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Spatial Analysis of Arsenic Contamination of Groundwater around the World and India

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Abstract: *Arsenic is one of the most poisonous element found on the earth's surface. In the inorganic form, it is more dangerous than in the organic form. The river basins and deltaic regions around the world, particularly in the tropical regions are facing serious problems of arsenic contamination of the groundwater. Most of the arsenic contamination of the groundwater is found in the shallow aquifers up to the depth of the 100 meters below the ground level. This paper analyses the spatial distribution of arsenic in groundwater around the world with special focus on India. Most of the data obtained from the literatures available in the various journals, books and reports. The information about the Indian scenario obtained from the reports of the Central Groundwater Board and the Ministry of Drinking Water and Sanitation. The data is plotted on the map with the help of ArcGIS 10.4.1.*

Keywords: *Arsenic, Groundwater, ArcGIS, Shallow aquifers, water contamination*

1. INTRODUCTION

Arsenic (As) with atomic number 33, atomic mass 74.9216 and melting point 816.8^{0}C is the 20th most abundant element in the earth's crust and 53rd most abundant on the earth's surface. As is an element of great concern in the environment due to the high toxicity of its certain species and wide occurrence in the environment. It is a metalloid that can combine with both metals and non-metals to form organic and inorganic compounds. It also shows metallic properties and it also co-exists with other metals like Iron, Copper, Nickel, Zinc, etc. and sulfide and oxide ores[1].

The very sustainability of the earth and the practice of day to day life depend upon the supply, circulation, and elimination of water. The complex system of the human body and the environment around it depends upon the perpetual circulation of water into, through and out of it. Even though it is fact that more than one billion people worldwide are still suffering from inadequate, unreliable (both quality and quantity) and/or difficult access to clean water and almost two billion from unsatisfactory sanitation (WHO reports).

Till the 1970s people in Ganga-Brahmaputra-Meghna (GBM) plain used surface water for their drinking and domestic needs. Due to the presence of a large number of pathogens in the surface water, they were responsible for a large number of diseases such as diarrhoea, cholera, dysentery especially among the children below the age of five years. These issues forced the people and authorities to promote the groundwater for drinking because as it was a safe and reliable source of water and also free from pathogens. A large number of handpumps and tubewells were drilled in the shallow aquifers of the Holocene period containing Arsenic for the purpose.

2. SOURCES OF ARSENIC IN WATER

2.1 Natural Sources of Arsenic in Water

The total amount of Arsenic in the earth's crust is estimated to be around 4.01 x 10^{16} Kg [2], [3]. 65% of the Arsenic deposit in the earth crust took place during the Carboniferous period although the world wide large scale groundwater contamination is reported from the late quaternary and deltaic deposits. The Arsenic which is responsible for the water contamination in GBM plain is of Quaternary origin and is associated with Holocene alluvial deposits. In the states of Assam, Meghalaya, Mizoram, Punjab, and Haryana, rivers originating in the Himalayas brought bring deposits in the form of load. The Indus region differs from GBM plain in the way that former having a relatively more arid climate, the prevalence of older quaternary (Pleistocene) deposits and dominance of unconfined and aerobic aquifer with greater apparent connectivity between the river systems and the aquifers than the latter.

More than 300 Arsenic containing minerals are found in nature. Of these, ~60% are arsenate, ~20% are sulfides and sulphosalts ~10% are oxides and the rest are arsenite, arsenide, native elements, and metal alloys. The most predominant presence in ores is Arsenian pyrite (Fe ($SAs0_2$), Arsenopyrite (FeAsS), lollingite ($FeAs_2$), Realgar (AsS), Orpiment (As_2S_3), Cobaltite (CoAsS), Niccolite (NiAs) and Cordite ($FeAsO_4.2H_2O$). ($Fe(AsS)_2$) is certainly the largest source of Arsenic in ore zones [4], [5] whose concentration is more than 10 wt.% (up to 19%)[6], [7]. Sulfide minerals such as chalcopyrite and Galena possesses a high amount of Arsenic and other trace element such as transition metals, Cadmium, Lead, Silver, Antimony, Gold, Phosphorous, Tungsten and Molybdenum. There are many oxide minerals and hydrous metal oxides where the presence of a large amount of Arsenic is found, either present in the mineral structure or is adsorbed in it.

Metamorphic rocks such as pelitic (slates and Phyllite) are known to have the highest concentration of Arsenic with an average of 18 mg Arsenic per kg of rocks. Concentration in sedimentary rocks are in the range 5-10mg/kg [8]. The concentration of Arsenic in the sedimentary rocks are more in comparison to igneous and metamorphic rocks. Sand and sandstone contain a lower amount of Arsenic in it due to the predominance of low Arsenic minerals (quartz and feldspar). The average concentration in sandstone is 4 mg/kg.

The composition of unconsolidated sediments does not differ from their indurated equivalents. Evidence shows that mud and clay have a higher concentration than sand and most carbonates depending upon texture and mineralogy. High concentration reflects an abundance of pyrite or iron. The abundance of sulfide minerals in the placer deposits in the streams establishes the relationship of sulfide and Arsenic concentration. Sediments from the rivers in the Bengal basin have Arsenic concentration averaging 2.0, 2.8 and 3.5mg/kg are generally found in samples from the GBM river respectively [9].

2.2 Anthropogenic Sources of Arsenic in Water

Various anthropogenic sources induce Arsenic concentration in groundwater. These are industrial wastes, ore processing, metal extraction, smelting, metal purification, alloys, chemical, glass, cement, leather industries. Industries that make fertilizers, pesticides, herbicides, fungicides, etc.; petroleum refineries, oil industry, pigment industries, coal mining, mine tilling, acid mine drainage, etc.

2.2.1 Industrialization

Over the years the industrial sector has grown tremendously in India. Certain industrial processes such as smelting of copper and zinc release Arsenic in the environment. Copper smelting produces 62000 tons of Arsenic which constitutes ~80% of the Arsenic released from all the smelters. After independence, growth in the electronic and automobile sector took a great flight. Lead industries have seen a rise due to large demands of batteries which further aggravated Arsenic contamination in the soil and water. Leaching of Arsenic-rich mineral ores form nearby mining areas is one of the most prevalent sources of Arsenic in water.

The Indian coal used in the thermal power plants for generating electricity has high ash content (35-45%) and is of lower quality. Due to the low quality, the coal produces more fly and bottom ash, a fraction of which is utilized and most of it is disposed of in ash ponds and landfills. The burning of coal in power plants releases AsO_6 consequently enters the water bodies through the leaching process [10].

Preservatives containing Arsenicals are used to protect the timber which are not durable from wood-boring crustaceans, mollusks, and fungi. Currently, the most widely used preservative for timber exposed in an aquatic environment is Chromated Copper Arsenate (CCA). 30% of the world's industrially utilized Arsenic is in the making of wood preservatives. Wood preservatives formulations such as CCA contains 22% of the pure Arsenic in it.

2.2.2 Agriculture

Excessive use of fungicides, herbicides, insecticides and phosphatic fertilizers in agriculture contribute to Arsenic contamination of groundwater by leaching to the nearby water bodies in the form of agricultural runoff and then infiltrating to the groundwater sources. The application of phosphatic fertilizers enhances the Arsenic concentration of groundwater since lead arsenate in the fertilizers help in the release of Arsenic in water. Before 1970, the use of Arsenic in the production of pesticides in the form of simple inorganic salts was huge, nearly 80%.

Due to the reduction in the consumption of pesticides in India, now only 50% of the Arsenic produced in India is used in the production of pesticides [2]. Most of the Arsenic compounds that are used in the pesticides are Monosodium Methane Arsenate ($HAsO_3CH_4Na$), Disodium Methane Arsenate ($Na2AsO_3CH_3$), Dimethyl Arsenic acid ($(CH_3)_2AsO_2H$) and Arsenic acid (H_3AsO_4).

2.2.3 In-efficiency in Development of Surface Water Potential Development

In spite of heavy investment of more than 300 billion dollars between 1951-2012 for the construction of large and medium dams, do not stand up to their proclaimed contributions and irrigation has reached only to 45% of India's net sown area. The overall water use efficiency and per capita water storage in these dams are too low in comparison to some of the advanced countries of the world. As the surface water resources could not meet the demands of the people and potential to harness them is not adequate, people are heavily dependent on groundwater, making India the largest groundwater extractor in the world. This resulted in extraction from deep aquifers which is responsible for the downward movement of Arsenic from shallow aquifers to deep aquifers.

Table 1: *Per-capita Storage of Waters in Dams in various countries*

Country	India	China	USA	Australia	Russia
Per-capita storage in Dams (m^3/person)	213	1111	1964	4733	6103

Source: *World Commission on Dams*

3. RELEASE OF ARSENIC IN WATER

Arsenic can be released in the groundwater probably through three different processes.

1. Release of Arsenic through oxidation of Arsenic-rich pyrite.
2. Release of Arsenic through a reductive dissolution of iron hydroxide and release of sorbed Arsenic in the groundwater.
3. Release of Arsenic through anion exchange of sorbed Arsenic with phosphate from fertilizers.

The pumping of oxygen due to an increased number of tubewells leads to the decomposition of the sulfide minerals and releases Arsenic. This process is only possible in some shallow dug wells. However, this is not the most prevalent and main cause of the release of Arsenic to groundwater.

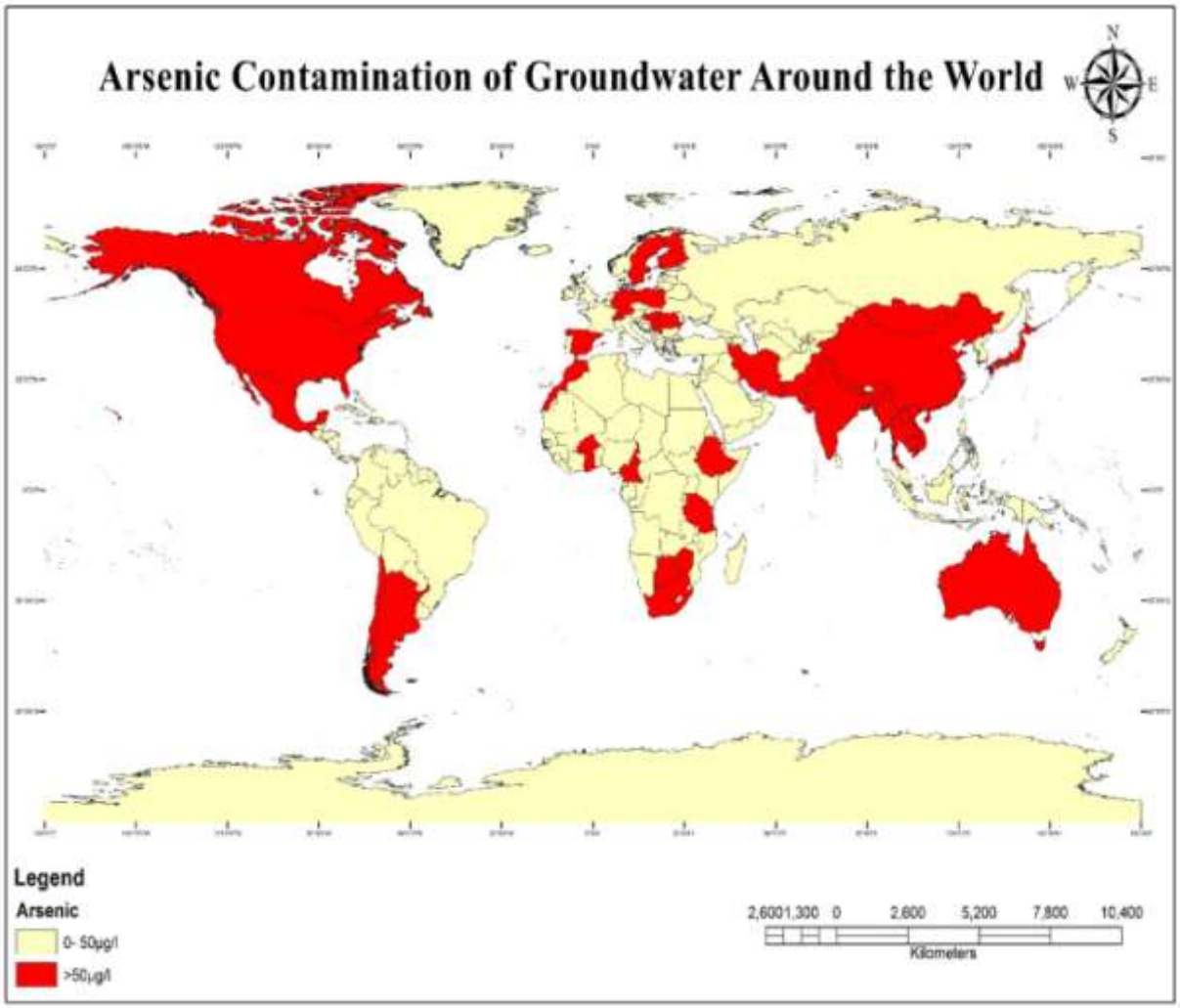
There are some reports about the role of micro-organism in the release of Arsenic to the groundwater where a reducing environment is developed [11]. This mechanism is driven by the microbial oxidation of organic matter in which the concentration of carbon in the aquifer reaches above 6%. This process is one of the most possible ways of the release of Arsenic to the groundwater and has a better explanation than the process associate with the pyrite oxidation [12]. The presence of the organic matter plays an important role in driving the redox reaction in the sedimentary aquifers in places where the source of Arsenic lies in the alluvial deposition brought down by the rivers [11], [13]. It is to be remembered that the distribution of Arsenic pollution has nothing to do with the release of Arsenic in the groundwater. Iron oxide and Arsenic is found everywhere in the sediments of delta plain, but buried swamplands are not. Where there is buried peat there are no bacteria. So, the rainwater percolating into the shallow aquifers retains its dissolved oxygen and, in its presence iron oxide remains stable, holding tightly to its Arsenic.

Another hypothesis states that the release of Arsenic takes place through anion exchange of sorbed Arsenic with phosphate from fertilizers. Most of the phosphate is added to the sediments through the application of fertilizers. However, this hypothesis is unconvincing because the amount of dissolved and sorbed phosphate already present in the aquifer volume exceeds the phosphate added through the application of fertilizers.

4. DISTRIBUTION OF ARSENIC IN WORLD

Arsenic contamination of groundwater is found in more than 100 countries in the world. Most of the Arsenic prone zones are located in the river basins and deltaic areas. The places which have the tropical climate are more vulnerable to Arsenic contamination as this climate favors the release of Arsenic from compounds of Arsenic.

Countries such as Vietnam, Myanmar, China, Mongolia, Taiwan, Cambodia, Lao PDR have areas of high Arsenic concentration in the groundwater. Apart from the Asian countries, several others are facing this threat. These include Argentina, Canada, Chile, Mexico, Hungary, USA and 95 other countries in the world which are depicted in the map given below.



Map-1 *Distribution of Arsenic around the world*

5. DISTRIBUTION OF ARSENIC IN INDIA

Till the year 2008 Indian standard of Permissible limit for Arsenic in water was 50 µg/l but in the year 2009, it was reduced to 10 µg/l. according to the report published by Central Groundwater Board in 2010 the total number of affected district was only 10 [14] but after 8 years another report containing quality of shallow aquifers in India published by CGWB reported that the total number of states having elevated level of Arsenic contamination is 20 [15].

Table-2 *Parts of District having Arsenic contamination of Groundwater between 0.01-0,05 mg/l*

S.No	State	District
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, Madhepura, Muzaffarpur, Purnea, Saharsa, Samastipur, Siwan, Vaishali, W. Champaran
4.	Chhattisgarh	Rajanandgaon
5.	Delhi	East, North Delhi

6.	Daman & Diu	Diu
7.	Gujarat	Amreli, Anand, Bharauch, Bhavnagar, Dahod, Gandhinagar, Kacchh, Mehsana, Patan, Rajkot, Surendranagar, Vadodra
8.	Haryana	Bihwani, Mahendragarh, Palwal, Rohtak, Sirsa, Sonipat
9.	Himachal Pradesh	Kangra
10.	Jammu & Kashmir	Jammu, Kathua, Rajouri
11.	Jharkhand	Sahebganj
12.	Karnataka	Raichur
13.	Madhya Pradesh	Betul, Burhanpur, Chhindwara, Dhar, Khandawa, Mandsaur, Neemach, Umaria
14.	Odisha	Gajapati
15.	Punjab	Faridkot, Gurudaspur, Hoshiarpur, Sangrur, Tarn Taran
16.	Rajasthan	Ganga Nagar
17.	Tamilnadu	Cuddalore, Dindigul, Nagapattinam, Peramblur, Ramnathpuram, Thirunelveli, Thiruvallur, Tuticorin
18.	Telangana	Nalgonda
19.	Uttar Pradesh	Azamgarh, Badaun, Bahraich, Basti, Deoria, Gorakhpur, Jhansi, Kaushambi, Maunath Bhanjnam, Pilibhit, Shahjahanpur
20.	West Bengal	Hoogly, Howrah, Koochbihar, Murshidabad, Nadia, North 24-Pargana, South 24- Pargana

Source: *Central Groundwater Board [15]*

Table-3 *Parts of the district having Arsenic contamination above 0.05 mg/l*

1.	Assam	Cahar, Jorahat, Nagaon, Dhemaji
2.	Bihar	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Purnea, Samastipur, Saran, Vaishali
3.	Chhattisgarh	Rajanandgaon
4.	Haryana	Ambala, Jhajjar
5.	Karnataka	Raichur
6.	Manipur	Bishunpur, Thoubal
7.	Punjab	Amritsar, Ropar, Tarn Taran
8.	Uttar Pradesh	Agra, Aligarh, Azamgarh, Balia, Balrampur, Deoria, Gonda, Gorakhpur, Lakhimpur kheri, Maunath Bhanjanam, Matura, Moradabad
9.	West Bengal	Hoogly, Malda, Murshidabad, Nadia, North 24- Pargana, South 24- Pargana

Source: *Central Groundwater Board Report, 2010 & 2018 [14], [15]*

Map-2 *Arsenic Contamination of Groundwater in India*

The earliest report on Arsenic contamination in India came from Chandigarh and different villages of Punjab and Haryana and Himachal Pradesh in Northern India in 1976 [16]. Then, in the year 1983 Arsenic contamination reports came from West Bengal. In the year 2002 the University of Jadavpur, for the first time, detected Arsenic contamination in the groundwater in Bihar from Semaria Ojhapatti village of Bhojpur District [17]. Then in the year, 2003-04 Arsenic concentration of groundwater were detected in the states of Uttar Pradesh, Assam and Jharkhand [18]–[20]. The only state where Arsenic contamination of groundwater was detected in villages of greenstone belts of Yadgir and Gulbarga districts in the year 2009 is Karnataka in South India.

According to a report published on 19th September 2016 by the Ministry of Drinking Water and Sanitation, Government of India, a total of 13210449 persons are severely affected by the adverse effects of Arsenic contamination of groundwater throughout India. The highest number of victims are from the state of West Bengal where more than 89 lakh persons are affected by it followed by Bihar with more than 16 lakh victims, Uttar Pradesh with 15 lakh victims and Assam with more than 12 lakh victims of Arsenic contamination of groundwater[21]. Two districts of Manipur are also reported to have been affected by this menace however, there is no official data about the number of victims.

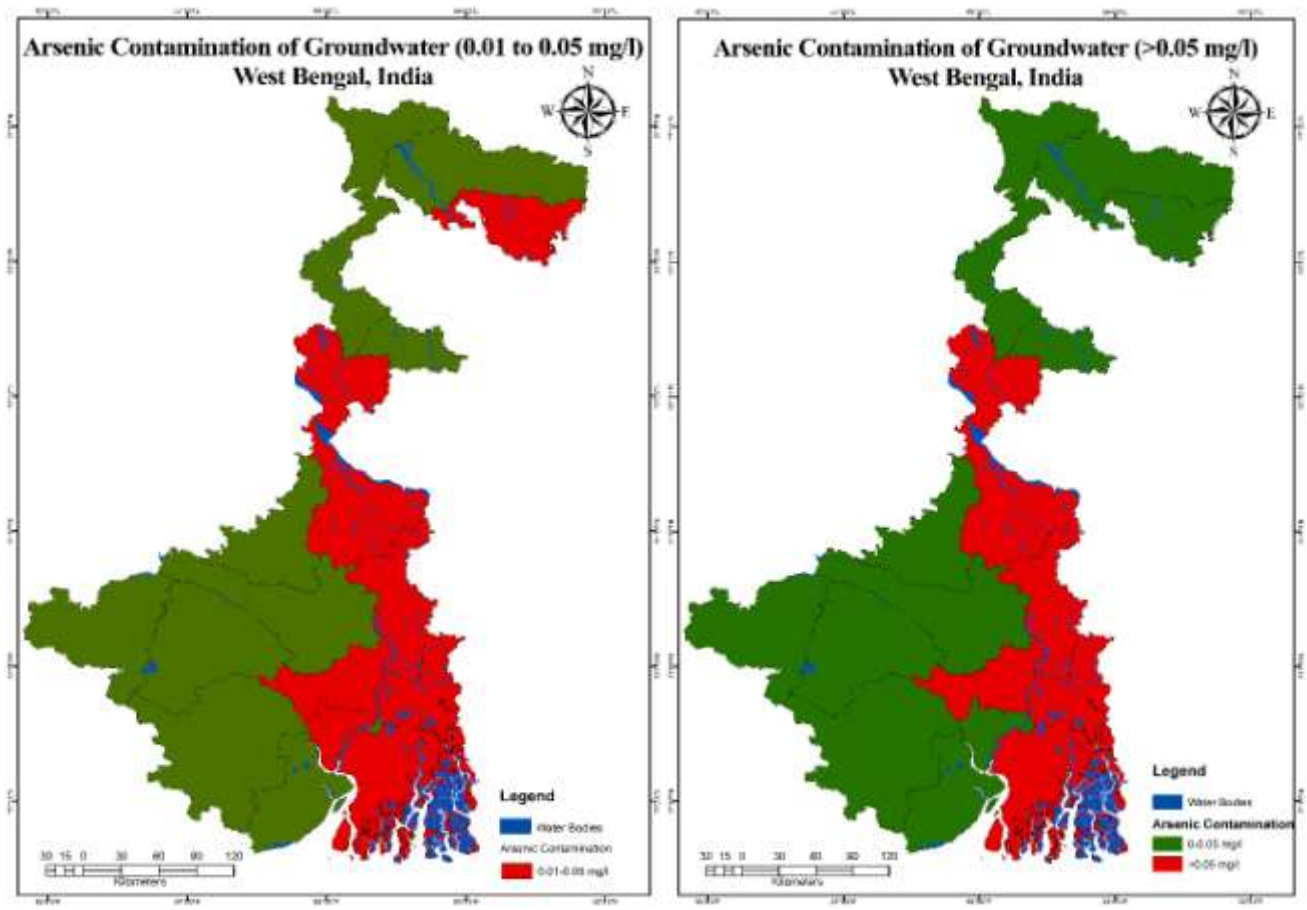
Table 4: *Number of Persons affected by consuming Arsenic-contaminated water in different states of India*

Name of state	**No. of Persons affected**
Arunachal Pradesh	22479
Assam	1236944
Bihar	1666039
Chhattisgarh	NA*
Haryana	142944
Himachal Pradesh	32752
Jammu & Kashmir	3642
Jharkhand	115862
Karnataka	47141
Kerala	7651
Madhya Pradesh	233444
Maharashtra	87
Manipur	NA*
Meghalaya	164
Odisha	42
Punjab	590103
Tripura	1118
Uttar Pradesh	159572
West Bengal	8950460
Total	13210449

Source: *Ministry of Drinking Water and Sanitation Report,2016 [22]*

5.1 West Bengal

The presence of Arsenic in the groundwater was first reported in the 1980s in West Bengal in India. In West Bengal, 79 Blocks in 8 districts are found to have Arsenic concentration in groundwater is above the permissible limit of 0.05 mg/l (permissible limit until 2009). Most of the areas are on the eastern side of the Bhagirathi river in the district of Malda, Murshidabad, Nadia, North 24-Parganas and South 24- Parganas and western side of the district of Howrah, Hoogly and Bardhaman. The occurrence of the Arsenic in the groundwater is mainly confined up to the depth of 100 meters. Below that level aquifers are free from Arsenic contamination. The total area affected by Arsenic contamination is 89193 km^2 which lies along the Ganga and Padma river. These areas have more than 8 million people who are consuming Arsenic-contaminated water. The spatial distribution of Arsenic-contaminated regions of west Bengal is shown in the map given below.

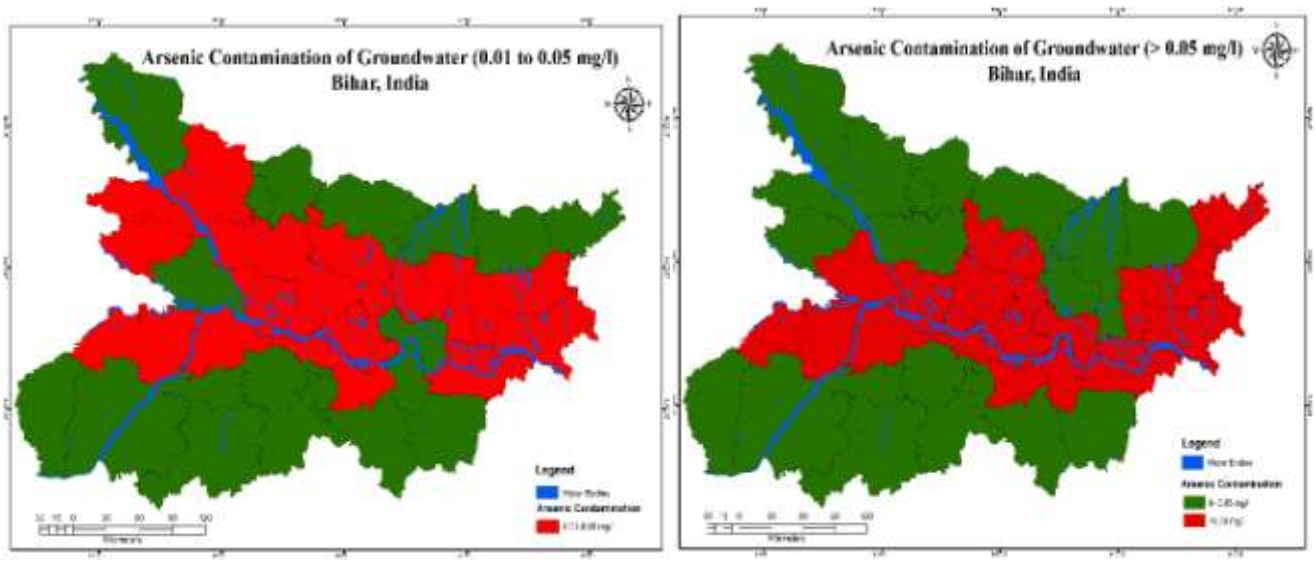


Map 3 & 4: *Arsenic Contamination of groundwater in West Bengal*

5.2 Bihar

Apart from the West Bengal, Arsenic contamination of groundwater has been found in the states of Bihar, Uttar Pradesh, Assam, Chhattisgarh, Haryana, Jharkhand, Karnataka, Punjab. The occurrence of Arsenic in the states of Bihar, West Bengal, and Uttar Pradesh is in alluvial formation but the states of Chhattisgarh it is in the volcanic rocks exclusively confined to N-S trending Donargarh-Kotri rift zone.

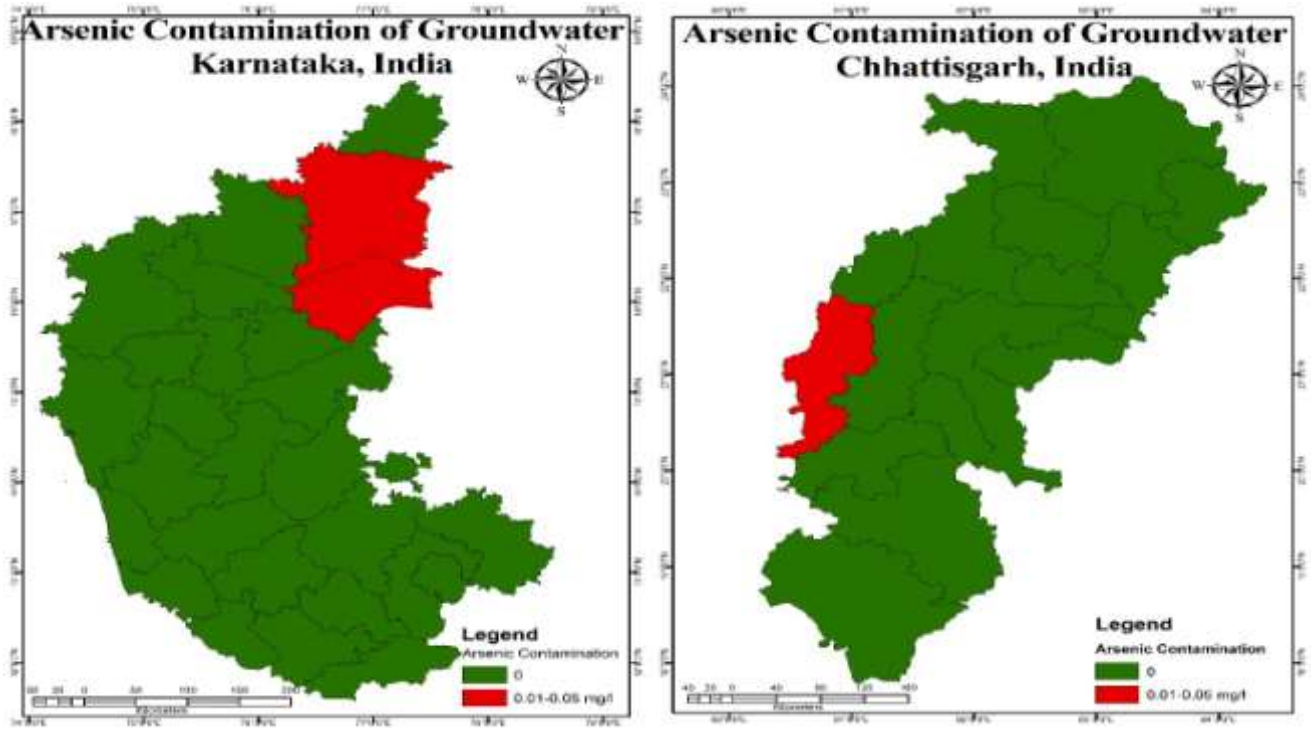
Bihar is the third most populous state in India. The total population of Bihar 10.41 million with a total geographical area of 94163 km^2. In Bihar, more than 16 million people are affected by consuming Arsenic-contaminated water. According to the 2010 report of CGWB, a total of 15 districts of Bihar was affected by Arsenic contamination of groundwater but in the 2018 report, the number has risen to a total of 19 districts. There is a wide variation in the concentration of Arsenic in groundwater in different districts. The districts where concentration level was found to be in the range of 0.01 mg/l to 0.05 mg/l are Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, E. Champaran, Gopalganj, Katihar, Khagaria, Lakhisarai, Madhepura, Muzaffarpur, Purnea, Saharsa, Samastipur, Siwan, Vaishali, W. Champaran. There are certain parts in each district where Arsenic concentration in groundwater is more than 0.05 mg/l and also below that. These districts are Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Purnea, Samastipur, Saran, Vaishali.



Map- 5 & 6: *Arsenic Contamination of Groundwater in Bihar*

5.3 Chhattisgarh and Karnataka

Most of the Arsenic contamination in West Bengal, Bihar, Uttar Pradesh, Haryana, Punjab is due to the deposition of alluvium brought down by the rivers originating from the Himalayas. These alluviums contain compounds such as arsenopyrite which is separated by the physical and chemical reaction in the later stage in the presence of a tropical and humid climate. But, in the case of Chhattisgarh and Karnataka Arsenic contamination is related to the geological origin. Indian plateaus are made by the deposition of volcanic matter and from there only compounds of Arsenic were also deposited in the states of Chhattisgarh and Karnataka. In Chhattisgarh, only one district Rajanandgaon is affected by the Arsenic contamination of groundwater whereas in Karnataka two districts namely Raichur and Yadgir are affected. According to an estimate, more than 100 thousand people in both states combined are leaving in the areas of elevated Arsenic concentration in groundwater.



Map- 7 & 8 *Arsenic Contamination of Groundwater in Karnataka and Chhattisgarh respectively*

6. CONCLUSION

After this study, it can be said that Arsenic is a global threat that victimizes millions of people around the world. There are both natural and anthropogenic sources of Arsenic in the groundwater. A large amount of Arsenic contamination of groundwater is aggravated by unsustainable development projects. The irresponsible nature of the government in the various countries which could not create infrastructure and inefficiently utilized surface water has played a major role in the Arsenic contamination of groundwater. In the world and also in India, most of the Arsenic hotspot regions are located near the river basins. The alluvium deposited by the rivers in millions of years is the major source of Arsenic in plain areas. but, in the plateaus, volcanic rocks are responsible for the Arsenic contamination of groundwater. Indian states which are located in the northern plains are the most affected because these states are densely populated and also the governments in these states failed to respond in time.

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