CHAPTER-1

INTRODUCTION

1.0 INTRODUCTION

1.1 Water: A basic natural resource

The basic natural resource available in abundance on the earth for sustaining life and environment is “water”. In day to day life, water is one of the most essential commodities for living creature on earth (CPCB, 2008). Water plays an important role in the world economy, as it functions as a solvent for a wide variety of chemical substances and facilitates industrial cooling and transportation. Hence, development of this natural resource plays a crucial role in economic and social development processes. According to statistics, 70.9% of the Earth's surface is covered by water and is vital for all known forms of life. On Earth, 96.5% of the planet's water is found in oceans, 0.9% is available in other saline sources and only 2.5% of the available water is fresh water. Out of this available fresh water 30.1% is available as groundwater, 1.2% as surface or other freshwater and the rest 68.7% is as glaciers and ice caps (Gleick, 1993). Furthermore, a division of the freshwater as surface or other sources is shown in Figure 1.1.

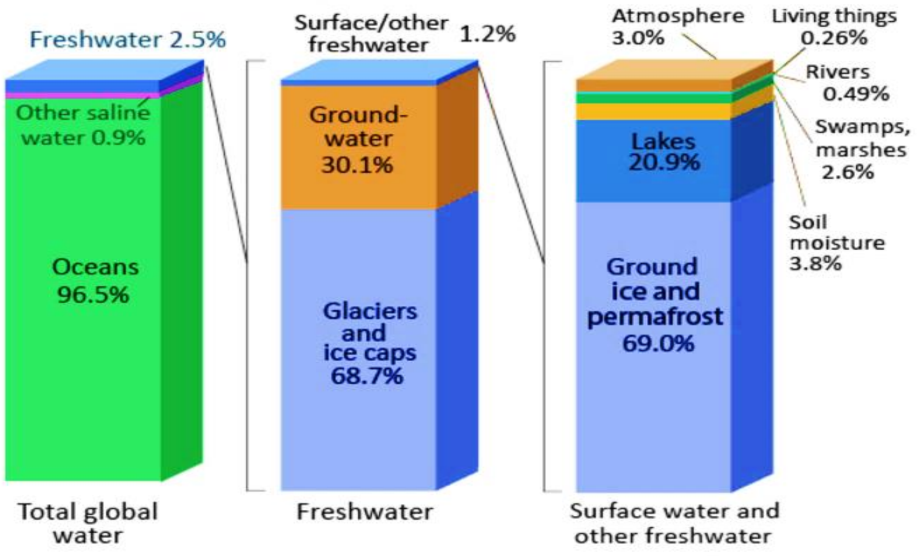

Figure 1.1: Water on earth

Although groundwater contributes only 0.6% among the total water resources on earth, this is the preferred and cheapest source of drinking water in rural as well as urban areas. In developing countries like India, groundwater is the major source of drinking water because disinfection is often not required. Groundwater caters to around 80% of the domestic water requirements. In urban areas, about 50% of the demand is met from ground water sources. Similarly in rural areas, more than 50 percent of irrigation and agricultural requirements come from this source (Srivastava et al., 2017).

1.2 Safe water for drinking

Safe drinking water is prime necessity for humans and other forms of life. Kulshreshtha (1998) forecasted that half of the world population will be facing water-based vulnerability problem by 2025. Azizullah et al. (2011) forecasted that two thirds of the world's population will face “moderate or severe water shortages” by 2025. According to UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS, 2017) 2.4 billion people are living without access to improved sanitation facilities, and nearly 700 million people are not receiving their drinking-water from improved water sources. Recently WHO reported that although significant improvements have been made in the area of availability of safe drinking water over the last decades across the globe, still two billion people are not able to avail safe drinking water and over 3.6 billion lacks access to adequate sanitation (WHO/UNICEF, 2021).

Even in plentiful water supply areas, people are increasingly at risk from pollution. The local geological conditions greatly affect the composition of groundwater. To avoid the negative effect of contaminants on human beings, it is imperative to maintain the required quality for drinking waters.

1.3 Groundwater

Groundwater meets drinking water requirement for a large population in India. Around 95% of the rural population and 30 to 40% of urban population in India depend on groundwater for their daily requirements (Ranjan et al., 2020). Many times, however inorganic chemicals and microorganisms contaminate the groundwater rendering them unfit for drinking. Due to complex flow regime, groundwater passes through various geological formations leading to contamination of shallow aquifers (Anwar et al., 2003). Arsenic, fluoride and iron are the commonly observed contaminants which are geogenic in nature. Contaminants such as nitrate, phosphate, heavy metals etc. owe their origin to various human activities. In our modern times, industrialization, urbanization and increase in population have led to fast degradation of our groundwater quality (Villa et al., 2010). The following diagram (Figure 1.2) depicts the probable cause of deterioration of groundwater quality (CGWB, 2018).

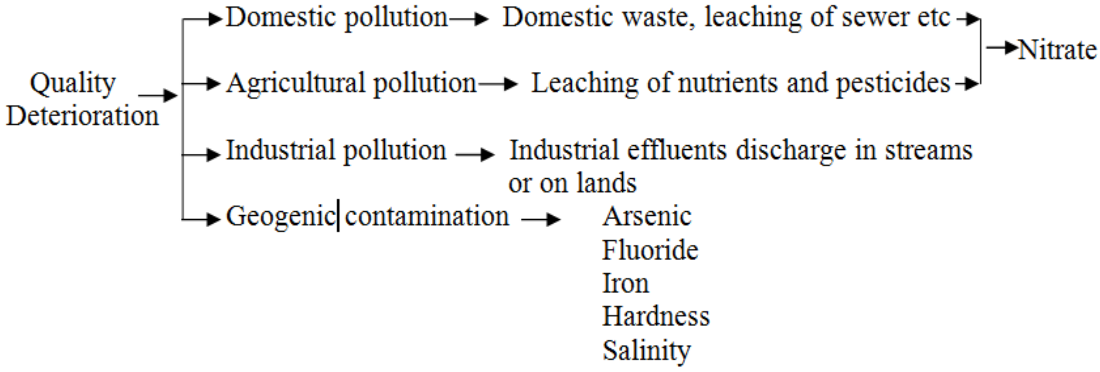

Figure 1.2: Quality deterioration of groundwater

1.4 Contamination of groundwater

There are severe economic and human health related impacts of contaminated groundwater which are diagnosed as worldwide problem (WHO, 2002). Dissolved chemical constituents such as nitrate (NO_3^-), fluoride (F^-) and arsenic (As (III) or As (V)) and other heavy metals are important constituents of such contaminations.

1.4.1 Nitrate contamination of groundwater

Over use of fertilizers to obtain greater crop yield has triggered excessive nutrient loads in soil, groundwater, and surface water of agricultural regions (Volk et al., 2009; Kundu et al., 2009). The use of large quantities of nitrogenous fertilizers leads to the nitrate (NO_3^-) contamination of groundwater; hence intensification of agriculture is believed to be one of the major causes of such contamination (Singh and Singh, 2004). Application of nitrogenous fertilizers in arable soils rapidly converts it into readily available, easily leachable and highly soluble NO_3^- form upon application. When quantity of nitrogen added to the soil exceeds the amount that the plants can use, the excess NO_3^- leaches out from the root zone by water percolating through the soil profile and ultimately accumulates into the groundwater to cause harmful biological effects in human beings (WHO, 2002).

Apart from excessive use of chemical fertilizers, uncontrolled discharges of municipal and industrial wastewaters on land, run off from septic tanks, processed food, dairy and meat products, decomposition of decaying organic matter buried into ground are the other most common sources of nitrate in ground and surface waters. These fertilizers and wastes are sources of nitrogen-containing compounds which are converted to nitrates in the soil. Due to high solubility in water, nitrates can move easily through soil into the drinking water supply and cause several environmental problems (Shrimali and Singh, 2001). Standard has been established to protect water users from the adverse effects associated with high nitrate intake (Sahli et al., 2006). A high level of nitrate (>45 mg NO_3^-/L or 10 mg N^-/L) in the drinking water can cause methemoglobinemia or blue baby syndrome in infants and gastrointestinal cancer in adults (McDonald and Kay, 1988).

Several methods of nitrate removal from drinking water have been applied before direct consumption. The severity of the problem (excessive nitrate) has attracted many of the researchers to find the economic approaches for the removal of nitrate from aqueous solutions. The most commonly used treatment methods to remove nitrate from water include chemical denitrification, ion exchange, reverse osmosis, electrodialysis, catalytic denitrification, electro-coagulation, electrochemical and biological denitrification.

1.4.2 Fluoride contamination of groundwater

Elevated fluoride concentration in drinking water can cause fluorosis which is one of the most important health related geo-environmental issue in many countries of the world including India. Fluoride of geogenic origin is a major inorganic pollutant found in groundwater (Meenakshi and Maheshwari, 2006). The interaction of igneous and metamorphic rocks with groundwater in India is considered as root cause of higher concentration of F^- in groundwater (Handa, 1988). Several other reasons also exist for elevated F^- concentration in groundwater which includes some anthropogenic activities such as use of phosphate fertilizers, pesticides, sewage and sludge, depletion of groundwater table etc. (Ramanaiah et al., 2006).

Fluorosis is considered as endemic public health problem spread out in 32 nations across the globe (Mukhopadhyay et al., 2017). The cause of crippling disorder is known to occur due to the entry of fluoride into the body. The dental, skeletal, and non-skeletal forms of fluorosis could occur from excessive ingestion of fluoride through drinking water.

To scale down excess fluoride from drinking water, a number of defluoridation techniques have been suggested. Depending upon their mode of action they are classified into three major types, viz., those based on chemical addition, adsorption processes, and the ion-exchange mechanism. Membrane processes such as reverse osmosis, nanofiltration, electrodialysis and Donnan dialysis were recently investigated to reduce fluoride concentration in water (Meenakshi and Viswanathan, 2007).

1.4.3 Arsenic contamination of groundwater

Among the contaminated groundwater used for drinking, arsenic contamination is reported as severe problem of concern. Arsenic is one of the lethal elements found in environment in abundance. Arsenic distribution and transport in environment is complex process and is governed by continuous cycling through air, soil and water. Arsenic in soil and groundwater is introduced during weathering of rocks followed by leaching and run off. Inorganic arsenic are present in the form of arsenate (As (V)) and arsenite (As (III)) in groundwater, inter-conversion of which takes place through oxidation-reduction. Arsenic is classified chemically as non-metal or metalloid belonging to Group-15 of the periodic table with atomic number 33 and atomic weight 74.92 respectively. The most common oxidation states of arsenic are –3 (arsenide, usually alloy like compound), +3 (arsenite, As (III), organo arsenic compound), and +5 (arsenates, As (V) which is the most stable inorganic arsenic oxi-compound). Both organic and inorganic forms of arsenic exist, however, inorganic forms are more toxic than organic (Lewis, 2007; Mudhoo et al., 2011).

Depending on pH, different forms of As (III) are H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, and AsO_3^{3-} whereas As (V) are found as H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, and AsO_4^{3-}. Obviously, most of them are anionic in character.

Protonation diagrams are generated by the following equilibrium relationships given in Eqs. 1.1, 1.2, 1.3 and Eqs. 1.4, 1.5, 1.6 (Pérez et al., 2016; Srivastava et al., 2016).

For arsenite (As (III)),

$$H_3AsO_3 \rightarrow H_2AsO_3^- + H^+ \quad pK_{a1} = 9.22 \quad (1.1)$$

$$H_2AsO_3^- \rightarrow HAsO_3^{2-} + H^+ \quad pK_{a2} = 12.13 \quad (1.2)$$

$$HasO_3^{2-} \rightarrow AsO_3^{3-} + H^+ \quad pK_{a3} = 13.40 \quad (1.3)$$

For arsenate (As (V)),

$$H_3AsO_4 \rightarrow H_2AsO_4^- + H^+ \quad pK_{a1} = 2.20 \quad (1.4)$$

$$H_2AsO_4^- \rightarrow HAsO_4^{2-} + H^+ \quad pK_{a2} = 6.97 \quad (1.5)$$

$$HAsO_4^{2-} \rightarrow AsO_4^{3-} + H^+ \quad pK_{a3} = 11.53 \quad (1.6)$$

Inorganic arsenic is classified as toxin and carcinogen by World Health Organization (WHO, 1993) and United States Environmental Protection Agency (USEPA, 1993). Devastating human health effects could be produced even at low concentration of arsenic. Chemical structure of arsenic spices is responsible for its toxic behavior. Arsine gas is marked as most toxic form, followed by inorganic trivalent compounds, organic trivalent compounds, inorganic pentavalent compounds, organic pentavalent compounds and elemental arsenic (USEPA, 2000).

Various technologies practiced for arsenic removal from groundwater based on various principles include chemical coagulation and precipitation (Wickramasinghe et al., 2004); adsorption (Lata and Samadder, 2016); electrochemical (Rao et al., 2015); electro coagulation (Chaudhari et al., 2014; Mehta and Chaudhari, 2015), reverse osmosis (Singh et al., 2003); and ion exchange (Korngold et al., 2011).

1.5 Global scenario of contamination

1.5.1 Nitrate contamination of groundwater: Global scenario

Nitrate contamination of the groundwater is a cause of concern throughout the world. The problem is prevalent in many parts of Europe, including Great Britain, France, Germany, and Switzerland, several parts of the United States, and in Keepak, Israel (Elyanow and Persechino, 2005). The groundwater nitrate concentrations in Europe exceed the international recommendations for drinking water (50 mg NO_3^-/L) in 22% of cultivated land (WHO, 1993). Similar concentrations have been found in the USA and in China (Laegreid et al., 1999). Table 1.1 shows the global scenario of nitrate contamination.

Table 1.1: Nitrate contamination in water: Global scenario

Country	Concentration range (mg/L)	Reference
Bulgaria	High	Gatseva and Argirova, 2008
France	>50	Elyanow and Persechino, 2005
Germany	50 - 370	Elyanow and Persechino, 2005
Great Britain	>50	Elyanow and Persechino, 2005
Israel	0-135	Elyanow and Persechino, 2005
Italy	5-50	Ghiglieri et al., 2009
India	>45	CGWB, 2010
Pakistan	11-160	Tahir and Rasheed, 2008
Senegal	5-113	Sall and Vanclooster, 2009
Spain	5-900	Caballeromesa et al., 2003
Switzerland	-	Elyanow and Persechino, 2005

1.5.2 Fluoride contamination of groundwater: Global scenario

Natural reasons and human activities are the major problem worldwide responsible for enhancement of fluoride contamination in the drinking water. The 1.5 mg/L of fluoride is the upper limit of fluoride concentration in drinking water set by

World Health Organization (WHO 2008;2012). Mottling of teeth in mild cases, softening of bones, ossification of tendons and ligaments and neurological damage in severe cases are the indication and manifestation of fluorosis caused mainly by long-term ingestion of high-fluoride drinking water USEPA (1997). China, India, Pakistan and Thailand are the Asian countries affected by fluorosis in the world. The information regarding affected countries have been summarized in the Table 1.2.

Table 1.2: Fluoride contamination in water: Global scenario

Country	Concentration range (mg/L)	Reference	Country	Concentration range (mg/L)	Reference
Algeria	>1	Mameri et al., 1998	Mexico	0.33-6.97	Diaz-Barriga et al., 1997
Argentina	0.2-5	Kruse and Ainchil, 2003	Morocco	>1	Mameri et al., 1998
Australia	>1	Mameri et al., 1998	New Zealand	>1	Mameri et al., 1998
Canada	>1	Mameri et al., 1998	Saudi Arabia	>30	Montoya et al., 2012
Egypt	>1	Mameri et al., 1998	South Africa	>30	Montoya et al., 2012
Iraq	>1	Mameri et al., 1998	Sri Lanka	>1	Mameri et al., 1998
Japan	>1	Mameri et al., 1998	Syria	>1	Mameri et al., 1998
Jordan	>1	Mameri et al., 1998	Tanzania	2-12	Mjengera and Mkongo, 2003
Kenya	0.1-25	Gaciri and Davies, 1993	Thailand	>1	Mameri et al., 1998
Libya	>1	Mameri et al., 1998	Poland	>2	Czarnowski et al.,1996
India	>1	Mohapatra et al., 2012	China	-	Wang and Huang,1995

1.5.3 Arsenic contamination of groundwater: Global scenario

Serious concerns of elevated arsenic contents in groundwater of unconsolidated aquifers along alluvial and deltaic plains of the world including southern, south-eastern and eastern parts of Asia have been reported (Table 1.3). The problem is compounded because the drinking water supply in these thickly populated parts is dependent on shallow aquifers which are found to be contaminated.

Table 1.3: Arsenic contamination in water: Global scenario

Country	Concentration range (µg/L)	Reference	Country	Concentration range (µg/L)	Reference
Bangladesh	High	Dhar et al., 1997	Spain	50-80	Barringer and Reilly, 2013
India	2-370	Mandal et al., 1996	U.K	11-80	Barringer and Reilly, 2013
China	50-640	Guo et al., 2001	U.S	> 50	Barringer and Reilly, 2013
Vitenam	37-43	Berg et al., 2001	Ghana	-	Garelick and Jones, 2008
Taiwan	-	Garelick and Jones, 2008	Romania	11-48	Mukherjee et al., 2006
Mangolia	-	Garelick and Jones, 2008	Australia	1-73	Mukherjee et al., 2006
Argentina	100-500	Nicolli et al., 1989	Myanmar	>50	Mukherjee et al., 2006
Chile	10-100	Bundschuh et al., 2012	Nepal	10-50	Shrestha et al., 2003
Mexico	8-624	Razo et al., 1990	Thailand	9.8-52	Williams et al., 1996
Hungary	-	Sancha and Castro, 2001	-	-	-
Japan	0-293	Kondo et al., 1999	-	-	-

1.6 Indian scenario of groundwater contamination

1.6.1 Nitrate contamination in groundwater: Indian scenario

Nitrate contamination of groundwater has been reported from various places in India. Table 1.4 summarizes the current status of nitrate contamination of groundwater in India.

Table 1.4: Districts in India with high nitrate concentrations in groundwater

S. N.	State	Parts of Districts having nitrate conc. > 45 mg /L
1.	Andhra Pradesh	Adilabad, Anantpur, Chittoor, Cuddapah, East Godavari, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahbubnagar, Medak, Nalgonda, Nellore, Nizamabad, Prakasam, Ranga Reddy, Srikakulam, Visakhapatnam, Vizianagaram, Warangal, West Godavari
2.	Bihar	Aurangabad, Banka, Bhagalpur, Bhojpur, Kaimur (Bhabua), Patna, Rohtas, Saran, Siwan
3.	Chhattisgarh	Bastar, Bilaspur, Dantewada, Dhamtari, Jashpur, Kanker, Kawardha, Korba, Mahasamund, Raigarh, Raipur, Rajnandgaon
4.	Delhi	Central Delhi, New Delhi, North Delhi, North West Delhi, South Delhi, South West Delhi, West Delhi, East Delhi,
5.	Goa	North Goa
6.	Gujarat	Ahmadabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dohad, Jamnagar, Junagadh, Kachchh, Kheda, Mehsana, Narmada, Navsari, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar, Vadodara
7.	Haryana	Ambala, Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendragarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonepat, Yamuna nagar
8.	Himachal Pradesh	Una, Solan, Hamirpur, Kangra, Mandi, Kullu
9.	Jammu &Kashmir	Jammu, Kathua, Anantnag, Kupwara
10.	Jharkhand	Chatra, Garhwa, Godda, Gumla, Lohardaga, Pakaur, Palamu, Paschimi Singhbhum, Purbi Singhbhum, Ranchi, Sahibganj
11.	Karnataka	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chikmagalur, Chitradurga, Davangere, Dharwad, Gadag, Gulburga, Hassan, Haveri, Kodagu, Kolar, Koppal, Mandya, Mysore, Raichur, Shimoga, Udupi, Uttara Kannada
12.	Kerala	Alappuzha, Idukki, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thiruvananthapuram, Thrissur, Wayanad

13.	Maharashtra	Ahmednagar, Akola, Amravati, Auragabad, Beed, Bhandara, Buldana, Chandrapur, Dhule, Gadchiroli, Gondia, Hingoli, Jalgaon, Jalna, Kohlapur, Latur, Nagpur, Nanded, Nandurbar, Nashik, Osmanabad, Parbhani, Pune, Sangli, Satara, Solapur, Wardha, Washim, Yavatmal
14.	Madhya Pradesh	Alirajpur,Anuppur, Ashok Nagar, Balaghat, Barwani, Betul, Bhind, Bhopal, Burhanpur, Chhatarpur, Chhindwara, Damoh, Datia, Dewas, Dhar, Gwalior, Harda, Hoshangabad, Indore, Jabalpur, Jhabua, Katni, Khandwa, Khargaon, Mandla, Mandsaur, Morena, Narsimhapur, Neemuch, Panna, Raisen, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Shivpuri, Sidhi, Tikamgarh, Ujjain, Umaria, Vidisha
15.	Orissa	Angul, Balasore, Bargarh, Bhadrak, Bolangir, Baudh, Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam, J.Singhpur, Jajpur,Jharsuguda, Kalahandi, Kendrapara, Keonjhar, Khurda, Koraput, Malkangiri, Mayurbhanj, Nawapada, Nayagarh, Phulbani, Puri, Sambalpur, Sundergarh, Sonapur
16.	Punjab	Amritsar, Bhathinda, Faridkot, Fatehgarh Sahib, Firozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Mansa, Moga, Muktsar, Nawan Shahr, Patiala, Rupnagar, Sangrur, Tarn-Taran, Barnala,
17.	Rajasthan	Ajmer, Alwar, Banaswara, Baran, Barmer, Bundi, Bharatpur, Bhilwara, Bikaner, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalor, Jhalawar, Jhunjhunun, Jodhpur, Karauli, Kota, Nagaur, Pali, Partapgarh, Rajsamand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur
18.	Tamil Nadu	Chennai, Coimbatore, Cuddalore, Dharmapuri, Dindigul, Erode, Kancheepuram, Kanyakumari, Karur, Madurai, Namakkal,Nilgiris, Perambalur, Pudukkottai, Ramanathapuram, Salem,Sivaganga, Theni, Thiruvannamalai, Thanjavur, Tirunelveli, Thiruvallur, Trichi, Tuticorin, Vellore, Villupuram, Virudhunagar
19.	Uttar Pradesh	Agra, Aligarh, Allahabad, Ambedkar Nagar, Auraiya, Azamgarh, Badaun, Baghpat, Balrampur, Banda, Barabanki, Bareilly, Basti, Bijnor, Bulandshahr, Chitrakoot, Etah, Etawa, Fatehpur, Firozabad, GB Nagar, Ghaziabad, Ghazipur, Hamirpur, Hardoi, Hathras, Jaunpur, Jhansi, Kannauj, Kanpur Dehat, Lakhimpur, Mahoba, Mathura, Meerut, Moradabad, Muzaffarnagar, Mirzapur, Raebareli, Rampur, Sant Ravidas Nagar, Shahjahanpur, Sitapur, Sonbhadra, Sultanpur, Shravasti, Siddarth Nagar, Unnao
20.	Uttrakhand	Dehradun, Haridwar, Udhamsingh nagar
21.	West Bengal	Bankura, Bardhaman

(Source: CGWB, 2014)

1.6.2 Fluoride contamination in groundwater: Indian scenario

Groundwater fluoride in high level is present in all the 31 districts and has become a serious health related issue in 23 districts of Rajasthan. Some of the important places having fluoride-rich groundwater, along with the important geological features responsible have been discussed by Madhavan and Subramanian, (2004). Fluorine is reported as lightest member of the halogen group in periodic table elements. Fluoride concentration above the permissible limit of 1.5 mg/L in groundwater is a major health problem in India. Table 1.5 summarizes the status of fluoride contamination of groundwater in India.

Table 1.5: Districts in India with high fluoride concentrations in groundwater

S. N.	State	Parts of Districts having F^- > 1.5 mg/L
1.	Andhra Pradesh	Adilabad, Anantpur, Chittoor, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahbubnagar, Medak, Nalgonda, Nellore, Prakasam, Ranga Reddy, Visakhapatnam, Vizianagaram, Warangal, West Godavari
2.	Assam	Goalpara, Kamrup, Karbi Anglong, Nagaon, Golaghat, Karimganj,
3.	Bihar	Aurangabad, Banka, Buxar, Jamui, Kaimur (Bhabua), Munger, Nawada, Rohtas, Supaul, Sheikhpura, Nalanda, Lakhisarai
4.	Chhattisgarh	Bastar, Bilaspur, Dantewada, Janjgir-Champa, Jashpur, Kanker, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Surguja
5.	Delhi	East Delhi, North West Delhi, South Delhi, South West Delhi, West Delhi
6.	Gujarat	Ahmadabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dohad, Junagadh, Kachchh, Mehsana, Narmada, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar, Vadodara
7.	Haryana	Bhiwani, Faridabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Kurushetra, Mahendragarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonepat
8.	Jammu & Kashmir	Rajauri, Udhampur

9.	Jharkhand	Bokaro, Giridih, Godda, Gumla, Palamu, Ranchi
10.	Karnataka	Bagalkot, Bangalore, Belgaun, Bellary, Bidar, Bijapur, Chamarajanagar, Chikmagalur, Hitradurga, Davangere, Dharwad, Gadag, Gulburga, Haveri, Kolar, Koppal, Mandya, Mysore, Raichur, Tumkur
11.	Kerala	Palakkad, Alappuzha, Idukki, Ernakulum, Thiruvananthpuram.
12.	Maharashtra	Amravati, Bhandara, Chandrapur, Dhule, Gadchiroli, Gondia, Jalna, Nagpur, Nanded, Ratnagiri, Sindhudurg, Yavatmal
13.	Madhya Pradesh	Alirajpur, Amravati, Beed, Balaghat, Barwani, Betul, Bhind, Chhatarpur, Chhindwara, Datia, Dewas, Dhar, Guna, Gwalior, Harda, Jabalpur, Jhabua, Khargaon, Mandsaur, Rajgarh, Satna, Seoni, Shajapur, Sheopur, Sidhi, Singrauli, Uajjain, Vidisha
14.	Orissa	Angul, Balasore, Bargarh, Bhadrak, Bandh, Cuttack, Deogarh, Dhenkanal, Jajpur, Keonjhar, Sonapur
15.	Punjab	Amritsar, Barnala, Bhatinda, Faridkot, Fatehgarh Sahib, Firozepur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Patiala, Sangrur, Tarn-Taran
16.	Rajasthan	Ajmer, Alwar, Banaswara, Barmer, Bharatpur, Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalor, Jhunjhunun, Jodhpur, Karauli, Kota, Nagaur, Pali, Rajsamand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur
17.	Tamil Nadu	Coimbatore, Dharmapuri, Dindigul, Erode, Karur, Krishnagiri, Namakkal, Perambalur, Puddukotai, Ramanathapuram, Salem, Sivaganga, Theni, Thiruvannamalai, Tiruchirapally, Vellore, Virudhunagar
18.	Uttar Pradesh	Agra, Aligarh, Etah, Firozabad, Jaunpur, Kannauj, Mahamaya, Nagar, Mainpuri, Mathura, Mau
19.	West Bengal	Bankura, Bardhaman, Birbhum, Dakshindinajpur, Malda, Nadia, Purulia, Uttardinajpur, South 24 Praganas

(Source: CGWB, 2018)

1.6.3 Arsenic contamination in groundwater: Indian scenario

Arsenic contamination creates a risk zone to approximately 40 million people in India (CGWB, 2014). In India, the first case of arsenic contamination of groundwater was reported from West Bengal in 1980, where 79 blocks in 8 districts were found to contain the arsenic beyond the permissible limit of 0.01 mg/L. In addition, States like Bihar, Chhattisgarh, Uttar Pradesh and Assam are also found to have arsenic contamination in groundwater. Arsenic in groundwater has been reported in 12 districts of Bihar, 5 districts in Uttar Pradesh and one district each in Chhattisgarh & Assam. Table 1.6 (a) and (b) show the occurrence of arsenic in groundwater in some state of India.

Table 1.6 (a): Districts in India with high arsenic concentrations in groundwater

S. No.	State	Parts of Districts having As between 0.01 to 0.05 mg/L
1.	Andhra Pradesh	Guntur, Kurnool, Nellore
2.	Assam	Golaghat, Jorhat, Lakhimpur, Nagaon, Nalbari, Sibsagar, Sonitpur
3.	Bihar	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, E.Champaran, Gopalganj, Katihar, Khagaria, Lakhisarai, Lohardaga, Madhepura, Muzaffarpur, Purnea, Saharsa, Samastipur, Siwan, Vaishali, W.Champaran
4.	Chhattisgarh	Rajnandgaon
5.	Delhi	East, North East
6.	Daman & Diu	Diu
7.	Gujarat	Amreli, Anand, Bharuch, Bhavnagar, Dahod, Gandhinagar, Kacchh, Mehsana, Patan, Rajkot, Surendranagar, Vadodara
8.	Haryana	Bhiwani, Mahendergarh, Palwal, Rohtak, Sirsa, Sonipat
9.	Himachal Pradesh	Kangra
10.	Jammu & Kashmir	Jammu, Kathua, Rajouri
11.	Jharkhand	Sahebganj

12.	Karnataka	Raichur, Yadgir
13.	Madhya Pradesh	Betul, Burhanpur, Chhindwara, Dhar, Khandwa, Mandsaur, Neemuch, Umaria
14.	Odisha	Gajapati
15.	Punjab	Faridkot, Gurdaspur, Hoshiarpur, Sangrur, Tarn Taran
17.	Rajasthan	Ganga Nagar
18.	Telangana	Nalgonda
19.	Uttar Pradesh	Azamgarh, Badaun, Bahraich, Basti, Deoria, Gorakhpur, Jhansi, Kausambi, Kushinagar, Maunath Bhanjanm, Pilibhit, Shahjahanpur
20.	West Bengal	Hooghly, Howrah, Kochbihar, Malda, Murshidabad, Nadia, North 24 Pargana, South 24 pargana

(Source: CGWB, 2019)

Table 1.6 (b): Districts in India with Arsenic (>0.05 mg/L) in groundwater

S. No.	State	Parts of Districts having As > 0.05 mg/L
1.	Assam	Sivsagar, Jorhat, Golaghat, Sonitpur, Lakhimpur, Dhemaji, Hailakandi, Karimganj, Cachar, Jorhat, Nagaon, Barpeta, Goalpara, Dhubri, Nalbari, Nagaon, Morigaon, Darrang & Baksha
2.	Bihar	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhiserai, Munger, Patna, Purnea, Samastipur, Saran, Vaishali
3.	Chhattisgarh	Rajnandgaon
4.	Haryana	Ambala, Ambala, Bhiwani, Faridabad, Fatehabad, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonepat, Yamunanagar.
5.	Jharkhand	Godda, Dhanbad, Sahebganj
6.	Karnataka	Raichur
7.	Manipur	Bishnupur, Thoubal
8.	Punjab	Amritsar, Ropar, Taran taran, Mansa, Amritsar, Gurdaspur, Hoshiarpur, Kapurthala
9.	Uttar Pradesh	Bahraich, Deoria, Lakhimpur, Azamgarh, Maunath Bhanjan, Agra, Aligarh, Balia, Balrampur, Gonda, Gorakhpur, Mathura, Muradabad, Balrampur, Bareilly, Basti, Bijnor, Chandauli, Ghazipur, Gonda, Gorakhpur, Lakhimpur Kheri, Meerut, Mirzapur, Rai Bareilly, Sant Kabir Nagar, Shajahanpur, Siddarthnagar, Sant Ravidas Nagar, Unnao
10.	West Bengal	Hooghly, Malda, Murshidabad, Nadia, North 24 Parganas, South 24 pargana, Bardhaman, Howrah

(Source: CGWB, 2019)

1.7 Standards for nitrate, fluoride and arsenic in drinking water

1.7.1 Standards for nitrate in drinking water

Average nitrate levels in groundwater in most European countries have been stable at around 17.5 mg/L NO_3^- (4 mg/L NO_3^--N) across Europe over a 20-year period (1992–2012), with some differences between countries both in trends and concentrations. Average concentrations are lowest in Finland (around 1 mg/L NO_3^- in and highest in Malta (58.1 mg/L in 2000 –2012) (Ward et al., 2018). World Health Organization (WHO, 2007; 2008) has recommended a guideline value (GV) of 50 mg NO_3^-/L. The United States and Canada suggest a maximum contaminant level (MCL) of 10 mg N/L (equivalent to 45 mg NO_3^-/L). In India, the current desirable limit (DL) is 45 mg NO_3^-/L (BIS, 2012).

1.7.2 Standards for fluoride in drinking water

To fight with tooth decay problem a small amount of fluoride (less than 1.0 mg/L) is essential for human body. However, concentrations above then 1.5 mg/L of fluoride result in staining of tooth enamel while at still higher levels of fluoride ranging between 5.0 and 10 mg/L brings pathological changes such as stiffness of the back and difficulty in performing natural movements (PHR, 2015). Hence, fluoride levels ranging from 0.8 to 1.2 mg/L are maintained for community water supplies commonly treated with NaF or fluorosilicates to reduce the incidence of dental carries.

A recommended value of 1.0 mg/L of fluoride is considered as desirable concentration of fluoride in drinking water, which can be extended to 1.5 mg/L of F^- in case no alternative source of water is available (WHO, 2002).

1.7.3 Standards for Arsenic in drinking water

Due to the adverse health effects including carcinogenic nature (Sarkar and Paul, 2016), maximum allowable concentration of arsenic in drinking water set by United States Environmental Protection Agency (UPSEA) is 0.01 mg/L (Iesan et al., 2008). World Health organization (Vaclavikova et al., 2008) also recommended the maximum permissible limit of 0.01 mg/L arsenic for drinking water. As per IS 10500: 2012 (BIS, 2012), the maximum permissible limit for Arsenic in drinking is 0.01 mg/L.

1.7.4 Globally accepted standards for nitrate, fluoride and arsenic in drinking water

Setting standards for a drinking water contaminant is a very difficult and imperfect process influenced by economic, political and social issues, in addition to scientific considerations. In fact, data relating human health effects to chemicals in drinking water are limited, and scientists have difficulty in predicting the effects of drinking small amounts of chemicals for many years. Drinking water guideline values have been derived for many chemical constituents. A guideline value normally represents the concentration of a constituent that does not result in a significant risk to health over life time consumption (WHO, 2006). Only a few chemicals have been shown to cause widespread health effects in humans as a consequence of exposure through drinking water when they are present in excessive quantities such as nitrate, fluoride, and arsenic (WHO, 2006).

Based on the toxic and deleterious nature, following limits have been set for the three anionic contaminants of drinking water selected for the present study (Table 1.7). Most of the countries have their own standards. Besides, many international organizations have formulated standards and advised guidelines. The international guidelines accepted widely are given below.

Table 1.7: Anions standards in drinking water

S. No	Contaminants	PL (mg/L) (BIS, 2012)	GV (mg/L) (WHO, 2017)	ML (mg/L) (EC, 2015)	MCL (mg/L) (USEPA, 2018)
1.	Nitrate (NO_3^-)	45	50	50	50
2.	Fluoride (F^-)	1.0-1.5	1.5	1.5	1.5
3.	Arsenic (Total As)	0.01	0.01	0.01	0.01

Where, BIS= Bureau of Indian Standard, WHO=World Health Organization, EC= European Commission, USEPA=United States Environmental Protection Agency, PL=Permissible limit, GV= Guideline value, ML=Mandatory limit, MCL= Maximum contamination level.

1.8 Simultaneous presence of more than one contaminant in groundwater for drinking in India

Apart from contaminants existing in groundwater sources individually, there are reports that one location may be affected by two or more contaminants. In order to identify places where more than one contaminant exist, a list of districts affected by all the three contaminants, namely- nitrate, fluoride and arsenic is presented in Table 1.8.

Table 1.8: State wise names of the districts (partly) in India affected by nitrate, fluoride and arsenic contamination of groundwater

S.N.	State/UT	Districts reported with contamination in groundwater		
		Nitrate **(Above 45 mg/L)**	**Fluoride** **(Above 1.5 mg/L)**	**Arsenic** **(Above 0.05 mg/L)**
1.	Andaman & Nicobar			
2.	Andhra Pradesh	Adilabad, Anantpur, Chittoor, Cuddapah, East Godavari, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahabubnagar, Medak, Nalgonda, Nellore, Nizamabad, Prakasam, Ranga Reddy, Srikakulam, Visakhapatnam, Vizianagaram, Warangal, West Godavari	Adilabad, Anantpur, Chittoor, Guntur, Hyderabad, Kadapa, Karimnagar, Khammam, Krishna, Kurnool, Mahabubnagar, Medak, Nalgonda, Nellore, Prakasam, Rangareddy, Visakhapatnam, Vizianagaram, Warangal,West Godavari	
3.	Assam		Goalpara, Kamrup, Karbi Anglong, Naugaon, Golaghat, Karimganj	Sivsagar, Jorhat,Golaghat, Sonitpur, Lakhimpur, Dhemaji, Hailakandi, Karimganj, Cachar, Barpeta, Bongaigaon, Goalpara, Dhubri, Nalbari, Naugaon, Morigaon, Darrang &Baksha
4.	Bihar	Aurangabad, Banka, Bhagalpur, Bhojpur, Darbhanga, Kaimur (Bhabua), Patna, Rohtas, Saran, Siwan	Aurangabad, Banka, Bhagalpur, Gaya, Jamui, Kaimur (Bhabua), Munger, Nawada, Rohtas Sheikhpura, Nalanda, Lakhisarai	Begusarai, Bhagalpur, Bhojpur, Buxar, East Champaran, Gopalganj, Katihar, Khagaria, Kishanganj, Lakhiserai, Madhepura, Muzaffarpur, Nawada, Rohtas, Saharsa, Samastipur, Siwan, Supaul, West Champaran

5.	Chhattisgarh	Bastar, Bilaspur, Dantewada, Dhamtari, Jashpur, Kanker, Kawardha, Korba, Mahasamund, Raigarh, Raipur, Rajnandgaon	Bastar, Bilaspur, Dantewada, Dhamtari, Janjgir-Champa, ashpur, Kanker, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Surguja	Rajnandgaon
6.	Delhi	East Delhi, Central Delhi, New Delhi, North Delhi, North West Delhi, South Delhi, South West Delhi, West Delhi	East Delhi, New Delhi, North West Delhi, South Delhi, South West Delhi, North Delhi, West Delhi	
7.	Gujarat	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Jamnagar, Junagadh, Kachchh,Kheda, Mehesana, Narmada, Navsari, Panchmahals, Patan,Porbandar, Rajkot,Sabarkantha, Surat, Surendranagar, Vadodara	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Junagadh, Kachchh, Mehesana, Narmada, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar,Vadodara	
8.	Haryana	Ambala, Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendargarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonipat,Yamuna Nagar	Bhiwani, Faridabad, Fatehabad, Gurgaon,Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendergarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonepat, Yamuna Nagar	Ambala, Bhiwani, Faridabad, Fatehaba,Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonepat, Yamunanagar
9.	Himachal Pradesh	Una, Solan, Hamirpur, Kangra, Mandi, Kullu		
10.	Jammu & Kashmir	Jammu, Kathua, Anantnag, Kupwara	Rajaori, Udhampur	
11.	Jharkhand	Chatra, Garhwa,Godda, Gumla, Lohardaga, Pakur, Palamu, Paschimi Singhbhum, Purbi Singhbhum, Ranchi, Sahibganj	Bokaro, Giridih, Godda, Gumla, Palamu, Ramgarh, Ranchi	Sahebganj
12.	Karnataka	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chamrajnagar, Chikmagalur, Chitradurga, Davanagere, Dharwad, Gadag, Gulburga, Hassan,Haveri, Kodagu,Kolar, Koppal, Koorg,Mandya, Mysore, Raichur, Shimoga,	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chamarajanagar, Chikmagalur, Chitradurga, Davanagere, Dharwad, Gadag, Gulburga, Hassan, Haveri, Kolar, Koppal, Mandya, Mysore, Raichur, Tumkur	

		Tumkur, Udupi, Uttar Kannada		
13.	Kerala	Alappuzha, Idukki, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thiruvananthapuram, Thrissur, Wayanad	Palakkad, Alappuzha, Idukki, Ernakulum, Thiruvananthpuram.	
14.	Madhya Pradesh	Alirajpur, Anuppur, Ashok Nagar, Balaghat, Barwani, Betul, Bhind, Bhopal, Burhanpur, Chhatarpur, Chhindwara, Damoh, Datia, Dewas, Dhar, Dindori, Guna, Gwalior, Harda, Hoshangabad, Indore, Jabalpur, Jhabua, Khandwa, Khargon, Katni, Mandla, Mandsaur, Morena, Narsimhapur, Neemuch, Panna, Raisen,Rajgarh, Ratlam, Rewa, Sagar,Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Shivpuri, Sidhi, Singrauli, Tikamgarh, Ujjain, Umaria, Vidisha	Alirajpur, Balaghat, Barwani, Betul, Bhind, Chhatarpur, Chhindwara, Datia, Dewas, Dhar, Dindori, Guna, Gwalior, Harda, Jabalpur, Jhabua, Khargon, Mandla, Mandsaur, Morena, Narsinhpur, Rajgarh, Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Sidhi, Singrauli, Uajjain, Vidisha	
15.	Maharashtra	Ahmednagar, Akola,Amravati, Auragabad, Beed, Bhandara, Buldana, Chandrapur, Dhule, Gadchiroli, Gondia, Hingoli, Jalgaon, Jalna, Kolhapur, Latur, Mumbai, Nagpur, Nanded, Nandurbar, Nasik, Osmanabad, Parbhani, Pune, Sangli, Satara, Solapur, Wardha, Washim, Yavatmal	Amravati, Beed, Chandrapur, Bhandara, Dhule, Gadchiroli, Gondia, Jalna, Nagpur, Nanded, Ratnagiri, Sindhudurg, Yavatmal	
16.	Manipur			Bishnupur, Thoubal
17.	Meghalaya			
18.	Orissa	Angul, Balasore, Bargarh, Bhadrak, Bolangir, Baudh, Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam, J.Singhpur, Jajpur, Jharsuguda, Kalahandi, Kendrapara,	Angul, Balasore, Bargarh, Bhadrak, Baudh, Cuttack, Deogarh, Dhenkanal, Jajpur, Keonjhar, Khurda, Mayurbhanj, Nayagarh, Nawapara, Sonpur	

		Keonjhar, Khurda, Koraput, Malkangiri, Mayurbhanj, Nawapada, Nayagarh, Phulbani, Puri, Sambalpur, Sundergarh, Sonpur		
19.	Punjab	Amritsar, Barnala, Bhatinda, Faridkot, Fatehgarh Sahib, Firozpur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Mansa, Moga, Muktsar, Nawan Shahr, Patiala, Ropar, Rupnagar, Sangrur, Tarn-Taran	Amritsar, Barnala, Bhatinda, Faridkot, Fatehgarh Sahib, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Patiala, Ropar, Sangrur,Tarn-Taran	Mansa, Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, Ropar.
20.	Rajasthan	Ajmer, Alwar, Banswara, Baran, Barmer, Bundi, Bharatpur, Bhilwara, Bikaner, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhalawar, Jhunjhunu, Jodhpur, Karauli, Kota, Nagaur, Pali, Partapgarh, Rajasamand, Sirohi, Sikar, SwaiMadhopur, Tonk, Udaipur	Ajmer, Alwar, Banswara, Barmer, Bharatpur, Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangar, Jaipur, Jaisalmer, Jalore, Jhunjhunu, Jodhpur, Karauli, Kota, Nagaur, Pali, Rajsamand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur	
21.	Sikkim			
22.	Tamil Nadu	Chennai, Coimbatore, Cuddalore,Dharmapuri, Dindigul, Erode, Kancheepuram, Kanyakumari, Karur,Madurai, Namakkal, Nilgiris, Perambalor, Puddukotai, Ramanathanpuram, Salem, Sivagangai,Theni, Thiruvannamalai, Thanjavur,Tirunelveli, Thiruvallur, Trichy, Tuticorin, Vellore, Villupuram, Virudhunagar	Coimbatore, Dharmapuri, Dindigul, Erode, Karur, Krishnagiri, Namakkal, Perambalor, Puddukotai, Ramanathanpuram, Salem, Sivagangai, Theni, Thiruvannamalai, Tiruchirapally, Thirunelveli, Vellore, Virudhunagar	
23.	Tripura			
24.	Uttar Pradesh	Agra, Aligarh, Allahabad, Ambedkar Nagar, Auraiya, Azamgarh, Badaun, Baghpat, Balrampur, Banda,	Agra, Aligarh, Etah, Kashiram Nagar, Firozabad, Jaunpur, Mahamaya Nagar, Mainpuri, Mathura, Mau,	Bahraich, Balia, Balrampur, Bareilly, Basti, Bijnor, Chandauli,

		Barabanki, Bareilly, Basti, Bijnor, Bulandsahr, Chitrakoot, Etah, Etawah, Fatehpur, Firozabad, GB Nagar,Ghaziabad, Ghazipur, Hamirpur, Hardoi, Hathras, Jaunpur, Jhansi, Kannauj, Kanpur Dehat, Lakhimpur, Mahoba, Mathura, Meerut, Mau, Moradabad, Muzaffarnagar, Mirzapur, Raebarelli, Rampur, Sant Ravidas Nagar, Shajahanpur, Sitapur, Sonbhadra, Sultanpur, Shravasti, Siddarth Nagar, Unnao	Sonbhadra, Varanasi and Unnao	Ghazipur, Gonda, Gorakhpur, Lakhimpur Kheri, Meerut, Mirzapur, Muradabad, RaiBareilly, Sant Kabir Nagar, Shajahanpur, Siddarthnagar, Sant Ravidas Nagar, Unnao
25.	Uttarakhand	Dehradun, Haridwar, Udhamsinghnagar		
26.	West Bengal	Bankura, Bardhaman	Bankura, Bardhaman, Birbhum,Dakshindinajpur, Malda,Nadia, Purulia, Uttardinajpur, South 24 Praganas	Bardhaman, Hooghly, Howrah, Malda, Murshidabad, Nadia, N-24 Parganas, S- 24 Parganas

(Source: CGWB, 2014)

Even with the assumption that the reported contaminations are not in the same source of drinking water, it is important from individual user's perspective to know about the existence of more than one contaminant in the groundwater of same district. Table 1.9 presents a summary of districts affected by two or more such contaminants.

Table 1.9 Districts of India reported with presence of more than one contaminant (nitrate, fluoride or arsenic) in groundwater beyond permissible limits for drinking

S. No.	State/UT	Districts with combination of contaminants in groundwater source			
		Nitrate (Above 45 mg/L) AND Fluoride (Above 1.5 mg/L)	**Nitrate (Above 45 mg/L) AND Arsenic (Above 0.05 mg/L)**	**Fluoride (Above 1.5 mg/L) AND Arsenic (Above 0.05 mg/L)**	**Nitrate (Above 45 mg/L) AND Fluoride (Above 1.5 mg/L) AND Arsenic (Above 0.05 mg/L)**
1.	Andaman & Nicobar				
2.	Andhra Pradesh	Adilabad, Anantpur, Chittoor, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahabubnagar, Medak, Nalgonda, Nellore, Prakasam, Rangareddy, Visakhapatnam, Vizianagaram, Warangal, West Godavari			
3.	Assam			Golaghat, Karimganj, Goalpara, Naugaon	
4.	Bihar	Aurangabad, Banka, Bhagalpur, Kaimur (Bhabua), Rohtas	Bhagalpur, Bhojpur, Siwan		Bhagalpur
5.	Chhattisgarh	Bastar, Bilaspur, Dantewada,Dhamtari, Jashpur, Korba, Mahasamund, Raipur, Rajnandgaon	Rajnandgaon	Rajnandgaon	Rajnandgaon
6.	Delhi	East Delhi, New Delhi, North West Delhi, South Delhi, South			

		West Delhi, North Delhi, West Delhi			
7.	Gujarat	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Junagadh, Kachchh, Mehesana, Narmada, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar, Vadodara			
8.	Haryana	Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendergar, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonipat, Yamuna Nagar	Ambala, Bhiwani, Faridabad, Fatehabad, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonipat, Yamuna Nagar	Bhiwani, Faridabad, Fatehaba, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonepat, Yamunanagar	Bhiwani, Faridabad, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonepat, Yamuna nagar
9.	Himachal Pradesh				
10.	Jammu & Kashmir				
11.	Jharkhand	Godda, Gumla, Palamu, Ranchi	Sahibganj		
12.	Karnataka	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chamarajanagar, Chikmagalur, Chitradurga, Davanagere, Dharwad, Gadag, Gulburga, Hassan, Haveri, Kolar, Koppal, Mandya, Mysore, Raichur, Tumkur			
13.	Kerala	Palakkad, Idukki, Thiruvananthpuram			
14.	Madhya Pradesh	Alirajpur, Balaghat, Barwani, Betul, Bhind, Chhatarpur, Chhindwara, Datia, Dewas, Dhar, Dindori, Harda, Jhabua, Khargon,			

		Mandla, Mandsaur, Morena, Narsinhpur, Rajgarh, Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Sidhi, Singrauli, Uajjain, Vidisha			
15.	Maharashtra	Amravati, Beed, Chandrapur, Bhandara, Dhule, Gadchiroli, Gondia, Jalna, Nagpur, Nanded, Yavatmal			
16.	Manipur				
17.	Meghalaya				
18.	Orissa	Angul, Balasore, Bargarh, Bhadrak, Baudh, Cuttack, Deogarh, Dhenkanal, Jajpur, Keonjhar, Khurda, Mayurbhanj, Nayagarh, Nawapara, Sonpur			
19.	Punjab	Amritsar, Barnala, Bhatinda, Faridkot, Fatehgarh Sahib, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Patiala, Ropar, Sangrur,Tarn-Taran	Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, Mansa, Ropar,	Mansa, Amritsar, Gurdaspur, Ropar	Amritsar, Ropar
20.	Rajasthan	Ajmer, Alwar, Banswara, Barmer, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhunjhunu, Jodhpur, Kota, Nagaur, Pali, Rajsamand, Sirohi, Sikar, Sawai Madhopur,Tonk, Udaipur			
21.	Sikkim				
22.	Tamil Nadu	Coimbatore, Dharmapuri,			

		Dindigul, Erode, Karur, Namakkal, Puddukotai, Ramanathanpuram, Salem, Sivagangai, Theni, Thiruvannamalai, Vellore, Virudhunagar			
23.	Tripura				
24.	Uttar Pradesh	Agra, Aligarh, Firozabad, Jaunpur, Mathura, Mau, Sonbhadra, Unnao	Balrampur, Bareilly, Basti, Bijnor, Ghazipur, Lakhimpur, Meerut, Moradabad,Mirzapur, Raebarelli, Shajahanpur, Siddarth Nagar, Unnao	Unnao	Unnao
25.	Uttarakhand				
26.	West Bengal	Bankura, Bardhaman	Bardhaman	Bardhaman, Malda, Nadia,South 24 Praganas	Bardhaman

(Source: CGWB, 2014)

The above analysis indicates that in India, there are 225 districts affected by both nitrate and fluoride, 38 districts with nitrate and arsenic, 26 districts with fluoride and arsenic and 17 districts by all of nitrate, fluoride and arsenic existing in the groundwater sources used for drinking. Hence, it is imperative to find a solution for simultaneous removal of nitrate, fluoride and arsenic from groundwater used for drinking purpose

1.9 Need of the study

Numerous studies have been reported concerning evaluation and successful implementation of techniques on removal of one contaminant (either nitrate, fluoride or arsenic) from groundwater intended for drinking. In the recent years, however, Shakya and Ghosh (2018) reported simultaneous removal of arsenic, iron, nitrate and Prathna et al. (2018) worked on arsenic and fluoride removal from contaminated groundwater. However, suitable methods for simultaneous removal of two or more contaminants coexisting or being encountered because of change from one place to another within the same district have not been examined with adequate details. The analyses of occurrence of nitrate, fluoride and arsenic in groundwater sources of India indicate that there are several districts where more than one contaminant exists. The present study focuses on simultaneous removal of nitrate, fluoride and arsenic coexisting in a source of water intended for drinking.

1.10 Objectives of the present study

The broad objective of the present study is to ascertain and evaluate an inorganic adsorptive material which can remove all the three major contaminants, namely nitrate, fluoride and arsenic from groundwater intended for drinking and develop a point of use (POU) treatment unit for family level applications.

As hydrous bismuth oxides (HBOs) have been observed to give good adsorptive potentials for anionic contaminants, the objectives of the present study are as follows:

- Selection of an effective adsorbent for simultaneous removal of nitrate, fluoride and arsenic from water used for drinking purpose.
- To characterize the adsorbent and utilize it for simultaneous removal of nitrate, fluoride and arsenic in batch and column adsorption process.
- To study the adsorption kinetics, isotherm and thermodynamic parameters of the system.

1.11 Structure of the thesis

The present thesis work is organized in five chapters. The broad description of each chapter is given below:

CHAPTER I: INTRODUCTION

This chapter includes the summary of occurrence of nitrate, fluoride and arsenic in groundwater sources intended for drinking purpose in Indian and global perspectives, their possible source and health effects on human body and permissible limits in drinking water. Towards the end of this chapter, the need of present study has been discussed.

CHAPTER II: LITERATURE REVIEW

This chapter presents the literature review concerning various methods of removal of nitrate, fluoride and arsenic, particularly through adsorption and ion exchange using inorganic adsorbents. The performance of various hydrous metal oxides (HMOs) tested for the purpose has been summarized. Observations related with sorptive properties of hydrous bismuth oxides (HBOs) have been put together to evaluate their potentials in anionic contaminants removal. The gap in the existing knowledge base in context of removal of contaminants from a simultaneously occurring condition has been identified in order to set the objectives of the present study.

CHAPTER III: MATERIALS AND METHODS

This chapter describes various materials and methods used in the present study. It focuses on methods of preparation of different forms of HBOs, methods of their characterization, batch and column experiments for kinetic studies, isotherm models, performance of the selected adsorbent in presence of competitive anions, regeneration and reuse studies and column experiments using groundwater spiked with selected contaminant.

CHAPTER IV: RESULTS AND DISCUSSION

This chapter summarizes the results of batch and column adsorption studies, kinetics, characterization of adsorbent before and after the contaminants sorption, isotherm models, effects of presence of competing ions, regeneration and reuse and performance of the adsorbent in removal of selected anionic contaminants from groundwater in column mode of operation.

CHAPTER V: SUMMARY AND CONCLUSIONS

Chapter five presents a brief summary of outcomes from the present study and conclusions derived from them in terms of efficiency and suitability of the adsorbent with respect to simultaneous removal of nitrate, fluoride and arsenic from groundwater in coexisting conditions. This chapter also suggests a few recommendations for future work.

REFERENCES

This is an alphabetically arranged list of sources which have been referred in the present study.