palakkad district, Kerala	0.32–2.78	Kukillaya and Narayanan (2014)
Jammu and Kashmir	The quality of underground water in tehsil Bishnah, district Jammu	0.00–0.93	Khanna (2015)
Manipur	In the area Imphal and Thoubal district, 45 samples collected during pre and post monsoon seasons	0.21–1.78	Oinam et al. (2012)
Odisha	Karlakot in the Nuapada district of Odisha	0.70–4.62	Patel et al. (2014)

phreatic aquifers was 1.0–4.4 mg/l and for deeper aquifers 0.5–2.9 mg/l in deeper aquifers. The people consuming or using this type of water are suffering from variety of fluorosis (Table 2).

In India fluoride is the 13th most abundant element. Earth's crust has 0.06–0.09% of fluoride content, In India fluorosis is one of the major health concerns for more than 62 million people (Singh et al. 2018). Rajasthan and Gujarat have been identified as having the most aquifers which have F^- contamination, which are containing alluvium aquifers,. whereas in Southern India aquifers are composed of limestone, quartzite and shale.

Fluoride contamination scenario in agriculture

Plants the same as humans are exposed to F very easily, there are many ways through which a plant can be exposed to fluoride ions: water, soil and air (Kumar and Anshumali 2015) Plants absorb the fluoride in a faster rate (Singh et al. 2018). They can absorb F present in the environment faster than the amount in the environment. The accumulation of fluoride in the plants depends on the following factors.

(1) Nature of Soil
(2) Plant Species
(3) Concentration
(4) Form of F

The uptake of F is also affected by the presence of other cations or anions and also by the change in soil pH. With the increase in the soil pH the F- intake also increases, whereas the increase in the Ca will lead to decrease in the F^- uptake (Ruan et al. 2004; Singh et al. 2018).

Fluoride complexes like HF and SiF4 are more toxic than other commonly known pollutants such as O_3, SO_2, PAN, Cl_2 or HCl (Kumar and Anshumali 2015). Inorganic Gaseous Fluoride is even more harmful than the Particulate F^- (Singh et al. 2018). Fluoride concentration leads to change in physiological, structural and biochemical changes which even leads to cell death. Taking Gossypium Hirsutum L, for example, a 73% reduction in the root's biomass was noticed when 1000 mg/ml F^- contaminated water was used (Kumar and Singh, 2015). Plants like Gladiolus sp. have necrotic effect at 20 µg F^- g^{-1} whereas cotton showed no impact to 4000 µg F^- g^{-1}.

Let us look at some of the following cases for agriculture contamination in India due to fluoride: Devi et al. (2016) found that Brachiariadistachya, Suaeda maritime, Prosopis Juliflora and Scopharindulci located near a fertilizers plant in Visakhapatnam, India accumulated 789, 684, 660 and 314 mg F^- Kg^{-1}, respectively.

In India, F^- contaminations in wheat, tomato and potato was recorded up to 10.72, 4.19 and 2.92 mg F^- g^{-1} when cultivated in the F^- contaminated area (5–15 µg mL^{-1}) of Dusadistrict, Rajasthan and in (Bhargava and Bhardwaj 2009; Yadav et al. 2012). Similarly, by Jha et al. (2008) in the village Jaraha located in UP, it was found that in Mentha Arvensis the total range of fluoride content was around 82.9 µg F^{-1} g^{-1}. A case study byJha et al. (2008) found about various fluoride levels of Cereals in Kolkata, where wheat had a contamination of around 5.9 µg g^{-1}, no fluoride was found in rice and around 5.6 µg g^{-1} amount of fluoride was found in maize. According to Lakdawala and Punekar (1973) a study in the capital of State Maharashtra, Mumbai, various fluoride levels were found in various vegetables (Table 3): in cucumber around 2.57–3.58 µg g^{-1}. In snake gourd around

Table 3 Fluoride concentration in different crops in other states of India

State	Vegetables or cereal crop	Concentration of fluoride	References
Birbhum District, West Bengal	Mustard	F_{Total} = 4.19–4.61(mg/kg) F_{Water} = 0.79- 0.95(mg/kg)	Gupta and Banerjee (2011)
Parsandan, Unnao District Uttar Pradesh	*Spinacea oleracea*	19.4–25.2 (mg/kg)	Jha et al. (2011a; b)
Gaya District, Bihar	Wheat	2.14–11.62 (mg/kg)	Ranjan and Yasmin (2015)
Bankura, West Bengal	Spinacea oleracea	4.5 ± 1.1(mg/kg)	Bhattacharya et al. (2017)
Talupula, Anantapur District, Andhra Pradesh	Arachishypogaea	7.5 ± 0.5 ppm	Nagaraju et al. (2017)
Mathura, Uttar Pradesh	Potato	1.662 (ppm) (SD)	Arora and Bhateja (2014)
Birbhum District, West Bengal	Paddy	79.00–82.66(mg/kg)	Bhattacharya et al. (2017)

2.16–3.44 µg g^{-1} amount of contamination was discovered. In Palamu a district in Jharkand it was found that the level of fluoride in the pulses was around 1.46–2.28 µg g^{-1} and also around 1.50–1.78 µg g^{-1} amount was found in cereals (Srikanth et al. 2008). In districts of Dhar and Jhabua a research by (MP.pdf) it was found that wheat had 0.75–9.02 µg g^{-1} and rice had around 0.51–5.52 µg g^{-1}', which is clearly more than the prescribed level (Ramteke et al. 2007).

Arsenic contamination and its impact in agriculture

Arsenic contamination scenario in India

Arsenic abundance in groundwater might be the natural contaminant but due to this issue countries like India, Argentina, Nicaragua, Chile, Spain, Mexico and Peru are having arsenic contamination above 10 µg/l which exceeds the allowable limit as per the World Health Organization (Saldaña-Robles et al. 2018). The study says that people living in rural areas of the country are at risk from arsenic contamination levels by drinking polluted groundwater in India, China, Nepal, Pakistan, Cambodia, Myanmar, and Vietnam which is affecting more than 100 million individuals. In India there are more than 10 States which have elevated levels of arsenic contamination in groundwater. Arsenic contamination in groundwater was first found in West Bengal (Das et al. 1996; Kumar and Singh 2020) and then in the states of North-East which includes Assam (Nath 2015), Manipur (Chandrashekhar et al. 2016), Arunachal Pradesh (Singh 2004), Tripura (Banerjee et al. 2011), Nagaland (Baruah et al. 2003; Oinam et al. 2012a, b). In north India the polluted springs are at the foot of the Himalayas in the terai region. It can also be seen in the Kathmandu basin. In Chhattisgarh, India, the polluted groundwater is in residue which originally came from volcanic rocks (Brammer 2008; Patel et al. 2005). Arsenic affected areas which are also known as hot spots are shown in the Fig. 3 below. Water samples mostly collected from ground water or wells are observed and analysed and the map has been prepared from this collected data which shows arsenic contamination in different states. Arsenic polluted areas have been shown on the analytical results of the Central Ground Water Board. The figure shows the contaminated area in the range 0.01 to 0.05 mg/l and more than 0.05 mg/l.

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Guha et al. (2012) carried out evaluation of arsenic pollution in groundwater in two affected blocks of West Bengal, India. The aim was to calculate the arsenic concentration in groundwater. There were a total of 15 blocks from which 5 blocks are prone to arsenic contamination. So out of these two blocks, 6 villages were selected, two from each category of low, medium, high which was given by public health and engineering directorate (PHED). Samples were taken from the tube well and it was found that the arsenic pollution was in the range of 0.01–0.10 mg/l which is very high from the permissible limit of WHO that is 0.01 mg/l and 0.05 mg/l, which is allowable limit as prescribed by our country. People are suffering from skin-related diseases by drinking this water,as it is unfit for drinking purposes.

Singh et al. (2013) carried out evaluation of arsenic polluted drinking water in Ballia district, Uttar Pradesh. The main aim was to study the effect of arsenic polluted water on the human chromosome. In this district the arsenic concentration in drinking water was around 0.37 ppm. 30 people were selected which includes 13 male and 17 female and took their blood sample to find the issue related to arsenic. It was found that out of 30 individuals, 20 people were suffering from keratosis, nine of them have pigmentation on limb, chest and tongue and two samples show Klinefelter syndrome.

Tamuli et al. (2017) carried out evaluation of arsenic contamination in Jorhat district of Assam. The aim was to find the occurrence of arsenicosis in drinking water.

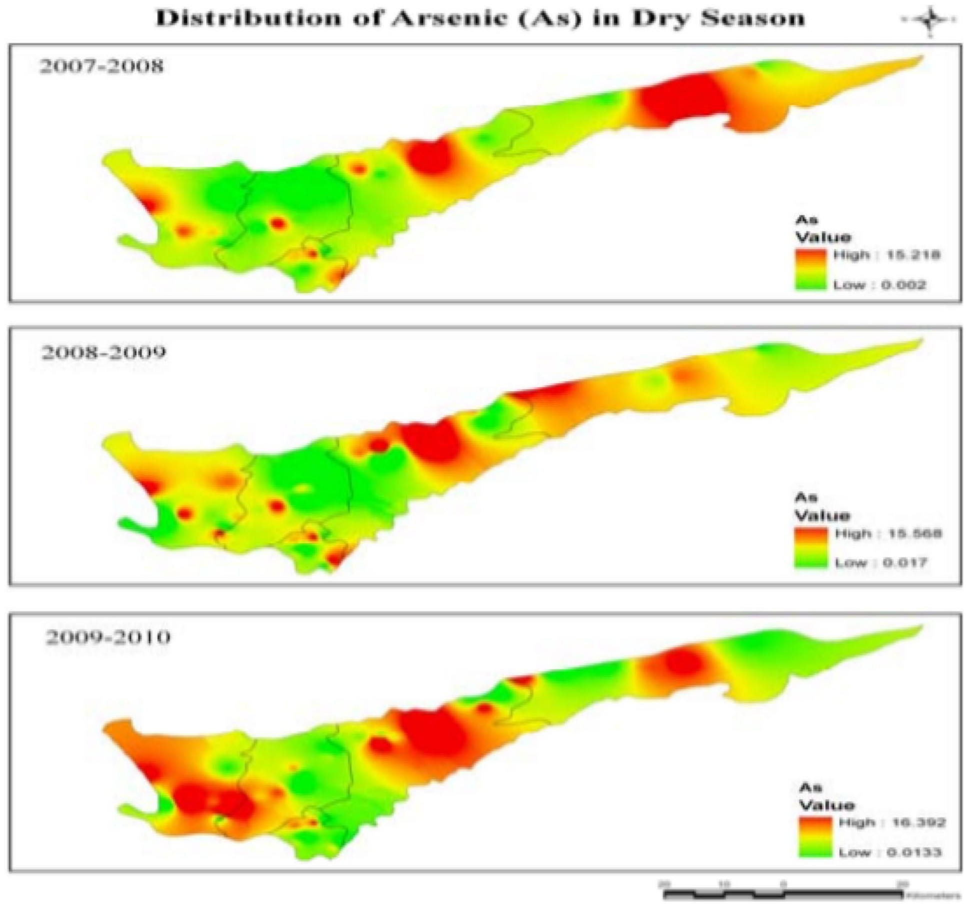

Fig. 3 Distribution of arsenic in dry season

In this study 30 groups were selected which includes 780 individuals using probability proportional to size (PPS) formula. 30 samples of groundwater were collected from each group and were tested by public health and engineering directorate (PHED) for arsenic contamination. Eighty-nine people were suspected with the arsenicosis out of which three people were confirmed as having arsenicosis and 86 people were tested by dermatologist. In this study it was found that the occurrence of arsenicosis from the selected groups is $0.38 \pm 0.019\%$. In the water sample the average concentration was found to be 66.9 µg/l. So high arsenicosis cases and elevated levels of arsenic in drinking water indicate that this polluted drinking water is the main reason behind arsenicosis amongst the people.

Mazumder et al. (2010) carried out a survey on groundwater pollution of arsenic in villages of Nadia, West Bengal. The aim was to carry out a home to home survey of arsenic contaminated villages. 2297 houses in 17 blocks of total 37 villages were surveyed, in which 10,469 people were tested and it was found that the prevalence rate of arsenicosis is 15.43%. It was expected that 0.84 million individuals were exposed to arsenicosis, but nearly 0.14 million individuals are exposed to arsenicosis. The elevated level of arsenic concentration in water which is used for drinking purposes was 1362 µg/l. In Nadia, many people have developed skin-related diseases and the main reason for this is poverty, lack of awareness regarding health and also lack of education.

Bhattacharjee et al. (2005) carried out evaluation of contamination of groundwater using different metal content in Sahebgunj district, Jharkhand. The aim was to survey for different metal content like calcium, iron, zinc, copper including arsenic. Nine blocks of Sahebgunj district were examined. Water samples were collected from each block and were studied. A total 1535 water samples were collected out of which 1317 were from tube wells and 218 were from wells. In this study three blocks of the district which are Sahebgunj, Rajmahal and Udhawa have elevated levels of arsenic concentration in groundwater which is more than 10 ppb and also Sahebgunj has high concentrations of iron and manganese. Water sample data of two other blocks, namely Taljhari and Pathna block have less arsenic concentration but tube wells of these places would require monitoring to prevent from arsenic contamination and its impact.

Bhatia et al. (2014) carried out evaluation of drinking water in Khap Tola village of Bihar. The main aim was to examine hand pump drinking water and to collect data of arsenic contamination. In this study they have selected a total 20 hand pumps in the village out of which 14 are

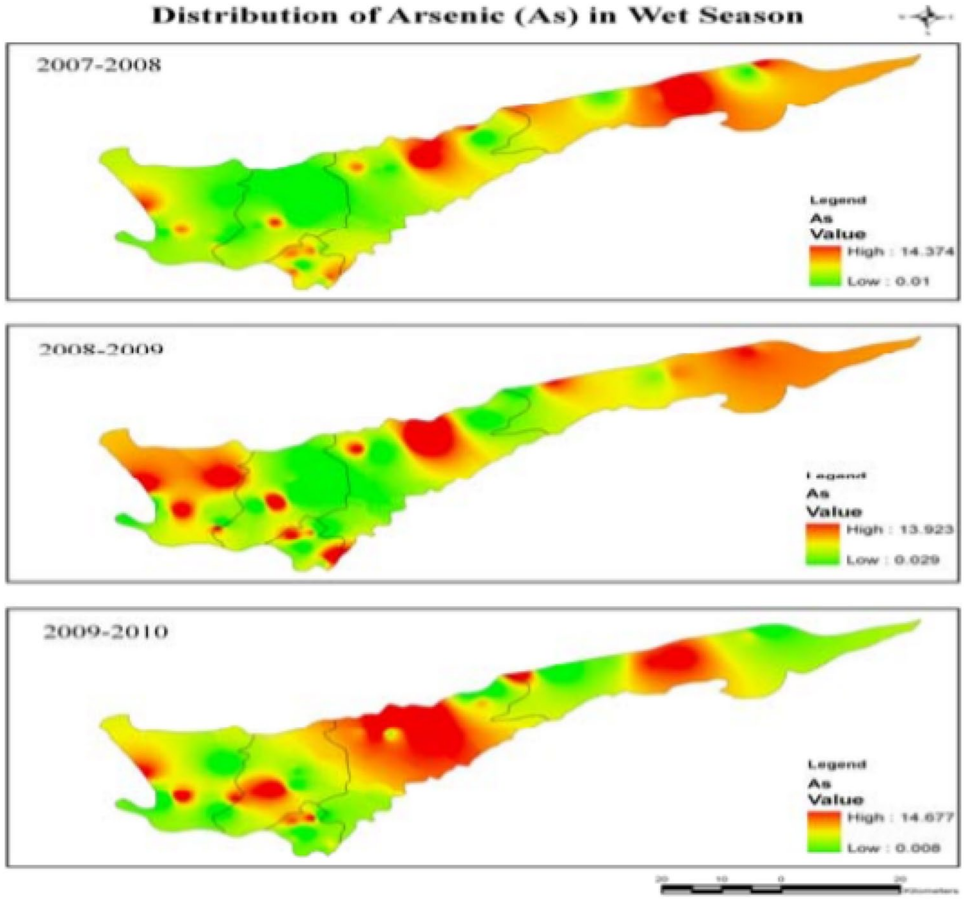

Fig. 4 Distribution of arsenic in wet season

private and remaining 6 are of government. Water samples from all the hand pumps were taken and examined to find arsenic contamination. It was found that all the samples were tested positive for arsenic contamination. Many samples had arsenic contamination more than 10 ppb which is permissible level of WHO and many other samples had arsenic contamination more than 50 ppb limit of BIS. Out of all the samples the maximum value recorded was 397 ppb. It indicates that the hand pump drinking water of Khap Tola has very high arsenic contamination.

Wu et al. (2020) carried out assessment of groundwater arsenic contamination in Gujarat, India. The aim was to find out arsenic contamination throughout Gujarat using geostatistical models. In 2015, central ground water board of India conducted surveys to obtain arsenic contamination in groundwater. They collected a total of 599 water samples from bore and tube wells. Out of these samples, 183 were not analysed and further 18 samples were examined due to insufficient information. 398 samples were analysed and it showed that 6% samples have arsenic contamination more than 10 µg/l. One of the samples recorded as 26 µg/l which is the highest of the state. In Gujarat Approximately 49,000 individuals living in rural areas and using bore wells or hand pump water are exposed to elevated levels of arsenic polluted groundwater and people are also affected from arsenic which includes prevalence of 670 people suffering from skin cancer.

Buragohain and Sarma (2012) carried out assessment of arsenic pollution in groundwater of Dhemaji district, Assam. The main aim was to examine arsenic pollution in five parts of Dhemaji district. 40 groundwater samples from tube and ring wells and also through public water supplies were collected for a duration of 3 years to analyse change in arsenic concentration. It was found that ground water of Dhemaji falls under critical conditions as some of the samples are exceeding WHO limit of 0.01 ppm and some of the samples which are collected from the foothills are very toxic. The GIS map of groundwater contamination by arsenic is shown in the Fig. 4 below. The flow of groundwater is in the direction of north to south. Year- and seasonwise distribution of arsenic is shown and it can be seen that in dry season arsenic contamination can be seen more in the south side, whereas during wet season arsenic contamination is more in the north side. More research towards contamination of water should be done and also the government should take arsenic into consideration while making investments related to water.

Acharyya et al. (2005) carried out assessment of groundwater arsenic pollution in Ambagarh chowki area,

Table 4 Arsenic concentration in different states or areas of India

State	Study area	Concentration of Arsenic(mg/L)	References
West Bengal	Ramnagar–Dhapdhapi area of Baruipur, West Bengal	> 0.05 mg/L	Pal et al. (2002)
West Bengal	Murshidabad, West Bengal, India. Samples from 35 wells were collected and examined	12–129 µg/L	Farooq et al. (2011)
Jharkhand	Ranchi city, Jharkhand, India. Samples were collected from 44 places during three seasons	0–0.015 mg/L	Tirkey et al. (2016)
Bihar	Groundwater contamination in five blocks of Patna, Bihar. 1365 tube-well samples were collected and examined	61% sample > 10 µg/L 44% sample > 50 µg/L 10.3% sample > 300 µg/L	Chakraborti et al. (2016)
West Bengal	South 24 Parganas, West Bengal. Water samples were collected for 3 years during winter, summer and monsoon	Monsoon: 906 µg/L Summer: 694 µg/L	Penland and Black (2015)
Uttar Pradesh	245 water samples were collected from tube and dug wells of Varanasi, Ghazipur and Mirzapur	60% sample > 10 µg/L 20% sample > 50 µg/L Maximum arsenic Singhaour village:- 180 µg/L	Shah (2010)
Assam	Groundwater contamination in Silchar, Assam. 60 water samples were collected from 30 sites before and after monsoon	27% sample: 0–10 mg/l 18% sample: 51– 100 mg/l 3% sample > 100 mg/l Pre and post monsoon recorded 181 and 161 mg/l	Kanungo (2016)
Chhattisgarh	Rajnandgaon District, Chhattisgarh. 20 water samples were collected from this region	148–985 mg/l	Patel et al. (2017a; b)
Bihar	Middle-Gangetic Plain, Bihar, India. Water samples from different location were collected and examined	Vaishali: 21 mg/l Bhagalpur: 599 mg/l Siwan: 150 mg/l Nautan: 397 mg/l Samastipur: 60 mg/l	Singh (2015)
West Bengal	Purbasthali, Burdwan district, West Bengal. Water samples were collected from 20 different tube wells	0.5–135 mg/l	Nag et al. (1996)
Manipur	628 water samples from 4 districts of Manipur were collected and examined	63.3% sample > 10 mg/l 23.2% sample: 10–50 mg/l 40% sample > 50 mg/l	Chakraborti et al. (2008)
Delhi	49 groundwater samples were collected from different location in Delhi	0.0170 ppm (Raney well no.7) to 0.100 ppm (Kotla Mubarak pur)	Lalwani et al. (2004)

Chhattisgarh, India. The main aim was to examine groundwater and to find out arsenic concentration in Dongargarh rift zone. Groundwater samples from 150 dug wells and 640 tube wells were collected and were examined by NEERI. It was found that four villages are severely affected by arsenic contamination, namely Kaurikasa, Joratarai, Jadutola and Sonsayatola. Many dug wells showed arsenic contamination more than 50 µg/l and few show contamination less than 10 µg/l. Dug well water in these affected areas have arsenic contamination ≤ 10 µg/l but tube and dug wells of kaurikasa area are very contaminated. Volcanic rocks in Dongargarh rift zone contain sulphide, especially pyrites and oxidation of these pyrites is the main reason behind arsenic pollution in groundwater.

Rahaman et al. (2013) carried out evaluation of groundwater arsenic pollution in Malda district, West Bengal, India. The main aim was to calculate the arsenic concentration in groundwater. This study includes five blocks under Malda district and samples were collected from these blocks. It was found that the arsenic pollution lies in between 0.41 and 1.01 mg/l which is more than the allowable limit of WHO for drinking water which is 0.01 mg/l. In groundwater the average agglomeration of arsenic ranged from 0.623 to 0.851 mg/l.; therefore, consuming this arsenic contaminated water might cause skin related disease to humans and animals in future (Table 4).

Arsenic contamination scenario in agriculture in India

Arsenic polluted groundwater is widely utilized for agricultural purpose. Toxic Arsenic is transmitted to the various plant body from soil which is being irrigated with arsenic rich water (Fields et al. 2007; Neidhardt et al. 2012; van Geen et al. 2006). Arsenic Pollution in the groundwater is a very common issue in India many districts use groundwater for drinking and irrigation purpose which might pose a danger. West Bengal and Bangladesh use groundwater for 80% of their irrigation purpose. It comes from springs between ca 20 and 120 m in youthful alluvial residue. The maximum allowable limit set by World Health Organization for arsenic concentration in water used for drinking purpose is 0.01 mg/L and maximum allowable limit set by FAO for arsenic concentration in water used for agricultural purpose is 0.10 mg/L (Ahsan and del Valls 2011; Bhattacharya et al. 2009; Shrivastava et al. 2014). The limit of arsenic contamination in non-polluted soil range is from 0.1 to 10 mg/Kg (Pether 1949; Shrivastava et al. 2014). In Gangetic fields of Uttar Pradesh, Bihar and Jharkhand high arsenic was noticed in groundwater. Arsenic could be really harmful component in the nature it is liable for the most elevated risk of mortality around the world due to its toxicity and individuals exposed to it (Shrivastava et al. 2014). The topographical review of India and the Central Ground Water Board examined the origin of arsenic in groundwater. As per them the current drainage system of Ganga–Brahmaputra causes sedimentation in West Bengal. Coal fields can be one of the sources for arsenic (Dey et al. 2014; Santra 2017).

Let us look at some of the cases for agriculture contamination in India due to arsenic.

Rahaman et al. (2013) carried out evaluation of Arsenic contamination in Malda district located in West Bengal in India with the aim to evaluate the impact on agriculture due to the arsenic-rich water used for irrigation. Some areas are selected and samples were taken for study. Different crop samples were collected which are grown on the basis of groundwater availability throughout the year. Also water samples from different depth of tube wells were taken. The arsenic contaminants were found in range from 0.623 to 0.851 mg/l which exceeds the allowable limit for irrigation. After a deep observation it was found that the arsenic concentration varies season to season. It is lowest in September and highest in April depending on the water requirement and type of crop cultivated. It was concluded that arsenic-rich groundwater was the only source of water which was used for irrigation and if continued it may cause harm to sustainable agriculture.

Kumar and Singh (2020) carried out research on arsenic contamination present in Ravi, Sutlej and Beas Rivers which are the tributaries of Indus river. The samples were taken from Amritsar and Taran district of Punjab. About 73 groundwater samples were taken from different wells and analysed. The mean Arsenic content found was 16.44 μg/l which is very high as per the WHO limit along with other toxic metals and major anions. Since these rivers are major source for irrigation and drinking water, the presence of arsenic causes major problems to human along with crops. With heavy use of pesticides and fertilizers it results in destabilizing the aquifers and increases carcinogenic.

Jain et al. (2018) carried out evaluation of arsenic contamination in Barpeta district located in Assam near river Brahmaputra. The main aim of the study was to calculate level of arsenic in irrigation and drinking water. Fifty groundwater samples were collected before monsoon and briefly analysed. It was found that some samples are above the permissible limit while some are not. Some samples contain arsenic greater than 500 μg/l. In the use of agriculture the fertilizers and pesticides contain arsenic. However, it was highly advised not to use arsenic contaminated water for agriculture, drinking and for preparing food at home.

Roychowdhury et al. (2005) examined arsenic contaminents from two gram panchayets located in district Murshidabad, West Bengal. The aim was to research and analyse plant contamination by arsenic by groundwater. Various plant, groundwater and soil samples were collected and analysed. It was discovered that the average amount of arsenic deposited annually from shallow tube wells on land was 5.02 kg ha^{-1}. The process through which roots of plants take up poisonous arsenic that is present in soil and water. After being consumed by humans and animals, it will move up the food chain, which is dangerous. Green leafy veggies were discovered to contain a high quantity of arsenic. Lack of proper groundwater withdrawal causes the groundwater table and arsenic content to rise. The abundance of rainfall in West Bengal and Bangladesh creates lakes, wetlands, and reservoirs of sweet water that may be used for agriculture, drinking water, and cooking while lowering the amount of eaten arsenic. Rahman et al. (2003) examined the arsenic contamination for about 7 years located in West Bengal state, district North 24-Parganas which was counted as one of the exceptionally arsenic influenced zone. The objective of research was to find the level of arsenic, people affected by it, effect on crops irrigated with arsenic rich water and its harmful effect. A total of 48,030 water samples were gathered from tube wells, and samples of other crops, including rice and vegetables, were also taken and examined. The arsenic content of the land, on which these crops were grown using arsenic-contaminated water, was discovered to be between 103 and 827 μg/l. Additionally, the average arsenic concentration of vegetables was 0.027 μg/g, while that of rice was estimated to be 0.323 μg/g. According to this average person living there consumes 100 μg arsenic per day through vegetables and rice which is very harmful to human. Since West Bengal is a source of rainfall water, proper storage of rainwater should be facilitated and used for irrigation.

Yadav et al. (2020) estimate the concentration of arsenic in the Chhattisgarh district of Rajnandgaon's Ambagarh Tehsil. In a brief analysis of the material and statistics, the paper discusses the effects of arsenic and other dangerous metals found in water on plants, food, and drinking water. Different villages' soil, water, plant, and animal stool samples were gathered. Arsenic level was discovered to be lower in surface water (0.017–0.048 μg/l) than groundwater (0.187–0.582 μg/l), along with other heavy metals.Arsenic levels in plant samples ranged from 0.3–27 mg kg^{-1}. Vigna unguiculata, sometimes known as cowpea, had a maximum arsenic level of 27 mg kg^{-1} which was significantly higher than the permitted limit of (1.0 mg kg^{-1}) (World Health Organisation WHO 1998) and consumption of it is harmful.

Srivastava and Sharma (2013) evaluated the arsenic contamination in villages of Ballia and Ghazipur district in eastern parts of Uttar Pradesh, India. The main goal was to quantify the amount of arsenic in the soil and water and educate the public about the need for appropriate safety precautions. Samples of water from tube wells, hand pump and deep boring from different villages were examined. The findings of the analysis show that groundwater had an arsenic concentration that ranged from 43.75 to 620.75 ppb, which is considerably high compared to the WHO standard of 10 ppb. Additionally, it was discovered in soil at levels of 5.40 to 15.43 ppm, which was extremely hazardous and detrimental to plants like spinach, cabbage, rice, beans, and others. The arsenic-rich water used for irrigation for years has increased arsenic content in soil and made plants and vegetables toxic and unfit for consumption. People should be educated regarding arsenic toxicity and its effect on growth and productivity of crop.

Rahaman et al. (2011) carried out the groundwater survey on level of toxic arsenic present in Jalalpur village located in West Bengal, India. The aim of this survey was to find methods for reduction of levels of arsenic concentration in rice by different ponding pattern of arsenic-rich groundwater for irrigation. Samples of various types of water, soils, and plants were taken and examined. The concentration of arsenic in the root, leaf, and shoot was higher during the panicle initiation stage than it was during harvest. In comparison to continuous ponding, intermediate or saturation ponding causes 1.5–1.7 kg/ha less hazardous arsenic to infiltrate fields and rice crops. Use of organic nutrients like vermicompost and poultry manure has shown significant reduction in level of arsenic in roots, shoot and leaf by 35%–40%. It was found that rice grains showed 0.70–1.67 mg/kg of arsenic contamination which was greater than maximum allowable limit of WHO. In rice crop, the degree of arsenic content is highest in roots followed by straw, husk and whole grain and lowest in milled grain.

Kumar et al. (2016a, b) conducted a research on arsenic contamination in Samastipur district located in Northern part of Bihar, India. The objective behind these survey was to calculate the arsenic content present in water, agriculture soil and inorganic characteristic of As. Nine groundwater and agriculture soil samples were gathered from various territories and studied. Rice, wheat, corn are the plants which are grown there using groundwater of irrigation The crops farmed there with arsenic-contaminated irrigation groundwater include rice, wheat, and maize. The total amount of arsenic in groundwater ranged from 1.3 to 104.7 μg/l, and the mean value was 20 μg/l, which is extremely dangerous and over the allowable limit for drinking purposes. Similar to arsenic, farm soil has between 3527 and 14,690 μg/kg of it, making it extremely dangerous for growing any crops there.

Farooq et al. (2019) carried out research in Kaliachak block located in West Bengal, district Malda. In this paper, the focus was on arsenic concentration in two different agricultural lands with two different crops been irrigated with arsenic-rich water. Two main crops are paddy and wheat. Twenty-nine different water samples from tube wells were taken and analysed. The content of arsenic in groundwater used for irrigation in paddy and wheat crop was 137 μg/l and 67.3 μg/l, respectively. After thorough investigation, it was discovered that the arsenic levels in 29 samples ranged from 2–850 μg/l. The amount of arsenic in several components of wheat and paddy crops, including the root, stem, leaf, and grain, was also examined. For wheat and paddy plants, roots had the greatest arsenic concentrations (4.82 mg/kg and 40.3 mg/kg, respectively). Thus level of arsenic concentration and its mechanism were different in both the plants (Table 5).

Challenges and future scopes

There are as of now two discovered routes through which fluoride is contaminating the groundwater, which are hydrogeological process and anthropogenic inputs (Handa 1975; Saxena and Ahmed 2003) mechanism noticed that hydroxyl ions were taking place of fluoride ions (Edmunds and Smedley 2005; Hem 1985). We can find fluoride a lot in the groundwater and that's mainly because of high amount of sodium ions and bicarbonate ions at higher pH (Dey et al. 2012; Guo et al. 2007; Saxena and Ahmed 2001). Leaching and adsorption process are the main processes for Fluoride migration from soil to water (Young et al. 2011). Plant do not generally uptake fluoride from the salt as really less amount of fluoride is soluble in soil. Many fluoride compounds are absorbed in the clay and oxy-hydroxide in the alkaline environment, among which very few are thoroughly mixed in the soil (Hong et al. 2016). In India many mitigation programs for fluoride were announced and many of them have been doing well, whereas the fluorosis awareness programs and drinking water program are spreading wide knowledge about the harmful effects of fluoride in their daily life. Due to this many households are a bit worried and have installed reverse osmosis(RO)-based point of use (POU) water purifiers to treat their water. Maintenance cost, steep installation prices and high skilled labor have an effect and limit the use of these equipments in developing countries like India.

Table 5 Arsenic concentration in different crops in other states of India

State	Vegetables or cereal crops	Concentration of arsenic	References
Jalangi and Domkal block, Murshidabad district, West Bengal	Wheat And Rice	7–362 mg/kg and 226.18–245.39 mg/kg,	Roychowdhury et al. (2002)
Ropar wetland, Punjab	Wheat grian	0.03–0.21 mg/kg	Sharma et al. (2016)
Nadia District, West Bengal	Wheat grain	0.23–1.22 mg/kg	Kundu et al. (2013)
Manipur valley	Rice grain	0.11–0.19 mg/kg	Chandrashekhar et al. (2016)
Bathinda district, Punjab	Rice grain	0–0.12 mg/kg	Sharma et al. (2020)
Hariharpar and Raninagar block, Murshidabad district, West Bengal	Rice grain	2.45–3.24 mg/kg	Hossain et al. (2015)
Chhattisgarh	Rice grain	18–446 μg/kg	Patel et al. (2005)
Patna district, Bihar	Rice grain, wheat, maize and lentil	(0.019, 0.024, 0.011 and 0.015) mg/kg	Singh and Ghosh (2011)
North 24 Pargana district, West Bengal	Boro and Aman rice	0.439 ± 0.124 mg/kg and 0.265 ± 0.089 mg/kg	Pal et al. (2009)
Samastipur district, Bihar	Vegetables, rice and wheat	(37–3947) μg/kg, (2.51–132) μg/kg and (7.7–108) μg/kg	Kumar et al. (2016a, b)

Government of India alongside many different NGOs and also UNICEF is trying to tackle the issue of Fluorosis as people in Rural India are not able to afford these types of purifiers and they consume and use the groundwater which is really harmful for them. Defluorination units are also unable to attach everywhere due to budgetary restrictions. The sole treatment for fluorosis is safeguarding the groundwater (Dubey et al. 2018).

There are many techniques available to tackle the excess fluoride in the groundwater, some of these are being used currently and some of them are the new future. Let us discuss some of the techniques below-

Adsorption Method, there are three following mediums which are used as the medium in the adsorption method: bone char, activated carbon, activated alumina each has F^- uptake capacity of 95%, 90%, 85–95%, respectively. The main advantage of this method is its cost-efficient and high removal capacity. The main impact or benefit of this process is that it makes and produces really less sludge or waste material when it's been treated (Mukherjee and Singh 2018). The development of nanotechnology and its numerous potential applications make it a joy for researchers to work on, and as a result, they have begun to work on the purification of contaminated water. Nanotechnology is the future in many disciplines, including defluoridation procedures. One such technique that is currently being developed is the adsorption of fluoride by nano-MGO under the effect of OH ions. In the future these techniques will be more widely acknowledged (Yadav et al. 2018).

Arsenic is natural or may be partly generated from anthropogenic practices such as intensive groundwater extraction, fertilizer application, coal burning and coal-ash metal leaching. Arsenic might occur in some two hundred minerals in varied forms as elementalarsenites, arsenic, sulphides, arsenides, oxides and arsenates. Arsenic occurs naturally in the atmosphere and, as it interacts with various elements such as oxygen, sulphur and halogen, it is converted to inorganic arsenic compounds. It is used mainly in agriculture, medicine and metallurgy. The high level of arsenic, especially in iron oxides, is found in metal oxides and sulphide minerals. The problem of arsenic pollution will occur in areas where these minerals are abundant only if the geochemical conditions favor the discharge of arsenic from these minerals. A few studies have indicated that groundwater arsenic contamination is typically confined to the Ganges delta alluvial springs, including sediments transported from Bihar's sulfide-rich mineralized regions. Research has shown that the vast portion of Indo-Gangetic alluvium extending further west and Brahmaputra alluvium has increased arsenic groups in wells placed in the late Quaternary and Holocene springs (Bhattacharya et al. 1997; Chatterjee et al. 1995). Major supply of arsenic in groundwater is of geogenic origin and is elaborately connected to the geological formation system and groundwater flow regime. The mitigation steps include various types of options, ranging from extracting arsenic from groundwater until it is removed and then looking at different aquifers, reducing the amount inside the geological structure itself, diluting the pollutants through artificial recharge, mixing with drinking water, etc. (Ghosh and Singh 2009).

Innovative choices to fight against arsenic hazard in groundwater and to guarantee supply of arsenic free water in the influenced region is done by several methods and they are as follows:

The strongest technical possibility is the in situ rectification of arsenic from groundwater or the reduction of groundwater pollution. However, due to the size of the set up and also the lack of full understanding of the physico-chemical and geochemical processes and behaviour of groundwater, in-situ rectification of arsenic polluted groundwater would be terribly costly and a challenging task.

Ex-situ rectification of arsenic from tapped groundwater appears to be a temporary solution for providing potable arsenic free groundwater for domestic use by suitable removal technologies. However, in order to provide irrigation water, this can prove valuable and unsustainable. Ex-situ methods will extract arsenic from tapped groundwater, but arsenic from the aquifers will not be able to be extracted. The main purpose of this method is to lower the arsenic content until water is drained from aquifers. The following measures for this methodology have been implemented.

Precipitation process:

This method includes coagulation/filtration, direct filtration, microfiltration, lime softening. Sorption co-precipitation with hydrolysing metals like Al3 + and Fe3 + is widely used for removing arsenic from water.

Ion exchange processes:

In these processes, on the surface of a solid section area unit, ions are electrostatically regulated and exchanged for ions of comparable charge dissolved in water. Usually, as a solid, an artificial ion exchange organic compound is used. The exchange of ions only eliminates charged As (V) molecules. If As (III) is present, it must be oxidised.

Solar oxidation and removal of arsenic (SORAS):

This approach uses daylight water irradiation in PET or various transparent ultraviolet radiation bottles to scale back the amount of arsenic from drinking water (Wegelin et al. 2000). The strategy is based on the chemical reaction of As(III) followed by adsorbable As(V) precipitation or filtration on Fe(III) oxides.

Iron oxide coated sand (IOCS):

The technique of arsenic removal by iron oxide coated sand (IOCS) adsorption has been developed by UNESCO-IHE. It is a byproduct of treatment plants for groundwater and is very inexpensive. This scheme is cost-effective for As(III) and As (V).

· Additionally, the provision of arsenic free groundwater by alternative healthy aquifers may prove to be a reasonable proposition. In addition, this has been studied in many fields and extensive studies and mapping will be required to find groundwater distribution.

Conclusion

We present a comparative study of arsenic and fluoride contamination of groundwater from different parts of India and its harmful impacts. It was noticed that the groundwater contaminated with arsenic was mainly seen in North and Northeast states of India while groundwater in many areas of Rajasthan and Gujarat are highly contaminated with fluorine. This contamination of water bodies is due to anthropogenic activities which include industrial effluents, agricultural activities, mineral processing, combustion of fossils and also natural activities like weathering of rocks, dissolution of minerals in groundwater, melting of snow etc. contributes for the contamination of groundwater. Overexploitation and poor management of the groundwater for day to day needs of irrigation and drinking purposes have led to a rise in level of arsenic and fluorine in soil, crops and water which results it in entering the food chain causing various skin diseases and cancer to one who consumes it. Proper watershed management systems should be installed for safe drinking water and more people should be educated regarding toxicity of arsenic and fluorine. Use of these contaminants free water for drinking can minimize the risk of harmful toxicity to the people who are affected by it. To remediate the groundwater with high fluoride and arseniccontamination, various techniques are adopted. They include ion exchange, adsorption, coagulation and precipitation, electrodialysis and reverse osmosis. Out of which reverse osmosis comes out to be the best available method. Onsite treatment includes artificial recharge methods such as constructing dams, percolation ponds, recharge of rain water through existing wells, etc. It was seen that the groundwater of deeper aquifer has low level of contamination, so water from this aquifer can be used in certain areas where there is no other source of water and also rain water harvesting can be done. People should adopt these certain measures to prevent using of contaminated groundwater.

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Conflict of interest The authors declare that they have no competing interests.

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