Anthropogenic and Geogenic contamination of ground water - A Review

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Abstract

Groundwater is a much-protecting and progressively origin of drinking water compared to surface water and is the second largest source of water for daily consumption, next to surface water resources. Out of 17 goals in SDG (Sustainable Development Goals), goal 6 is about clean water and sanitation for all, which is prescribed by the United Nations Organization and signed by India, directed to secure the attainability and viable control of water for all. The contamination of groundwater is a major threat, mostly in growing cities due to anthropogenic and geogenic activities. Anthropogenic activities like industrial growth, population explosion, increasing agricultural activities etc are the major contributing factors which add nitrate and fluoride to ground water. Similarly, among geogenic contaminants, Fluoride, Sulfate, Iron, Arsenic and Nitrate, also has a greater impact in global scenario.

Keywords :- *Groundwater, Anthropogenic, Geogenic, Contamination*

1. Introduction :

Pure drinking water is the earliest and top most need of human life in the earth (Rashid et al., 2022). India extracts over 75 billion m^3 of groundwater annually (Annan 2005) and is the largest source of liquid freshwater on Earth (69% of freshwater is in ice caps, 30% in groundwater, and 1% in surface waters) and is also vital for life (Dalin et al., 2017). Portable groundwater is considered as one of the most significant asset natural sources for drinking and other domestic purposes in India (Li and Qian 2018; Adimalla and Qian 2019; Adimalla 2020; Kaur et al., 2019). Around 68% of the Indian population depends on groundwater for their everyday purposes (Maurya 2020). Pure water is a prerequisite for human beings along with other organisms. Portable water must follow the standard limit as per (IS:10500:2012). Universal and equitable access to safe and affordable drinking water by 2030 is a target of the United Nations Organization under the Sustainable Development Goal 6, "Ensure availability and sustainable management of water and sanitation for all" (Septon et al., 2021). sustainable goals for handling water is to assist its use in society to fulfill the need which connects both the present and upcoming futures (Loucks 2000). In Northwestern India, groundwater is the main source of origin understanding the phenomenon, distribution, and contamination sources which is important for the protection of the health of the local population (Coyte et al., 2019). Groundwater is being used for irrigation as well as providing a more consistent source of drinking water than seasonally fluctuating lakes, rivers, and ponds (Hug et al., 2020). In this presence scenario of high birth rate, growing industrialization, agricultural activities and urbanization, free aquifers are utilized. All over the world, utilization of groundwater is much bigger than its replenish able rate (CWC, 2019; Jandu et al., 2021; Tanwar et al., 2022). Recently, the quality of groundwater has come under serious threat from the combined effects of anthropogenic and geogenic processes (Belkhiri et al., 2018; Keesari et al., 2016; Mukate et al., 2017). According to Abualnaeem et al. (2018) and Yidana et al. (2010), anthropogenic factors include groundwater over-exploitation, improper sewage disposal, intensive farming practises, unplanned industrialization, and urban expansion. Geogenic factors include mineral dissolution, SWI, saltwater up-coning, and the impact of nearby aquifers (Jia et al., 2018; Mountadar et al., 2018; Zghibi et al., 2014).

FRAMEWORK OF THE STUDY:

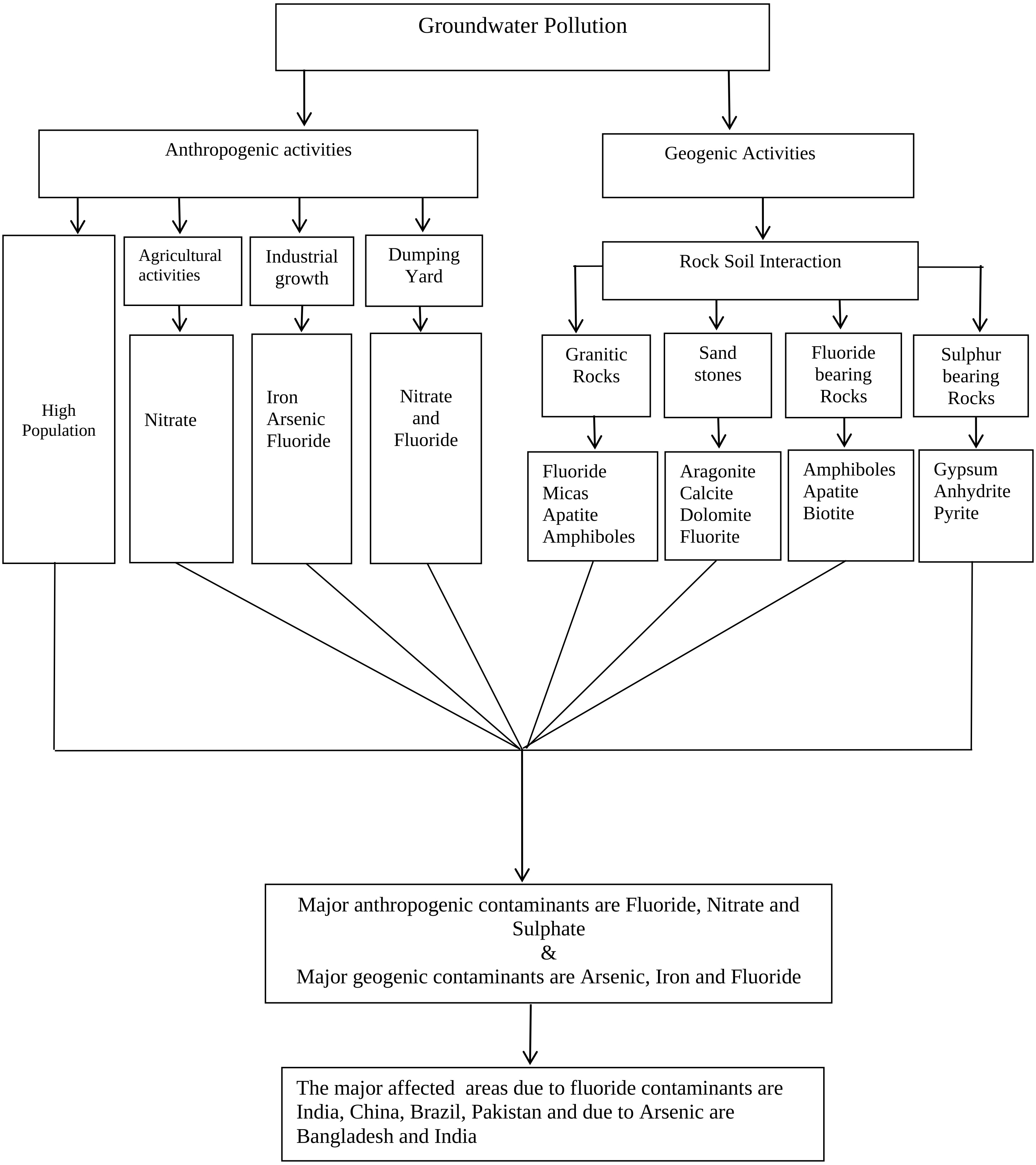

Fig 1: The flow diagram of the present research

1.1 GROUNDWATER POLLUTION STRATEGY:

The quality of groundwater deterioration is caused by factors like population explosion, vast growth of industries, huge dumping in many metropolitan cities (Srivastava et al., 2014). Over the past thirty years, the contamination of chemical in groundwater aquifer has a common matter to study (Li et al., 2021). The availability of fresh ground water is only 0.05% of the total water resources, hence, to maintain the sustainability of this resource, it is very essential to protect it from contamination. Water contamination means destruction and inadequacy in its system, which decreases the potential to play natural role and cause damage to the greenery of the environment (Briffa 2020). Groundwater pollution most often results from improper disposal of wastes on land (Hassan 2016). As Industrialization is rapidly growing, the source of groundwater is leading to bring out the deterioration of quality across the urban-conglomerates through leaching (Das et al., 2018). Before entering the groundwater , human can control the unacceptable chemicals to go into it. But if the chemical quantity enters into the ground, then the infiltration of water is being restricted (Nightingale and Bianchi 1980). Researchers like (Ramesh et al., 1995) in their study explained the scattering of micro elements in groundwater due to some anthropogenic activities (such as sewerage waste water, industrial effluents etc). Eswari and Ramanibai (2000) have estimated the periodic difference of iron in the water of Chennai, Tamil Nadu, India. (Wu and Sun 2016) have studied that sources like cultivation farming with use of phosphate fertilizer, pesticide, industrial activities burning of coal, deposition of fly ash have raised the absorption of fluoride in groundwater.

1.2. OBJECTIVES AND SCOPE:

- To find out the major factors in groundwater contamination.
- To explore the different anthropogenic and geogenic contaminants in groundwater
- To investigate the extent of contamination level in different places.

1.3. ACTIVITIES OF GROUNDWATER POLLUTION:

Groundwater is mainly contaminated by two sources

- Anthropogenic sources
- Geogenic sources

2. ANTHROPOGENIC ACTIVITIES:

Urbanization is a pervasive form of land cover/land use alteration that is rapidly growing (Paul and Meyer 2001). It converts the croplands, forests, grasslands, pastures, wetlands and other cover types to residential, transportation, commercial and industrial uses, thereby increasing the areas of impervious surfaces (Tsegaye et al., 2006). Industrial discharges, urban activities, agriculture fertilizers and disposal of sewage wastes are affecting the groundwater quality adversely. A study found that due to leaching factor fluoride from fertilizers could contaminate soil (Farooqi et al., 2007). Along with them, researchers (Howard and Gerber 2018) in their study of metropolitan areas and growth in groundwater found that oil tanks spill leakage, discharging of chemicals from dying industries, seepage into cesspools and from dumping sites to collect and migrate into the groundwater table, which leads to the pollution of groundwater system. Akhtar et al., 2021, also emphasized the contamination of ground water which is due to climate change, agricultural activities, natural disasters and geological activities. Direct impact is a result of animal husbandry activities, deforestation of woods, agriculture, industrial pollution or urban as well as from accidents (oil spills) and recreational activities. Due to agricultural activities, discharging of sewage and industry, urban areas groundwater are more polluted. Researchers like Rao (2006); (Sankararamakrishnan et al. 2008); (Das et al., 2020); (Suthar et al., 2009) in their study found that states like Andhra Pradesh, Uttar Pradesh, West Bengal and Rajasthan have nitrate as an impurity in groundwater and it consequences are on quality of water and the health of humans and its pollution in groundwater is due to urban waste and industrial effluents.

2.1. Agricultural activities:

Rekha et al., 2011 found the use of more amount of fertilizers which contain chemicals and pesticides in agricultural land helps in nitrate leaching, which causes more amount of nitrate in groundwater. Peechattukudy and Double, 2017 also found that nitrate is the cause of severe health hazards in human beings. Along with them, Sinha Ray and Elango 2019 observed that in India, nitrate concentration above the permissible limit is detected in many states of India. Also (Suthar et al., 2009) stated that use of heavy amount of fertilizers in cropping system which contain nitrogen is a big way of pollution in groundwater due to anthropogenic activities.

2.2. Industrial activities:

Selvakumar et al., 2017, discovered that industrial effluents from several metropolitan cities that are discharged near water bodies contaminate groundwater as a result of rapid urban development and the growth of industries. Also, they discovered that excessive salt concentrations, sulphate, and nitrate raise critical problems with water used for drinking and domestic uses. The shallow aquifer has been contaminated by the effluent of different industrial activities in cities. According to (Ado et al., 2015), the extent of the impact of the growth of industries and its effluents has a major effect on groundwater pollution, like the effluent discharged from tanneries and detergent industries into the river. Because of the geographical distribution, or the existence of fluoride belt-3 throughout the nation, fluoride is naturally present in the ground water in India.

2.3. Activities in Dumping site:

According to Yasin et al., 2017, open dumping and the disposal of municipal solid waste in landfills are prevalent practices in developing nations and it was concluded that poor waste management leads to groundwater contamination from Leachates discharge. Health, land, water, and air were discovered to be the regions most susceptible to damage from open dumping (Muhammad and Zhonghua 2014). Researchers like (Sajid et al., 2012) discovered that there is a direct influence on groundwater due to the open dumping of waste. According to research by Chakraborti et al. (2011) groundwater aquifers can become contaminated with nitrate and by leakage bacteria into untreated sewage dumping places and leaches from waste dumps. In addition, (Raju 2006) describes the iron-related pollution of blending processes and home sewage leakage effluents that takes place in the Andhra Pradesh, India, region surrounding Tirumala-Tirupati.

2.4. ANTHROPOGENIC EFFECT OF CONTAMINATION IN GROUNDWATER:

The illnesses caused by pollution include cancer, dermatitis, digestive and respiratory issues, nervous system disorders, and many others (Wang et al., 2021). (Majumdar and Gupta 2000) examined health data indicating that excessive nitrate levels in European consumers' water contribute to stomach cancer. It results in conditions like stomach cancer in adults and infants, as well as the blue baby syndrome (also known as newborn methemoglobinemia) (WHO, 2017). Along with other researchers (Eggers et al., 2018) found that groundwater contains a high concentration of nitrate, putting pregnant women, young children, and infants at danger of health problems and even death.

3.GEOGENIC ACTIVITIES:

The chemical characteristics of groundwater are influenced by the solubility of minerals and chemical processes that regulate the release of trace elements from aquifer materials. As a result of the interaction between groundwater and aquifer materials, natural (geogenic) hazardous materials have the potential to contaminate groundwater and cause serious health issues for people (Hug et al., 2020). Moreover, (Romic and Romic 2003) noted that the iron in ground water is primarily sourced from geogenic processes in the urban region. Together with them (Zuane 1990), indicated that groundwater chemical contamination has depended on the sedimentology of the soil, in which water passes prior to reaching the artisan basin. (Ramesh et al., 1995) and his colleagues discovered that groundwater becomes contaminated as a result of the biochemical activity of soils and rocks. Also (Gaonkar et al., 2019), has shown that fluoride contamination of groundwater is caused by geogenic processes, and sources include the kind of rocks, how rocks interact with water, ion exchange, leaching, and fluoride mineral composition.

3.1. AGENTS BY WHICH GEOGENIC CONTAMINATION CAUSED:

The chemical composition of groundwater is a result of both kinetically controlled reactions with the artesian basin and water that seeps into the subsurface (Appelo and Postma 2005). The type of rock and the manner in which abrasive materials aggregate are the two main factors affecting the water quality in wells drilled through solid rock (Banks et al., 1998). Importantly, the phenomena and makeup of groundwater are determined by the aquifer's geological characteristics (Demlie et al., 2007). Due to the cessation of raw material deposits inside the Earth's crust, including gasoline, oil, road salts, and chemicals, the contaminants in groundwater are of geogenic nature (Basu et al 2014; Pandey et al. 2016; Subba Rao et al. 2020; He et al. 2020). Srivastava et al., (2014) noted that highly penetrable formations such as permeable deposits, laterites, and alluvium can move the surface contamination to the bottom of artesian basins. Chouhan and Flora (2010) explained that fluoride and arsenic are the two most pervasive geogenic contaminants in the world, with fluorine in the form of fluoride and arsenic in the form of arsenate or arsenite which affects hundred of billions people in worldwide. By studying the geochemical process of groundwater, researchers like Pant et al. (2021) discovered that an area having high concentration of heavy metals in the groundwater is a result of the geology and geochemical activity happening inside the earth crust.

Demlie et al. (2007) found that the geological conditions of the artesian basin control the phenomena and composition of groundwater by comparing its chemical components. In their geological investigation, the researchers (Regenspurg et al., 2022) discovered that fumarolic gases, which are abundant in aquifers, due to lack of calcium and fluoride which is associated with volcanic activity. Different types of rocks have different effects on filters and how elements are released into groundwater. S. Ali, S. Thakur, (2016); La Olaka, (2016), discovered that volcanic rocks, which contain fluoride scrambled in groundwater due to interactions between water and rock in the artesian basin, eventually leading to an excess amount of fluoride accumulation in groundwater. Narsimha and Venkatayogi, (2017); Venkatayogi, (2015), found that the normal sources of fluoride in the rocks having F-bearing minerals are like amphiboles, apatite, biotite, and other minerals that outcrop the area. They concluded that the rocks that surfaced in the area were irresponsible because of the elevated fluoride levels in the surface water. They also discovered that the geogenic sources of fluoride in granitic rocks such fluorite, micas, apatite, amphiboles, etc. and in minerals like clay, apatite, hornblende, and biotite which are the simple benefactor of contamination (Subba Rao, 2018). In his study, (Anazawa, 2006) discovered that volcanic rocks contained the highest concentrations of fluoride, followed by alkaline igneous rocks, ultramafic rocks, and lime stone. CEPA, 1996 discovered in his study that the source of fluoride in aquatic sprinklers, which provide roughly 20000 kg of inorganic fluoride globally each year. (Vithanage and Bhattacharya, 2015) discovered in their investigation that soil fluoride concentration was also present due to the presence of rocks containing granite and gneisses.

According to the research on geogenic contaminants in groundwater (Panno et al., 2006; Mullaney et al., 2009), found that weathering of saline intrusions, volcanic activity, bed rock, natural brines, and climatic settling had no effect on chloride levels. Also Pande and Moharir (2018); Kothari et al., (2021) discovered that the soil porosity and rocks' permeability of an area also have a significant effect in boosting the concentration of chloride. According to (Ahada and Suthar, 2017), the geology of a particular region is caused by the depletion of important cations like magnesium and calcium, which causes the weathering and dissolution of calcium and magnesium-containing rocks and makes the groundwater hard in nature.

Tisserand (2014) discovered that minerals containing sulphur, such as pyrite, anhydrite, and gypsum, are the sources of sulphates in geogenic contamination. Also, Subba Rao (2018) investigated how aquifer mineral sulphates dissolve in groundwater. Ligate et al., (2021) stated that various characteristics of geographical development in groundwater have different properties and structures in aquifer and groundwater composition. Harmful inorganic pollutants are mixed into groundwater under specific circumstances, such as pH low and high. Many sources contribute to the presence of nitrate in groundwater.

In unconfined and fractured aquifers, mixing of water from various sources frequently affects the nitrate concentration. Nitrate concentrations in aquifers are typically shown to decrease with depth or down gradient, according to the study by (Panno et al., 2006). Also Rajmohan and Elango (2005), found the presence of lithogenic and non-lithogenic sources in the district Palar and Cheyyar of Tamil Nadu having high iron concentration. (Raju 2006) describes the iron contamination of groundwater caused by the dissolved rocks and ferruginous minerals. Also, it has been discovered that soil's lateritic nature is to blame when groundwater has a high iron level.

3.2. EFFECT OF GEOGENIC CONTAMINATION IN GROUNDWATER :

Arsenic contamination of groundwater affects a large population in West Bengal and Bangladesh. According to WHO report, it is the "biggest population poisoning in history" (Smith et al., 2000). Marghade et al. (2020) discovered that a higher fluoride concentration (1.5 mg/L) can lead to skeletal and dental fluorosis, but that a higher concentration in food and water is hazardous to health. Also, Micozzi (1994) discovered that iron stains clothes, dishes, teeth, and gums, which promotes bacterial growth and reduces water flow. Moreover, increased iron leads to anaemia and the development of adverse health conditions.

4. FINDINGS OF THE STUDY:

4.1. Major findings of Anthropogenic activities:

Table 1.0- (Anthropogenic contamination)

Sl No.	Type of activities	Type of contaminant	Areas affected and % of affection	References
1	Mining, Pesticide usage	Nitrate	Australia	Stranger et al., (2005); Boyle et al (1998)
2	aluminum refining, fertilizer and semiconductor manufacturing, glass and ceramic production, coal combustion, brick manufacturing,	Fluoride	Pakistan	Pickering 1985; Rahaman et al., 2011
3	Dumping sites/ waste water	Nitrate, Iron, Chloride	Assam, Bihar, Chhattisgarh, J&K, Jharkhand, Madhya Pradesh, Manipur, Orissa areas are affected due to iron	Sunpriya acharya (2014); Bhatnagar and Pooja, (2013)
4	Agriculture	Nitrate, Fluoride, Sulphate	1.46–3.28 mg/L fluoride contamination is found in Rajasthan Jhunjhunu district	Borah and Saikia (2011); Suthar et al., (2008)
5	Industry	Fluoride, Nitrate	< 10 mg/l nitrate is found in industry	Mishra et al., (2009)

4.2. Major findings of Geogenic activities:

Table 2.0- (Geogenic contamination)

Sl No.	Sources of generation	Type of contaminant	Areas affected and % of affection	References
1	Aquifer properties and aquifer geometry of a region	Arsenic	Asia (32), Europe (31), Africa (20), Australia (4)	E. Shaji et al., (2020)
2	Padma- Meghna plain, Bed-rock Groundwater, Lower Mekong basin aquifer, Volcanic deposits	Arsenic	Bangladesh, Canada, Cambodia, Argentina	Chakraborti et al., (2015); Dhar et al., (1997); Stranger et al., (2005); Boyle et al (1998)
3	As-rich pyrite, arsenopyrite, orpiment and realgar, Sedimentary and Igneous rock, and in Earth crust	Arsenic	40 thousand people are affected through arsenic contamination in West Bengal (Malda, Bankura, Purulia)	Swaran (2015); Mandal et al., (1996); Acharyya (2005); Saha (2009)
4	Igneous, Metamorphic, granite, sedimentary rocks, lime stone, evapotranspiration and Volcanic activity,	Fluoride	60% of areas are affected in India and affected countries like Bulgaria, Brazil, Australia	Kimambo et al., (2019); Ayoob and Gupta, (2006)
5	Lithogenic and Non lithogenic source, Dissolution of rocks and ferruginous mineral, ubiquitous chemical contamination in aquifer	Iron, Chloride, Sulphate, Nitrate	Bihar (31-38 districts)	Rajmohan and Elango (2005); Raju (2006)

4.3 Districts/ areas of different states in India have fluoride contamination in groundwater more than 1.5 mg/L

Table 3.0- (Study of Fluoride contaminated areas in different parts of India)

Sections	Areas affected by Fluoride	Polluted districts	Range (mg/l)	References
East	Assam	Karbi	1.6-29.0	Das et al., 2003
	Bihar	Gaya, Nawada	0.2-8.32	Ray et al., 2000; Singh et al., 2009
	Chhatisgarh	Raipur, Durg, Korba	>10	Patel et al., 2015
	Odisha	Balasore, Anugul, Bhadrak, Baudh, Deogarh, Dhenkanal, Jajpur, Khurda, Nayagarh, Sonpur,	0.6-9.2	Das et al., 2003; Mishra et al., 2009
	West Bengal	Nadia, Purulia	1.1-14.47	Chakrabarti and Bhattacharya, 2013;
North	Delhi	North West Delhi, South West Delhi, West Delhi, New Delhi, North Delhi	0.2 -32.0	Singh et al., 2009; Susheela et al., 1996;
	Haryana	Jhajjar, Kaithal, Fatehabad	0.23 -18.0	Bishnoi and Malik, 2009; Gupta and Mishra, 2014;
	Rajasthan	Ajmer, Alwar, Banswara, Barmer, Bhilwara, Bikaner, Churu, Dausa, Jhunjhunu, Chittaurgarh	0.1 -10.0	Madhavan and subramanium, 2002;
West	Gujarat	Panchmahals, Porbandar,	1.5 -18.0	Chinoy et al., 1992
South	Andhra Pradesh	Adilabad, Anantpur,Vishakhapatnam	0.4 -29.0	Rao and Devdas, 2003; Sujatha (2003)

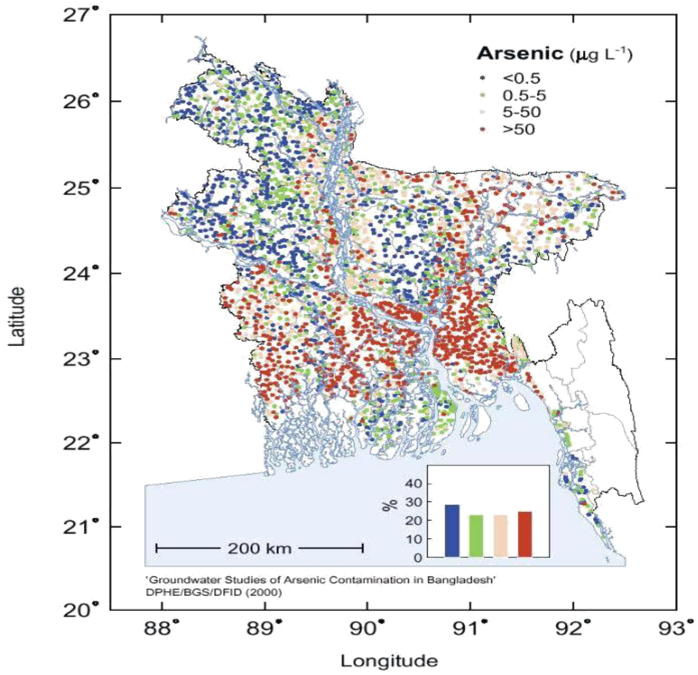

Fig 1- (Contamination map of Arsenic in Bangladesh Ref BGS and DPHE, 2000)

(BGS and DPHE, 2000) describes the map of Bangladesh where Arsenic contamination in groundwater is more on large and smaller scales. Particularly high as concentrations are frequently found in the south and southeast of the country.

5 . FOCUS ON GEOGENIC CONTAMINANTS:

The national and international focus of geogenic contaminants are:

International	National	Contaminants	References
Morocco, Argentina, Egypt, Turkey, Iran Ethiopia, China, Brazil, USA	Assam, Bihar, Chattisgarh, Odisha, West Bengal, Delhi, Haryana, Rajasthan	Fluoride	CGWB (2014), Mumtaz et al., (2015), State of Environment report (2009)
Bangladesh, Western USA, Mongolia, Chile, Argentina, Mexico,	Assam, Bihar, Jharkhand, Karnataka, Punjab, West Bengal	Arsenic	Radheshyam Jadav (2017) Times of India
Brazil, Chile, India, South Africa	Assam, Gujrat, Haryana, Odisha, Bihar, Tripura, West Bengal	Iron	Ministry of Jal Shakti

5.1 Pictorial view of contaminated areas globally and in India:

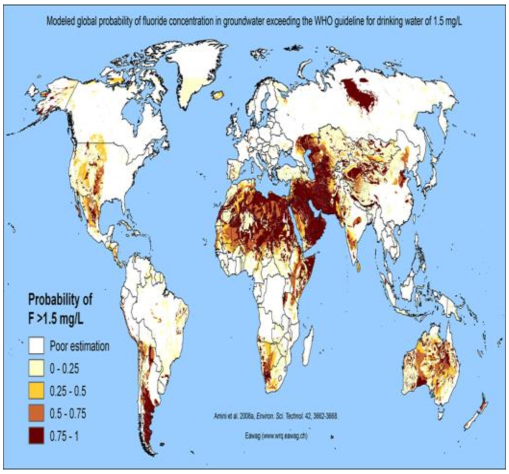

Fig 2. (Global view of Fluoride contamination)

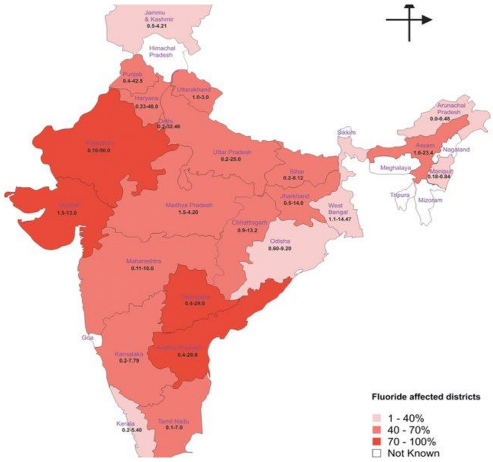

Fig 3. (India view of Fluoride contamination)

Fig 4. (Global view of Arsenic contamination)

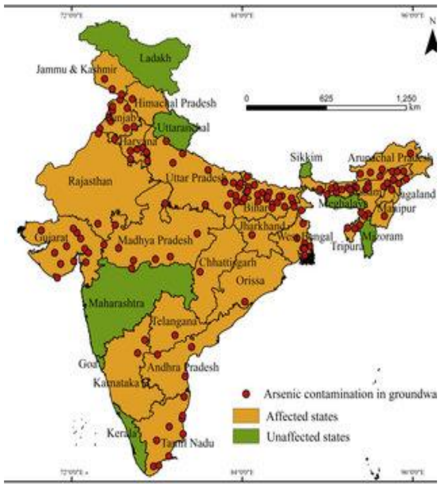

Fig 5. (Indian view of Arsenic contamination)

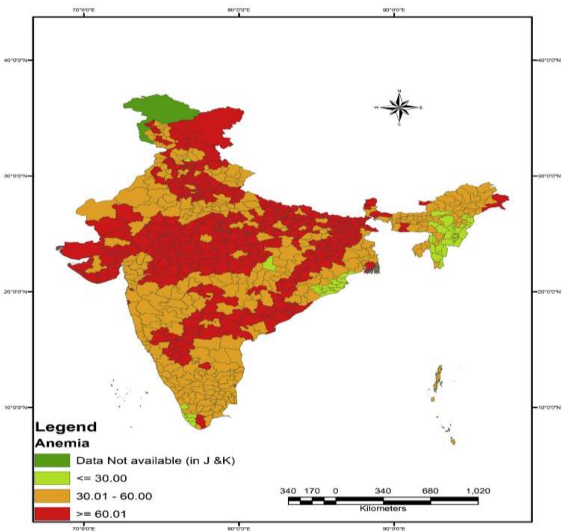

Fig 7. (Indian view of iron contamination states)

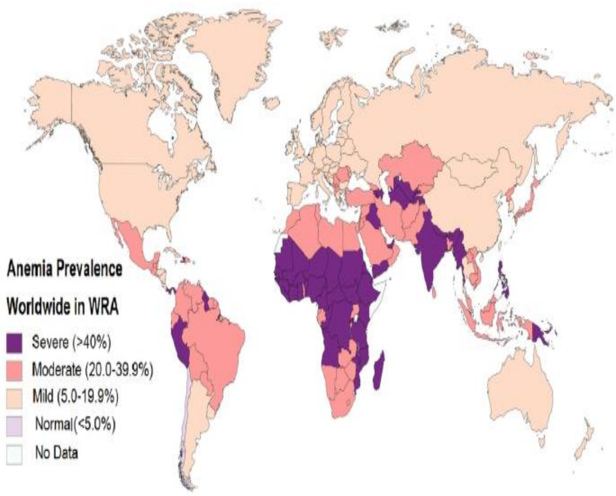

Fig 6. (Global view of Iron contamination)

6 . CONCLUSION:

As per the literature review, it is concluded that the major factors contributing for groundwater contamination are the anthropogenic activities. Out of anthropogenic activities, agriculture is the major contributing factor in groundwater contamination. Among all anthropogenic contaminants, nitrate and fluoride are the cause for higher side of contamination. These contaminants mostly originated from the pesticides and insecticides used in the agricultural fields. Countries like Australia, Pakistan and India, are mostly affected by nitrate and fluoride. Similarly, among geogenic contaminants, Fluoride, Sulfate, Iron, Arsenic and Nitrate, also has a greater impact in global scenario and the effect of fluoride is more due to the Fluoride (F^-) bearing rocks, volcanic activity and also partly from arsenic rich pyrite. It is marked that countries like China, Brazil, India, Bangladesh, Canada and Argentina are affected mostly due geogenic activities. Hence, the geogenic contamination is 35-40% globally due to arsenic and fluoride.

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REFERENCES:

[1] Adimalla, Narsimha. "Spatial distribution, exposure, and potential health risk assessment from nitrate in drinking water from semi-arid region of South India." *Human and ecological risk assessment: an international journal* 26.2 **(2020)**: 310-334..

[2] Adimalla, Narsimha, and Hui Qian. "Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in the agricultural region of Nanganur, south India." *Ecotoxicology and environmental safety* 176 **(2019)**: 153-161.

[3] Ado, Abdulmumini, et al. "A review on industrial effluents as major sources of water pollution in Nigeria." *Chemistry Journal* 1.5 **(2015)**: 159-164.

[4] Akhtar, Naseem, et al. "Various natural and anthropogenic factors responsible for water quality degradation: A review." *Water* 13.19 **(2021)**: 2660.

[5] Annan, Kofi. "Water is essential for life." *General Assembly Report (A/60/158)* **(2005)**.

[6] Basu, Ankita, et al. "A review on sources, toxicity and remediation technologies for removing arsenic from drinking water." *Research on Chemical Intermediates* 40 **(2014)**: 447-485.

[7] Belkhiri, Lazhar, et al. "Spatial analysis of groundwater quality using self-organizing maps." *Groundwater for Sustainable Development* 7 **(2018)**: 121-132.

[8] Briffa, Jessica, Emmanuel Sinagra, and Renald Blundell. "Heavy metal pollution in the environment and their toxicological effects on humans." *Heliyon* 6.9 **(2020)**: e04691.

[9] Brindha, K., and L. Elango. "PAHs contamination in groundwater from a part of metropolitan city, India: a study based on sampling over a 10-year period." *Environmental earth sciences* 71 **(2014)**: 5113-5120.

[10] Chouhan, Swapnila, and S. J. S. Flora. "Arsenic and fluoride: two major ground water pollutants." **(2010)**.

[11] Chowdhury, Anirban, et al. "A critical review on geochemical and geological aspects of fluoride belts, fluorosis and natural materials and other sources for alternatives to fluoride exposure." *Journal of Hydrology* 574 **(2019)**: 333-359.

[12] Coyte, Rachel M., et al. "Co-occurrence of geogenic and anthropogenic contaminants in groundwater from Rajasthan, India." *Science of the Total Environment* 688 **(2019)**: 1216-1227.

[13] CWC. “Water and related statistics”. Central Water Commission, Department of Water Resources, RD and GR, Ministry of Jal Shakti, Government of India, New Delhi, India **(2019)**.

[14] Dalin, Carole, et al. "Groundwater depletion is embedded in international food trade." *Nature* 543.7647 **(2017)**: 700-704.

[15] Das, Madhumita, et al. "Groundwater quality assessment and mapping using multivariate statistics and analytic hierarchy process in Bhubaneswar city, Odisha, India." *International Journal of Water* 12.3 **(2018)**: 195-207.

[16] Demlie, Molla, et al. "Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, central Ethiopia." *Hydrogeology Journal* 15.6 **(2007)**: 1169-1181.

[17] Hassan, K. “Groundwater pollution in some areas between the Al-Kifl stream and the Shatt al-Hindi. J. Hum”. Sci/Coll. Educ. Humanit, 23 **(2016)**.

[18] He, Xiaodong, et al. "Poor groundwater quality and high potential health risks in the Datong Basin, northern China: research from published data." *Environmental geochemistry and health* 43 **(2021)**: 791-812.

[19] Howard, Ken, and Richard Gerber. "Impacts of urban areas and urban growth on groundwater in the Great Lakes Basin of North America." *Journal of Great Lakes Research* 44.1 **(2018)**: 1-13.

[20] Hug, Stephan J., et al. "Arsenic and Other Geogenic Contaminants in Groundwater–A Global Challenge." *Chimia* 74.7-8 **(2020)**: 524-524.

[21] Jandu, Anchal, Anju Malik, and Sanju Bala Dhull. "Fluoride and nitrate in groundwater of rural habitations of semiarid region of northern Rajasthan, India: a hydrogeochemical, multivariate statistical, and human health risk assessment perspective." *Environmental Geochemistry and Health* **(2021)**: 1-30.

[22] Kaur, Lakhvinder, et al. "Hydrogeochemical characterization of groundwater in alluvial plains of river Yamuna in northern India: An insight of controlling processes." *Journal of King Saud university-science* 31.4 **(2019)**: 1245-1253.

[23] Keesari, Tirumalesh, et al. "Understanding the hydrochemical behavior of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India–a step towards sustainable development." *Groundwater for Sustainable Development* 2 **(2016)**: 143-153.

[24] Li, Peiyue, and Hui Qian. "Water resources research to support a sustainable China." *International Journal of Water Resources Development* 34.3 **(2018)**: 327-336.

[25] Li, Peiyue, et al. "Sources and consequences of groundwater contamination." *Archives of environmental contamination and toxicology* 80 **(2021)**: 1-10.

[26] Ligate, Fanuel, et al. "Groundwater resources in the East African Rift Valley: Understanding the geogenic contamination and water quality challenges in Tanzania." *Scientific African* 13 **(2021)**: e00831.

[27] Loucks, Daniel P. "Sustainable water resources management." *Water international* 25.1 **(2000)**: 3-10.

[28] Majumdar, Deepanjan, and Navindu Gupta. "Nitrate pollution of groundwater and associated human health disorders." *Indian journal of environmental health* 42.1 **(2000)**: 28-39.

[29] Maurya, Jitendra, et al. "Evaluation of ground water quality and health risk assessment due to nitrate and fluoride in the Middle Indo-Gangetic plains of India." *Human and Ecological Risk Assessment: An International Journal* 27.5 **(2020)**: 1349-1365.

[30] Mohapatra, M., et al. "Review of fluoride removal from drinking water." *Journal of environmental management* 91.1 **(2009)**: 67-77.
[31] Muhammad, Akhtar Malik, and Tang Zhonghua. "Municipal solid waste and its relation with groundwater contamination in Lahore, Pakistan." *Research Journal of Applied Sciences, Engineering and Technology* 7.8 **(2014)**: 1551-1560.
[32] Mullaney, John R., David L. Lorenz, and Alan D. Arntson. *Chloride in groundwater and surface water in areas underlain by the glacial aquifer system, northern United States*. Vol. **2009**. Reston, VA: US Geological Survey, **2009**.
[33] Mukate, Shrikant, et al. "Impact of anthropogenic inputs on water quality in Chincholi industrial area of Solapur, Maharashtra, India." *Groundwater for Sustainable Development* 7 **(2018)**: 359-371.
[34] Adimalla, N., and S. J. E. E. S. Venkatayogi. "Mechanism of fluoride enrichment in groundwater of hard rock aquifers in Medak, Telangana State, South India." *Environmental Earth Sciences* 76 (**2017**): 1-10.
[35] Nightingale, Harry I., and William C. Bianchi. "CORRELATION OF SELECTED WELL WATER QUALITY PARAMETERS WITH SOIL AND AQUIFER HYDROLOGIC PROPERTIES 1." *JAWRA Journal of the American Water Resources Association* 16.4 **(1980)**: 702-709.
[36] Pande, Chaitanya B., and Kanak Moharir. "Spatial analysis of groundwater quality mapping in hard rock area in the Akola and Buldhana districts of Maharashtra, India." *Applied Water Science* 8 **(2018)**: 1-17.
[37] Pandey, H. K., S. K. Duggal, and Ajit Jamatia. "Fluoride contamination of groundwater and it's hydrogeological evolution in District Sonbhadra (UP) India." *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences* 86 **(2016)**: 81-93.
[37] Pant, Neeraj, et al. "Impact of geology and anthropogenic activities over the water quality with emphasis on fluoride in water scarce Lalitpur district of Bundelkhand region, India." *Chemosphere* 279 **(2021)**: 130496.
[38] Panno, S. V., et al. "Characterization and identification of Na-Cl sources in ground water." *Groundwater* 44.2 **(2006)**: 176-187.
[39] Peechattukudy, Lizmol A., and R. M. Dhoble. "Removal of nitrate from water by adsorption–A review." *IJSTE-International Journal of Science Technology & Engineering* 3.09 **(2017)**: 322-325.
[40] Rashid, Abdur, et al. "Hydrogeochemical assessment of carcinogenic and non-carcinogenic health risks of potentially toxic elements in aquifers of the Hindukush ranges, Pakistan: Insights from groundwater pollution indexing, GIS-based, and multivariate statistical approaches." *Environmental Science and Pollution Research* 29.50 **(2022)**: 75744-75768.
[41] Regenspurg, Simona, et al. "Origin and migration of fluoride in the area of the Aluto Volcanic Complex (Main Ethiopian Rift)." *Applied Geochemistry* 146 **(2022)**: 105403.
[42] Rekha, P. Nila, et al. "Nitrate leaching to shallow groundwater systems from agricultural fields with different management practices." *Journal of Environmental Monitoring* 13.9 **(2011)**: 2550-2558.
[43] Farid, Sajid, Musa Kaleem Baloch, and Syed Amjad Ahmad. "Water pollution: Major issue in urban areas." *International journal of water resources and environmental engineering* 4.3 **(2012)**: 55-65.
[44] Selvakumar, S., N. Chandrasekar, and G. Kumar. "Hydrogeochemical characteristics and groundwater contamination in the rapid urban development areas of Coimbatore, India." *Water Resources and Industry* 17 **(2017)**: 26-33.
[45] Sinha Ray, S. P., and L. Elango. "Deterioration of groundwater quality: implications and management." *Water governance: Challenges and prospects* **(2019)**: 87-101.
[46] Srivastava, SUDHIR K., J. S. Bhargav, and Y. S. Kumar. "Contamination of shallow groundwater of Bhubaneswar city due to urbanization." *Pollution Research* 33.1 **(2014)**: 139-14.
[47] Subba Rao, N., B. Ravindra, and Jianhua Wu. "Geochemical and health risk evaluation of fluoride rich groundwater in Sattenapalle Region, Guntur district, Andhra Pradesh, India." *Human and ecological risk assessment: An international journal* 26.9 **(2020)**: 2316-2348.
[48] Suthar, Surindra, et al. "Nitrate contamination in groundwater of some rural areas of Rajasthan, India." *Journal of hazardous materials* 171.1-3 **(2009)**: 189-199.
[49] Tanwer, Naresh, et al. "Spatial distribution of uranium in groundwater and its health risk assessment in Haryana, India." *Rasayan Journal of Chemistry* 15.01 **(2022)**: 343-349.
[50] Tisserand, Delphine, et al. "Geogenic arsenic in groundwaters in the western Alps." *Journal of Hydrology* 518 **(2014)**: 317-325.
[51] Tsegaye, Teferi, et al. "Development of chemical index as a measure of in-stream water quality in response to land-use and land cover changes." *Water, Air, and Soil Pollution* 174 **(2006)**: 161-179.
[52] Wang, Yanxin, et al. "Genesis of geogenic contaminated groundwater: As, F and I." *Critical Reviews in Environmental Science and Technology* 51.24 **(2021)**: 2895-2933.
[53] WHO, Geneva. "Guidelines for drinking-water quality." *World health organization* 216 **(2011)**: 303-304.
[54] World Health Organization. "Guidelines for drinking-water quality: first addendum to the fourth edition." **(2017)**.

[56] Yasin, Hafsa, and Muhammad Usman. "Site investigation of open dumping site of Municipal Solid Waste in Faisalabad." *Earth Sci. Pak* 1.1 **(2017)**: 23-25.
[57] Zhang, QingLi, et al. "Surface water quality of factory-based and vegetable-based peri-urban areas in the Yangtze River Delta region, China." *Catena* 69.1 **(2007)**: 57-64.
[58] Chakraborti, Dipankar, et al. "Groundwater arsenic contamination in Bangladesh—21 Years of research." *Journal of Trace elements in Medicine and Biology* 31 (2015): 237-248.
[59] Dhar, Ratan Kr, et al. "Groundwater arsenic calamity in Bangladesh." *Current science* (1997): 48-59.
[60] Stagner G, VanTroung T, Le Thi My Ngoc KS, Luyen TV, Thanh TT. Arsenic in groundwaters of the Lower Mekong. Environ Geochem Health 2005;27:341-57.
[61] Boyle, D. R., R. J. W. Turner, and G. E. M. Hall. "Anomalous arsenic concentrations in groundwaters of an island community, Bowen Island, British Columbia." *Environmental geochemistry and health* 20 (1998): 199-212.
[62] Pickering, W. F. "The mobility of soluble fluoride in soils." *Environmental Pollution Series B, Chemical and Physical* 9.4 (1985): 281-308.
[63] Rahman, Ismail MM, et al. "Selective separation of arsenic species from aqueous solutions with immobilized macrocyclic material containing solid phase extraction columns." *Chemosphere* 82.4 (2011): 549-556.