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Arsenic Contamination of Groundwater in Bhojpur District of Bihar, India: A Threat to Sustainability

Zanieczyszczenie wód gruntowych arsenem w dystrykcie Bhojpur w Bihar w Indiach: zagrożenie dla zrównoważonego rozwoju

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Abstract
Arsenic contamination of water is now a global problem. More than 100 countries, including India, are facing the problem of a high level of arsenic in the groundwater. There is a wide range of negative impacts of arsenic contamination on society and the economy, threatening sustainability in the contaminated areas. To examine the magnitude and effects of arsenic in the Shahpur block of the Bhojpur district, Bihar, India, we tested groundwater samples from many different locations. Household surveys and personal interviews were conducted to find out the societal response to this problem. Sample testing results confirm a high rate of arsenic contamination in the area. Our study found that; the low education level of the area is hampering the sustainable solution to the problem. We came to know that people who are suffering from arsenic diseases are discriminated against the society. Further, we have also found that the economic burdens of arsenic contamination are more on the marginalized section of the community. Since crops are irrigated with high arsenic concentrated water, soil quality is degrading, responsible for poor agriculture output and economic loss. It has also been found that most of the mitigation measures employed are not sustainable in the long term. Awareness regarding arsenic toxicity is needed for the sustainable intervention of this problem. After examining all the mitigation measures, we concluded that rainwater harvesting and rooftop rain harvesting is the most sustainable and cost-effective measure to tackle this menace.

Key words: sustainability, arsenic contamination, groundwater, water accessibility, socio-economic burden
Słowa kluczowe: zrównoważony rozwój, zanieczyszczenie arsenem, wody gruntowe, dostępność wody, obciążenia społeczno-ekonomiczne

1. Introduction
The word sustainable was originated from the Latin word *sustinere*, which implies *to hold up*, *to support* and *maintain*. In the oxford dictionary, *sustainability is defined as an ability to keep something going on for a long time without compromising quality*. The current form of the concept of sustainability was established during the UN conference for Human Environment held in Stockholm in 1972. The idea was further developed with a holistic approach by World Commission on Environment and Development (WCED), also recognized as Brundtland Commission. According to the WCED, sustainable development is the *development that meets the needs of the present generation without compromising the needs of the future generations to meet their needs* (WCED, 1987). In this regard, for a sustainable water supply, the water resources should be appropriately managed, protected, and utilized so that future generations do not have to feel the scarcity of both quality and quantity. Access to a safe water supply is a fundamental right of every human being. The quality and quantity of water available affect the health and socio-economic development of an individual and society. Hence, water available should be sustainable in terms of quality and quantity.

Water has a high priority in the Millennium Development Goals (MDGs). Its target 7C is to ensure half of the world population has a safe and sustainable water supply (UN, 2000). In the 2030 agenda for sustainable development goals (SDGs), a dedicated plan for water and sanitation aims to *ensure availability of sustainable management of water and sanitation to all* and to address water more holistically (UN, 2015). The target text in MDGs and SDGs addressing water is similar, referring to *safe drinking water*. However, a key difference is that safety was measured only indirectly through the proxy of improved sources in MDGs. In contrast, water quality is also included in the indicator in SDGs. The SDGs indicator of safely managed drinking water service will provide a more accurate presentation of drinking water quality because improved sources mentioned in MDGs are often faecally contaminated. The SDGs prioritize supplying chemically safe water to populations. The priority chemical contaminants considered in the definition at the global level are fluoride and arsenic. These are the two chemicals that occur widely in the drinking water, resulting in a substantial burden of disease globally. Monitoring of arsenic will be required for tracking target 6.1, but reducing exposure to arsenic will also be essential for progress towards other SDGs targets, especially within Goal 3 (*Ensure healthy lives and promote well-being for all ages*).

Due to the increase in population, both quality and quantity of water resource have been continuously deteriorating. Over the year, unsustainable groundwater and surface water exploitation has caused a severe water pollution problem. According to the Falkenmark indicator, a country or a region is water-stressed when water availability goes below 1700 cubic meters/person/year. In India, more than 800 million people in 12 river basins have per capita water availability below 1000 cubic meters/person/year, which is a threshold for water scarcity. The per capita availability of water in 1951 was 5177 cubic meters which went down to 1544 cubic meters at the end of 2011. It is estimated that the per capita availability of water will remain only 1341 cubic meters by 2025 and will remain 1140 cubic meters by the end of 2050. According to NITI Aayog, 163 million people do not have safe water near their premises, and more than 70% of the surface water in India is contaminated (NITI Aayog, 2018). Since the potential to harness surface water for beneficial purposes and infrastructure is not adequate for the supply of surface water, there is immense pressure on the groundwater resources in India. It has led to overexploitation and unsustainable use of groundwater resources, making India the largest extractor of groundwater globally (Saha et al., 2017). The untenable and illogical extraction and use of groundwater resources have led to the problem of groundwater contamination in more than 200 districts across 20 states of India (CGWB, 2018). Various agents and sources are responsible for groundwater contamination, but all can be grouped under three categories: geogenic, biogenic, and anthropogenic (Figure 1). Contamination such as salinity, iron, fluoride, and arsenic can be grouped under geogenic. These are responsible for moderate to severe health impacts and diseases. Most of the common contaminants in groundwater worldwide are fluoride and arsenic. Drinking and consuming water with an elevated level of arsenic (>0.5 mg/L) can cause skin pigmentation and skin cancer. Consuming water with a high level of fluoride may prove responsible for tooth day and crippled bones. Therefore, even if the water is available in plenty, it is indirectly scarce due to the problem of contamination.

Arsenic with atomic number 33, atomic mass of 74.92, and a melting point of 816.8^{0}C is the 20th most abundant element in the earth's crust and 53rd most abundant element found on the planet. It is a metalloid that can combine with both metals and non-metals to form inorganic and organic compounds. It also shows metallic properties and co-exists with other metals like Fe, Cu, Ni, Zn, etc. as sulfide and oxide ores (Boyle and Jonasson, 1973). Incidences of elevated levels of arsenic concentration in groundwater have been reported many countries worldwide. It has been estimated that more than 200 million people worldwide are exposed to an elevated level of arsenic in drinking water (groundwater) (Naujokas et al., 2013). Different countries have different guidelines for the maximum permissible limit for arsenic in drinking water based on convenience. According to the World Health Organization (WHO) 2011 guidelines, the maximum limit should be 0.1 mg/L. Most developing countries keep the upper limit close to 0.5 mg/L. Because of the resource constraints in these countries, lowering the limit will put an extra burden on water companies to meet the given standards. Many studies have already been done on arsenic in drinking water and its effect on human health (Adeloju et al., 2021; Huang et al., 2019; Jha and Tripathi, 2021). Arsenic can cause problems in reproductive systems and congenital disabilities and harm the central nervous system (Abdul et al., 2015). Some studies also find the relation between consuming elevated levels of arsenic and children's mental health (Genuis, 2009; Wasserman et al., 2007). Several studies are available related to economic costs imposed on households due to arsenic contamination of groundwater (Das et al., 2016; Thakur and Gupta, 2016). The studies found that low-income families incurred the most significant number of sick days. After getting infected by the disease, the poor household is further pushed into misery and poverty. Their savings are exhausted for the treatment, and they face difficulties in earning their livelihood.

2. Arsenic Contamination

2.1. Arsenic Sources and Mobilization

Arsenic is found in the natural environment in plenty in the earth's crust and small magnitude in rock, soil, water, and air. It is always present as compounds with oxygen, chlorine, Sulphur, carbon, and hydrogen on the one hand, and with lead, gold, iron on the other hand. Therefore, arsenic sources can be categorized into three categories: geogenic, biogenic, and anthropogenic routes (Sparks, 2005).

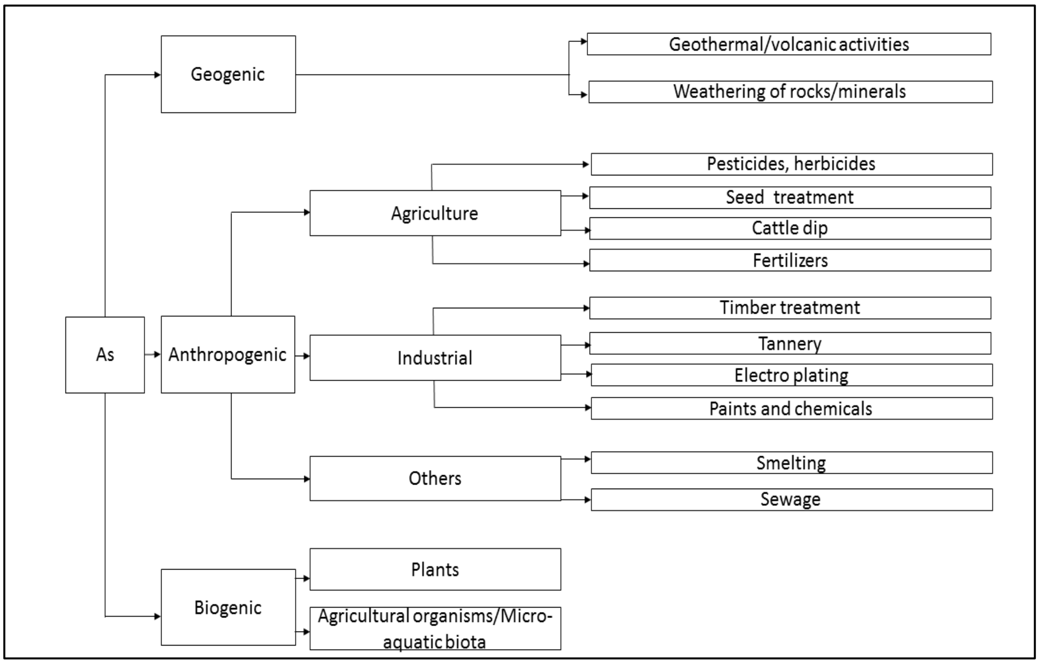

Figure 1. Different sources of arsenic in the ecosystem (Thakur and Gupta, 2016)

In Bihar, the arsenic content in the groundwater is determined mainly by the geological formation. Bihar is located in the Gangetic plains and covered by the Quaternary sediments of recent to sub-recent age (CGWB, 2016). In all these areas, a multi-tire aquifer system is present. The sediment of the central Gangetic basin differentiates into Holocene and Pleistocene depositions. The arsenic hotspots are confined to younger alluvial deposits (Holocene) aquifer depths 50-60 meters below ground. The aquifers of older depositions (Pliocene-Pleistocene) are mainly free of arsenic contamination (Smedley and Kinniburgh, 2002). A layer of clay that protects the deeper aquifer can be used for community drinking water supply by deep tubewells having a yield capacity of 150 cubic meters per hour (Saha et al., 2017).

The arsenic in Bihar and Shahpur block (Study area) probably originates from the ore zones of the Himalayas. After that, it is eroded by the Ganges River and its tributaries. The eroded materials are then transported and deposited along their course. Mukherjee et al. (2012) described that rainfall received on the flood plains of Bihar facilitates the percolation of organic carbon to the groundwater, which stimulates microbial respiration, triggering a reductive dissolution of Arsenic and iron in the solid phase (Mukherjee et al., 2012). These hydro-geochemical phenomena produce bicarbonate (HCO3) in shallow groundwater that helps further mobilization of Arsenic in the groundwater (Saha and Sarangam, 2010; Sahu and Saha, 2014). It is to be noted that the affected aquifers are the most used and popular source of drinking water in both Shahpur block and the state of Bihar.

2.2. Spatial Distribution of Arsenic Problem

The elevated level of geogenic arsenic contamination in drinking water has been identified in more than 105 countries (Singh, 2017; Singh and Stern, 2017). Every year new locations are being discovered where arsenic is present in the elevated level against the WHO (2011) and BIS (2012) recommendations (0.1 mg/L) (BIS, 2012; WHO, 2011). Most of the arsenic vulnerable areas are found in the river basin and the deltaic regions. The places with the tropical climate are more susceptible to arsenic contamination of groundwater because this type of climate favors the mobilization and release of arsenic from its compounds (Nickson et al., 2000; Ravenscroft et al., 2009). The spatial distribution of arsenic contamination in shallow aquifers worldwide can be assessed from my previous work (Ranjan, 2019).

Currently, 20 states and 86 districts of India (Figure 2) are facing the challenge of elevated levels of arsenic (>0.1 mg/L) contamination in groundwaters (CGWB, 2018). In India, Ganga-Brahmaputra and Meghna (GBM) plains are the hotspot zones of arsenic contamination (Figure 3). Around 80% of the affected area of India lies in this plain. Bihar is also part of this plain where arsenic-contaminated sediments are deposited by the river Ganga. More than 1.6 million people in 19 districts of Bihar are facing this severe menace. The most affected (Figure 4) district (>0.5 mg/L of arsenic concentration) are Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Purnea, Samastipur, Saran, and Vaishali (CGWB, 2018).

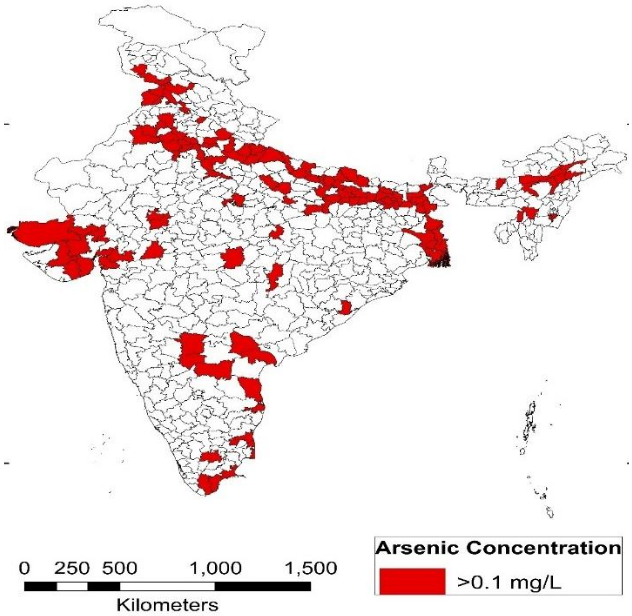

Figure 2. Spatial distribution of arsenic contamination of groundwater across India (Central Groundwater Board, 2018)

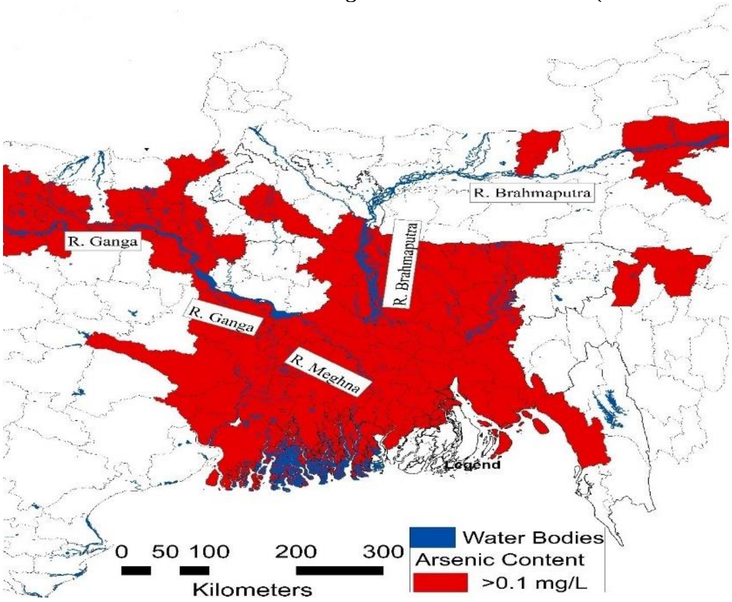

Figure 3. Arsenic hotspot regions (Central Groundwater Board, 2018; British Geological Survey, 2001)

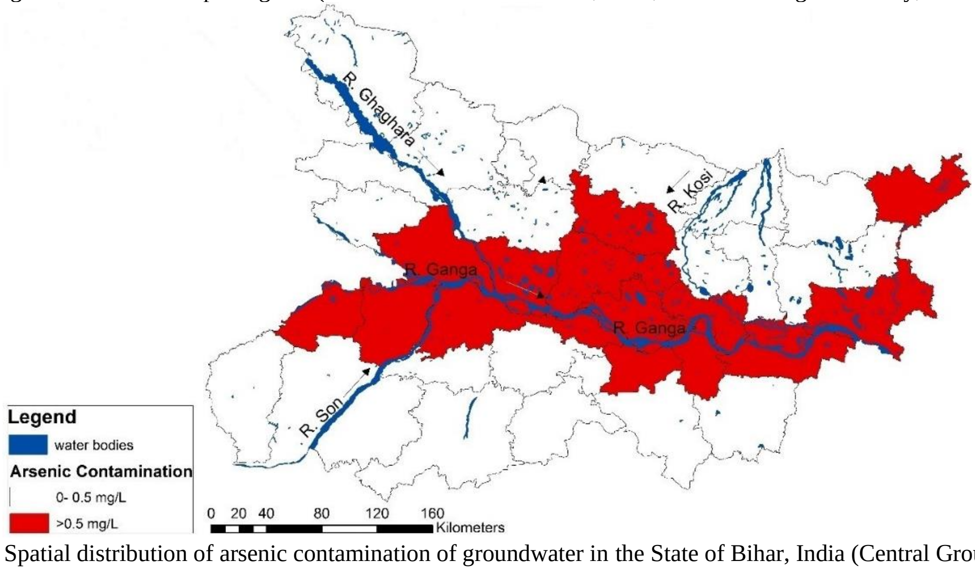

Figure 4. Spatial distribution of arsenic contamination of groundwater in the State of Bihar, India (Central Groundwater Board, 2018)

3. Objective of the study

The current study investigates the magnitude of groundwater arsenic contamination in the Shahpur block of Bhojpur district, Bihar, India. The objective of the study can be summarized in the following points:

1. To analyze the socio-economic impact of arsenic contamination of groundwater in the study area.
2. To assess the sustainability of the arsenic mitigation interventions in the contaminated areas.

4. Methods and Methodology

4.1. Data collection and data analysis tools

150 groundwater samples were collected and tested from seven habitations of the Shahpur block of Bhojpur district in Bihar, India. These samples were collected in polyethylene bottles pre-washed with nitric acid (1:1). The samples were collected from the handpumps, tubewells, and borewells after operating and pumping them for at least 2-5 minutes. After collecting the samples, they were tested on-site using the field test kit (FTK) developed by National Chemical Laboratories, Pune, India, and Prerna Laboratories, which WHO and BIS recognize.

The impact of arsenic contamination on society and the economy was evaluated by surveying 382 households. This survey was conducted using stratified random sampling. The first level of categorization was done based on social and educational disadvantages (General, SC & ST). Equal representation was given to every section of the society based on their relative population (Table 1). To know the society's response towards arsenic patients, we have personally interviewed the affected persons. Furthermore, we have used the remotely sensed data for analyzing the terrain characteristics of the study area. These data were collected from the Survey of India, Google earth pro, and Landsat 8. The primary data was analyzed and represented using ArcGIS, SPSS, and MS-Excel tools.

Data regarding the aquifer system, magnitude, and spatial distribution of arsenic in groundwaters in India has been obtained from the Central Groundwater Board (CGWB). Data regarding drinking water standards to know if the quality of groundwater available in the study area satisfies the minimum permissible level of arsenic in waters. The World Health Organization (WHO) 2011 guidelines for drinking water and Bureau of Indian Standards (BIS) 2012 guidelines have been referred to these data.

Table 1. Determination of sample size in the study area

Village name	Population	SC Population	ST Population	% of the total population of the study area	Representation in sample size		
					Total	SC	ST
Isharpura	4461	405	47	11	42	4	1
Deomalpur	6773	801	47	16.51	63	7	1
Sarna	5568	434	0	13.57	52	4	0
Semaria Ojha Patti	5788	1071	0	14.11	54	10	0
Lachchhutola	3223	229	0	7.88	30	2	0
Parariya	730	20	0	1.77	7	1	0
Shahpur (N.P.)	14469	1914	21	35.27	134	17	1
Total	41012	4874	115	100	382	45	3

4.2. The Study area

The study area, i.e., the Shahpur block of Bhojpur district, Bihar, India, is located on the southern bank of river Ganga in the northwestern part of Bhojpur district roughly between $25^0 44' 0''$ N and $25^0 34' 40''$ N latitude and between $84^0 19' 40''$ E and $84^0 32' 0''$E longitude (Figure 5). The total area of this block is around 205 square kilometers. Due to its location, newer alluvium is deposited annually by the river Ganga, making it a younger flood plain. The general slope of the area is towards north and north-east. The general elevation of the area is around 50-60 meters above mean sea level. The gradient is 0.5 m/km, approximately from south to north. The northern part of this area is pitted with the oxbow lakes, meander scars with point bars left over by the old Ganga channels. According to Koppen's climatic classification, the area falls under the *Cwg* type of climate. This type of climate prevails mainly in the Ganga plains, eastern Rajasthan, Assam, and Malwa plateau. It is a monsoon type of climate with dry winters. The average temperature varies between 39 degrees Celsius in June and goes down to 6 degrees Celsius in January. Most of the rainfall received is from the summer monsoon between mid-June to the end of September. The area's average annual rainfall is around 1080 mm, which varies between 1025 mm and 1106 mm (CGWB, 2013).

The Bhojpur district of Bihar, is divided into 14 blocks. Each block is again composed of several clusters of villages known as gram panchayat (GP), and each GP has several villages. Shahpur block has a total of 22 GPs. Out of these, we have selected 7 for our study (Figure 5). The area's total population is 194486 persons, out of which 102702 are males, and 91784 are females. The sex ratio of the whole block is 893.6 females per 1000 males.

The effective literacy rate[1] is 70.2 %, whereas the crude literacy rate[2] is 58.53%. A detailed description of the demographics of Shahpur blocks and seven habitations under study are given in the following table 2.

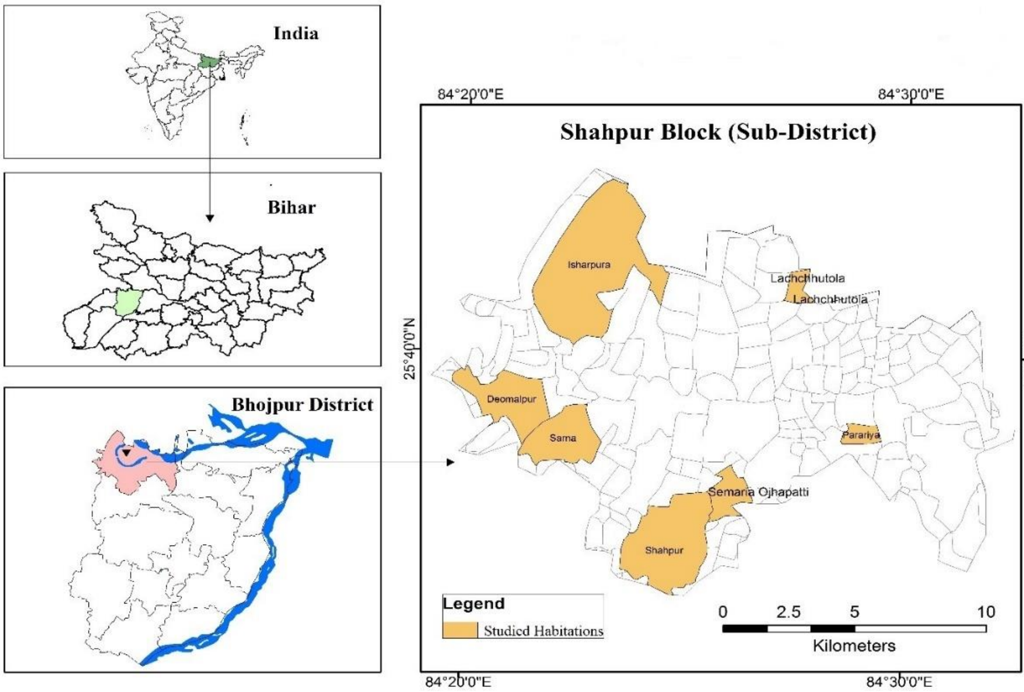

Figure 5. Location map of the study area

Table 2. Demographic profile of the study area (Census of India, 2011)

Parameters	Name of village (habitations)						
	Isharpura	Deomalpur	Sarna	Semaria Ojha Patti	Lachchhutola	Parariya	Shahpur (N.P.)
GP	Isharpura	Deomalpur	Sarna	Semaria	Lachchhutola	Karza	Shahpur
Total area sq. kilometer	22.8	6.64	51.6	2.19	0.98	1.02	10.2
Total population	4254	6773	5568	5788	3223	1454	17767
Population density (Pop/m^2)	187	1020	107	2642	3288	1425	1741
Sex ratio (females/1000 males)	878	910	863	925	841	968	912
Literacy rate (%)	59.5	64.4	54.2	65.5	59.1	62.9	59
Female literacy rate (%)	49.9	54.8	47.4	57.2	46.7	54.6	46
SC population	405	801	434	1071	229	20	1914
ST population	47	47	0	0	0	0	21
Totalworkers	1155	1359	1497	1359	676	268	3838
Total Female workers	90	144	267	165	16	84	664
Main workers	1036	1212	1200	1102	265	125	3205
Marginal workers	119	147	297	257	411	143	633
Cultivators	487	463	515	380	177	50	1020
Agricultural labourers	406	543	570	617	474	81	1228
Non-workers	3306	3722	3946	3817	2049	462	10631

5. Results and Discussion

The primary source of drinking water in the area is groundwater sources pumped mainly through handpumps (Table 3). The piped water connection and household taps are available in significant amounts only in Lachchhapur and Parariya. In Lachchhapur, more than one-fourth of the household uses tap water from treated sources for drinking purposes. In Parariya, around one-third of households use tap water from the treated sources, but approximately 17 % of homes use tap water from untreated sources (Table 3). Due to the high percentage of use of groundwater sources for drinking purposes, it is necessary to use these sources sustainably. The contamination of the groundwater sources is a significant concern for these areas.

Table 3. Percentage distribution of significant sources of drinking water (Census of India, 2011)

[1] Effective literacy: It is the total number of populations aged 7 and above which are literate.

[2] Crude literacy: It is total number of populations which are literate.

Village/ habitations	Percentage distribution of major source of drinking water									
	Tap water from treated source	Tap water from un-treated source	Covered well	Un-covered well	Hand pump	Tubewell/ Borehole	Spring	River/ Canal	Tank/ Pond/ Lake	Other sources
Isharpura	1.2	0.3	0.7	3.1	94.7	0	0	0	0	0
Deomalpur	5.4	1.2	0.8	0	91.3	0.8	0	0.1	0.1	0.2
Sarna	2.2	0.8	0.8	0.2	90.9	0.5	0	0	0	4.6
Semaria Ojha Patti	0	0	0.3	1.6	97	0.1	0	0	0.4	0.4
Shahpur (N.P.)	3.1	0.8	1.1	3	88.4	0.3	0	0.1	0.3	3
Lachhatola	26.6	0	0.3	0	68	0	0	0.3	0	4.8
Parariya	32.2	16.6	0.5	5.4	44.9	0	0	0	0.5	0
Shahpur Block	3.4	0.9	0.6	1.5	91.8	0.2	0	0	0.1	1.5
Bhojpur District	2.7	1	0.7	1.1	92.3	0.8	0	0.1	0.1	1.1

In the last two decades, the trace of elevated level of arsenic has been found in the drinking water, irrigation water, and food products in Various places of Bihar (Suman et al., 2020). Various government and non-government organizations have tried to estimate the number of populations potentially exposed to arsenic contamination. However, it is a challenging task as arsenic exposure is probable through food products. Cases of exposure have been found from many places where geogenic arsenic has not been confirmed to date. The food crops grown locally and irrigated with arsenic-contaminated water are sold in the open market and consumed by the people far away from the place of production. There is also evidence of arsenic in dairy products. The possible reason for this is that the fodder is grown in arsenic-contaminated soil and irrigated with contaminated water. A recent study finds that the total number of people exposed to arsenic contamination in Bihar is around 9 million (Bhattacharya, 2019). Another study done in 2016 by the Ministry of drinking water and sanitation n the Ministry of Jalshakti, Government of India, reported that 16 million people are at risk from arsenic contamination in the State of Bihar alone (Ministry of Drinking water and Sanitation, 2016). Arsenic contamination has an acute negative impact and far-reaching consequences on all aspects of life, health, social, and economical.

After the test of the samples, the magnitude of arsenic contamination of groundwater in the Shahpur block seems to be very high. We have tested 150 samples from 7 habitations using the FTK. In our current study, it has been found that (Table 4) most of the samples (more than 80%) have arsenic concentration exceeding the WHO, 2011 and BIS, 2012 guidelines about the maximum permissible limit for arsenic in drinking water (0.1 mg/L) (WHO, 2011 & BIS, 2012).

Table 4. Result of samples tested for arsenic contamination in groundwaters, (sample tested both in pre-monsoon season in June 2021 and in post-monsoon season of November 2020)

Village	Number of samples tested	Arsenic Contamination (mg/L)		Mean Concentration (mg/L)	WHO Standard (2011)
		Maximum	Minimum		0.1 mg/L
Isharpura	25	1.2	0.1	0.65	
Deomalpur	20	1.0	0.1	0.55	
Sarna	30	0.7	0	0.35	
Semaria Ojha Patti	15	0.5	0	0.35	
Lachchhatola	5	1.4	0.2	0.80	
Parariya	5	1.2	0.1	0.65	
Shahpur (N.P.)	50	0.5	0.1	0.35	

5.1. Effect of Arsenic contamination on Health

The first report of adverse health effects from consuming arsenic-contaminated water came from Poland in 1898 (Mandal and Suzuki, 2002). Keratosis, hyper, and hypo-pigmentation are the most common diseases caused by arsenic ingestion in the human body. Exposure to a high level of arsenic for a long time may affect the respiratory system, causing laryngitis, bronchitis, rhinitis, and tracheobronchitis (Parvez et al., 2010; Sanchez et al., 2016). Consuming arsenic-contaminated water alters myocardial deportation and cardiac arrhythmia, leading to heart failure (ATSDR, 2019; Chen et al., 2007). Arsenic also harms both peripheral and central nervous systems. Some studies found that arsenic affects the mental health of children. Log time continued exposure to arsenic may be responsible for the children's low IQ, slow cognitive development, and consequently poor memory (Syed et al., 2012; Wasserman et al., 2007, 2004). There is information on the connection between consuming arsenic-contaminated water (>0.5 mg/L) and adverse pregnancy outcomes. The report reveals the high rate of spontaneous abortions, stillbirths, and neonatal death (Ahmad et al., 2001; Kwok et al., 2006; Vahter, 2009). We have found many patients sufferings from arsenic skin lesions in the studied villages. We have not performed any medical testing on them because it is beyond the aim of this project. We have physically tried to identify the symptoms and compared them with the past study on health information. It can be estimated that more than 10000 people from the Shahpur block may be suffering from the diseases manifested by consuming arsenic-contaminated water.

5.2. Impact of Arsenic on Society

The arsenic problem significantly affects socio-economic structures (Das et al., 2016; Thakur and Gupta, 2016). It has been found that social issues are linked with health and economic problems. The social issues start with the lack of knowledge and awareness directly coupled with the education of an individual and society. As we can see (Table 2) that the average literacy of the study area is around 45%, and the female literacy rate is below 30%, there is a dearth of knowledge and awareness regarding arsenic contamination among the inhabitants. Most households in the area do not use any filtration option (Table 5). Due to the lack of knowledge, people boil water before drinking, which often increases the concentration of arsenic in the water.

Table 5. Percentage distribution of households using different filtration options and distance of water sources from their households (Household survey, 2021)

Percentage distribution of households		Isharpura	Deomalpur	Sarna	Semaria Ojha Patti	Shahpur (N.P.)	Lachchtola	Parariya
Water Treatment Methods	Boil	0.7	0.9	0.4	1.1	1.7	0.6	0.9
	Strain through cloth	0.5	1.2	1.4	1.7	1.1	0.9	1.3
	Use ceramic, sand or another filter	1.8	2	2.7	3	8.4	1.1	1.7
	Electronic Purifier	1.2	1.7	0.8	2.2	8	0.9	1.1
	Other treatment	0.8	0.9	0.6	1	1.5	0.7	0.5
	No treatment	95.1	93.3	94.1	91	79.1	95.8	94.5
Distance of water sources	Within premises	79.8	61.7	81.5	69.3	79.2	59.8	44.9
	Near Premises	10.6	32.8	13.3	17.5	15	29.9	46.3
	Away	9.6	5.5	5.2	13.2	5.8	10.3	8.8

Due to the lack of knowledge, people often mistake symptoms of arsenic poisoning as leprosy or other contagious skin disease and start practicing untouchability and discrimination. Lack of education makes people superstitious, and they believe that this disease is due to the curse of evil or the act of God. Lack of information creates the problem of marriage, employment, and even the simplest social interaction. The Father of the bride does not want to marry their daughter in the villages where the problem of arsenic contamination is prevalent. Similarly, a groom does not want to marry a girl from arsenic hit villages. Our study found that the people suffering or showing the symptoms of arsenic poisoning on their bodies are debarred from society, ostracized, and are not allowed to participate in social gatherings. They do not allow to visit places of worship. When women get infected, they are sent back to their maternal house because families fear getting this disease. In some cases, women have to face a situation of divorce. It has been found that people with poor socio-economic conditions who are economically marginalized and living below the poverty line are most likely to get diseases manifested by arsenic contamination.

5.3. Economic Impact of Arsenic contamination

Arsenic contamination in groundwater has a severe economic impact on the people residing in the arsenic-affected areas. Studies (Bhattacharya, 2019) have found that the poor population is more exposed to such problems.On the one handthey are unable to adopt the mitigation measures to reduce the risk of a health threat, and on the other , they do not have access to adequate nutritional intake. All these factors ultimately increase the economic burden of poor households in the form of medical expenditure. Moreover, arsenic-free water is not only an expensive blot but also a financial burden. Research finds that by reducing the arsenic concentration to 0.5 mg/L, the monthly and annual gain per household can be calculated to be around INR 290 and INR 3500, respectively.

Similarly, if the concentration is reduced to half of the current level, the economic benefit would be around INR 161 per month and INR 1934 per annum (Roy, 2008). Poor households witnessed a maximum number of sick days. In such a case, people find it challenging to work for more than 3 hours/day compared to 8 hours/day work by a healthy person. Studies found that the threat of melanosis and keratosis increased with cumulative exposure, more commonly found in economically poor class individuals. Poor people cannot afford advanced filtration options, and they also find it difficult to buy bottled drinking water from the market.

Another aspect of the economic impact of arsenic contamination is in the context of agriculture productivity. Most of the irrigation in the middle Gangetic plains is done from the waters pumped from the shallow aquifers. As a result, rice, vegetables, and dairy products get affected by arsenic contamination. Bhattacharya (2019) found and reported arsenic concentration in potato, brinjal, arum, amaranth, radish, lady's finger, cauliflower, and relatively low level of arsenic in beans, green chili, tomato, bitter gourd, lemon, and turmeric. Arsenic contaminated water used for irrigation impacts the quality of food grains, adversely affects soil quality and reduces the quantity of food production. Due to arsenic in the food products, cultivators find it challenging to sell their products because people avoid products from these places to the best of their knowledge. When cultivators cannot sell their crops, they face substantial economic loss and often go into debt when they do not get the correct prices. It can be said that arsenic contamination in groundwater puts a question mark on the sustainability of agriculture production and the associated livelihood and health of the affected population.

6. Sustainable mitigation measures for arsenic contamination

The sustainability of arsenic mitigation interventions can be stated as *the capacity to continue to be implemented for a long term and delivering the output without compromising the quality*. Arsenic mitigation techniques being presently used in Bihar are multi-village piped water supply scheme through a conventional treatment plant from the safest aquifers. The intake water is treated with activated alumina (AA), granular ferric hydroxide, cerium oxide-metallic iron or iron-coated sand or brick dust, ion exchange media and coagulation, flocculation and sedimentation/filtration. These mitigation measures can be assessed and evaluated against the parameters of environmental and socio-economic sustainability.

6.1. Environmentally sustainable measure

The strategy for drinking water supply based on surface water, which is common in the Bhojpur district (Shahpur and Barahara block), has been identified as a long-term solution by the NRDWP framework and can pose limitations to environmental sustainability. About one-fifth of the Indian population is estimated to be exposed to arsenic contamination. If all these populations are served with the piped water supply through the surface water treatment plant, then water available in the rivers, dams, ponds, lakes, etc., may go down. Over exploitation of these surface water resources may harm the aquatic ecosystem and prove fatal to the flora in the catchment areas. Several examples exist in the country where rivers and lakes have dried up due to the over-abstraction of water and lowered catchment flows (Saleth, 2011; Singh and Singh, 2020; Singh et al., 2015).

Similarly, the water supply from the deep aquifers is being promoted in the Bhojpur district (also all over the state of Bihar) through *har ghar nal ka jal* (tap water to every household) scheme, an ambitious project of the Government of Bihar is not sustainable. Drawing large amounts of water from the deep aquifers will lower the water table in the long term. Furthermore, the clay layer, which acts as a barrier between shallow aquifer (arsenic-contaminated) and deep aquifer (non-arsenic-contaminated), can leak due to void created by drawing a large amount of water. It will convert an arsenic safe aquifer into an arsenic-contaminated one.

From the above observation, there are always some drawbacks in the mitigation interventions in the context of environmental sustainability. Technologies must be designed and implemented, keeping local conditions in consideration. Rainwater harvesting in the Gangetic plains where rainfall is adequate in the monsoon is the best option in this regard. It can be incorporated in combination with the rooftop rainwater harvesting system, which is new to the local people but may prove sustainable in the long run.

6.2. Socially sustainable measures

Social sustainability in terms of arsenic contamination is rooted within the question of arsenic-free accessibility of water. Neither policy nor approaches in the arsenic mitigation have been considered and incorporated the social realities of arsenic impacted communities for which mitigation techniques are implemented. Policies and programs are based on assumptions that mitigation interventions would serve each person and household equitably. The efforts are being made in searching for a suitable place for the installation of a water supply system. Still, there is no monitoring of whether all beneficiaries have an equitable right of access to mitigation technologies. When people are given choices between arsenic-contaminated handpumps at home and arsenic-safe water supply systems located at some distance, people most of the time choose the nearest options. It is true in the case of women who have to do all household work and fetch water. The time she will spend fetching water from a distant location may have been utilized in completing other works or doing something to earn money. It is also hampering the capability of an individual.

Apart from physical accessibility, social accessibility is an important concern in Indian villages. Still, there are several villages where caste-based discrimination is prevalent. People of the dominant caste have a monopoly over the water resources, and they do not allow the people from the socially marginalized sections to collected water from that system. The question of social accessibility is also true in the case of household piped water connections.

Despite the household connections, the water may not reach the houses of marginalized sections. The dominant group either breaks the pipe so the water cannot reach the socially deprived people's house, or they use water for irrigation and consequently pressure drops too much, or no water remains in the system.

6.3. Economically sustainable measures

The economic sustainability of a water delivery system depends on its affordability. The piped water supply system is either a single village scheme or a multi-village scheme, is very expensive to install and operate. When stakeholders do not recover their operation and management (O & M) costs, they do not remain sustainable in the long run. There are instances in the study area when a community-based water supply system is transferred to local inhabitants for O & M, and then the scheme failed miserably. It is due to two reasons: the irregular supply of electricity and the high diesel prices. In both cases, poor inhabitants cannot pay for the operating pumps either through diesel or electricity. Another problem observed in the Shahpur block was the affordability of the bottled water, which is claimed to be safe and arsenic-free, supplied by private agencies. In most cases, buying bottled water from private agencies puts an extra burden on the household's monthly budget. It was analyzed that the monthly charges of the community-based supply system run by government agencies are affordable and manageable to some extent by the inhabitants.

6.4. Sustainable Potential Option for Safe Drinking Water

Considering all the mitigation strategies, we have concluded that most arsenic mitigation efforts are least sustainable when put against the environmental, social, and economic perspectives. In Bihar, the average annual rainfall is around 1200 mm, out of which more than 85% is received during the monsoon period (June to September); rainwater harvesting could be a sustainable solution for the supply of arsenic-free water. Surface water and rainwater harvesting have been recognized as a solution for getting arsenic-free water in quality affected areas (Giri et al., 2011; Planning commission of India, 2007). Only a fraction of the rainfall is preserved in India, and the rest is wasted in surface runoff. A significant amount of runoff can be preserved by the arsenic hit villages at the local level in the ponds and Ahar-Pyne systems (Indiawaterportal). This water can be filtered locally can be used for cooking and drinking. When considering rainwater harvesting to tackle the arsenic problem, the local condition regarding the environment, climate, social system, cultural acceptability, and economic affordability should be considered. Decentralized use and management of rainwater offer a sustainable prospect for solving the problem of arsenic contamination. Accessibility to safe drinking water enables women, men, and children to enjoy their life without any fear. The money and time saved after the availability of safe drinking water to their premises may enhance their skills and capability, which will make way for a developed society.

7. Conclusion

This study finds that the most popular and widely used source of drinking water in the study area is groundwater. Due to the low level of education (less than 50%) in the study area, superstition is prevalent in society. People are not aware of the problem of arsenic contamination and its related toxicity. Though there is an elevated level of arsenic in groundwater, people do not find it necessary to filter the water before use. More than 90% of the household do not treat water before consuming. Due to unawareness and less knowledge, people also boil water before use, proving harmful rather than beneficial. Further, it has also been found that the bottled water business, which is claimed to be arsenic-free, is growing in the area. The economically marginalized people cannot afford bottled water and do not have money to install good quality electronic filters. Hence, most of the burdens associated with arsenic contamination if put on poor people.

The burdens put on by arsenic contamination are a threat to society's social sustainability. The community's social structure is degrading because people showing symptoms of arsenic manifested diseases are being socially discarded, discriminated and ostracized. When people have a disease, they lose their physical strength, and they remain sick. It puts a two-way burden on them – one through medical treatment and the other through job loss. Further, arsenic contamination is placing a question mark on the sustainability of agriculture production. Farmers are getting less yield per unit of land; contaminated products, and they cannot sell their contaminated products. These issues are putting a negative economic impact on the area's farmers and proving to be fatal to their livelihood. The mitigation measures employed until now have not proved sustainable on the grounds of environment, society, and economy. The wastes released from the water treatment plants in the arsenic-contaminated areas are dumped on the ground or in ponds, further increasing the arsenic concentration in soil and water in that particular place. In India, people are often discarded and discriminated against by caste, color, and religion. The public water supply system delivering safe and arsenic-free water is captivated by the dominant community of the habitations, and marginalized sections are devoid of the facilities. Further, the multi-village and the single village system for supplying arsenic safe water is not economically sustainable in the Shahpur Block (study area) and other places in India. The poor peasants find it hard even to pay the operation cost for these systems, and hence it is becoming hard for stakeholders to recover their O & M cost.

To reduce socio-economic problems and develop cost-effective mitigation techniques, community participation is necessary. There is an urgent need to make people aware of groundwater's arsenic contamination and toxic effects. Considering the geography of the study area, the best mitigation interventions could be rainwater harvesting and rooftop rain harvesting. These interventions are cost-effective, easy to maintain, socially acceptable, and environmentally and economically sustainable in the long term.

References

1. ABDUL K.S.M., JAYASINGHE S.S., CHANDANA E.P.S., JAYSUMANA C., DE SILVA P.M.C.S., 2015, Arsenic and human health effects: A review, *Environ. Toxicol. Pharmacol*, 40: 828-846.
2. ADELOJU S.B., KHAN S., PATTI A.F., 2021, Arsenic contamination of groundwater and its implications for drinking water quality and human health in under-developed countries and remote communities - A Review, *Appl. Sci*, 11, 1926.
3. AHMAD S.A., SAYED M.H., BARUA S., KHAN M.H., FARUQUEE M.H., JALIL A., HADI S.A., TALUKDER H.K., 2001, Arsenic in drinking water and pregnancy outcomes, *Environ. Health Perspect*, 109: 629-631.
4. ATSDR, 2019, *Arsenic Toxicity: What are the Physiologic Effects of Arsenic Exposure*, Agency Toxic Subst. Dis. Regist, http://www.atsdr.cdc.gov/csem/csem.html.
5. BHATTACHARYA A.K., 2019, Arsenic Contamination in the Groundwater of West Bengal, Jharkhand and Bihar with a Special Focus on the Stabilization of Arsenic-Laden Sludge from Arsenic Filters, *EJGE*, 24: 1-23.
6. BIS, 2012, *Drinking Water Specification (Second Revision)*, New Delhi.
7. BOYLE R.W., JONASSON I.R., 1973, The geochemistry of arsenic and its use as an indicator, *J. Geochemical Explor*, 2: 251-296.
8. CGWB, 2013, *Ground Water Information Booklet: Bhojpur District, Bihar*, Patna.
9. CGWB, 2016, *Central Ground Water Board, Ministry of Water Resources*, Government of India, http://www.cgwb.gov.in/Dynamic-GW-Resources.html.
10. CGWB, 2018, *Groundwater Quality in Shallow Aquifers in India*, Faridabad.
11. CHEN Y., FACTOR-LITVAK P., HOWE G.R., GRAZIANO J.H., BRANDT-RAUF P., PARVEZ F., GEEN A., VAN AHSAN H., 2007, Arsenic Exposure from Drinking Water, Dietary Intakes of B Vitamins and Folate and Risk of High Blood Pressure in Bangladesh: A Population-based, Cross-sectional Study, *Am. J. Epidemiol*, 165: 541-552.
12. DAS A., ROY J., CHAKRABORTI S., 2016, *Socio-Economic Analysis of Arsenic Contamination of Groundwater in West Bengal*, Springer.
13. GENUIS S.J., 2009, Toxicant exposure and mental health - Individual, social, and public health considerations, *J. Forensic Sci*., 54: 474-477.
14. GIRI P.K., BHATTACHARYYA K., SINHA B., ROY N.R., 2011, Mitigation options of arsenic uptake by rice plant in arsenic endemic area, *ORYZA-An Int. J. Rice*, 48: 127-131.
15. HUANG S., CHENG Y., GUO H., 2019, Arsenic Exposure in Drinking Water and Occurrence of Chronic Kidney Disease: The Association and Effect Modifications by Comorbidities, *Environ. Epidemiol*., 3: 167.
16. INDIAWATERPORTAL, https://www.indiawaterportal.org/articles/ahar-pynes-traditional-flood-harvesting-systems-south-bihar.
17. JHA, P.K., TRIPATHI, P., 2021, Arsenic and fluoride contamination in groundwater: a review of global scenarios with special reference to India, *Groundw. Sustain. Dev*., 100576.
18. KWOK R.K., KAUFMANN R.B., JAKARIYA M., 2006, Arsenic in drinking-water and reproductive health outcomes: A study of participants in the Bangladesh integrated nutrition programme, *J. Heal. Popul. Nutr*., 24: 190-205.
19. MANDAL B.K., SUZUKI K.T., 2002, Arsenic round the world: A review, *Talanta*, 58: 201-35.
20. MUKHERJEE A., SCANLON B.R., FRYAR A.E., SAHA D., GHOSH A., CHOWDHURI S., MISHRA R., 2012, Solute chemistry and arsenic fate in aquifers between the Himalayan foothills and Indian craton (including central Gangetic plain): influence of geology and geomorphology. Geochim, Cosmochim, *Acta*, 90: 283-302.
21. NAUJOKAS M.F., ANDERSON B., AHSAN H., APOSHIAN H.V., GRAZIANO J.H., THOMPSON C., SUK W.A., 2013, The broad scope of health effects from chronic arsenic exposure: update on a worldwide public health problem, *Environ. Health Perspect*, 121: 295-302.
22. NICKSON R.T., MCARTHUR J.M., RAVENSCROFT P., BURGESS W.G., AHMED K.M., 2000, Mechanism of arsenic release to groundwater, Bangladesh and West Bengal, *Appl. Geochemistry*, 15: 403-413.
23. NITI AAYOG, 2018, *Composite Water Management Index 2018*.
24. PARVEZ F., CHEN Y., BRANDT-RAUF P.W., SLAVKOVICH V., ISLAM T., AHMED A., ARGOS M., HASSAN R., YUNUS M., HAQUE S.E., BALAC O., GRAZIANO J.H., AHSAN H., 2010, A prospective study of respiratory symptoms associated with chronic arsenic exposure in Bangladesh: Findings from the health effects of arsenic longitudinal study (HEALS), *Thorax*, 65: 528-533.
25. PLANNING COMMISSION OF INDIA, 2007, *Report of the task force on formulating action plan for removal of arsenic contamination in West Bengal*, New Delhi.
26. RANJAN A., 2019, Spatial Analysis of Arsenic Contamination of Groundwater around the World and India, *Ijissh*, 4(10): 6-15.
27. RAVENSCROFT P., BRAMMER H., RICHARDS K., BRAMMER H., 2009, *Arsenic Pollution: A Global Synthesis*, Wiley-Blackwell.
28. ROY,J., 2008, Economic benefits of arsenic removal from ground water - A case study from West Bengal, India, *Sci. Total Environ*., 397: 1-12.
29. SAHA D., MARWAHA S., MUKHERJEE A., 2017, Groundwater Resources and Sustainable Management Issues in India, *Clean and Sustainable Groundwater in India*, eds. Saha D., Marwaha S., Mukherjee A., Springer Singapore, Singapore.

30. SAHA D., SARANGAM S.S., 2010, *Evaluation of hydrogeochemical processes in arsenic-contaminated alluvial aquifers in parts of Mid-Ganga Basin , Bihar , Eastern India*, 799–811.
31. SAHU S., SAHA D., 2015, Role of shallow alluvial stratigraphy and Holocene geomorphology on groundwater arsenic contamination in the Middle Ganga Plain, India, *Environmental Earth Science*, 73: 3523–3536, DOI: 10.1007/s12665-014-3637-3.
32. SALETH R.M., 2011, Water scarcity and climatic change in India: the need for water demand and supply management, *Hydrol. Sci. J*., 56: 671-686.
33. SANCHEZ, T.R., PERZANOWSKI, M., GRAZIANO, J.H., 2016, Inorganic arsenic and respiratory health, from early life exposure to sex-specific effects: A systematic review, *Environ. Res*., 147: 537–555.
34. SC & ST, EMPOWERMENT OF THE SOCIALLY DISADVANTAGED GROUPS, https://niti.gov.in/planningcommission.gov.in/docs/plans/mta/mta-9702/mta-ch14.pdf.
35. SINGH N., SINGH O.P., 2020, Sustainable arsenic mitigation: Problems and prospects in India, *Arsenic Water Resources Contamination*, Springer, pp, 131-156.
36. SINGH R., SINGH S., PARIHAR P., PRATAP V., 2015, Ecotoxicology and Environmental Safety Arsenic contamination , consequences and remediation techniques: A review, *Ecotoxicol. Environ. Saf*., 112: 247-270.
37. SINGH S.K., 2017, Conceptual framework of a cloud-based decision support system for arsenic health risk assessment, *Environ. Syst. Decis*., 37: 435-450.
38. SINGH S.K., STERN E.A., 2017, Global arsenic contamination: living with the poison nectar, *Environ. Sci. Policy Sustain. Dev*., 59: 24-28.
39. SMEDLEY P.L., KINNIBURGH D.G., 2002, A review of the source, behaviour and distribution of arsenic in natural waters, *Appl. Geochemistry*, 17: 517-568.
40. SPARKS D.L., 2005. Toxic metals in the environment: the role of surfaces, *Elements*, 1: 193-197.
41. SUMAN S., SHARMA P.K., SIDDIQUE A.B., RAHMAN M.A., KUMAR R., RAHMAN M.M., BOSE N., SINGH S.K., GHOSH A.K., MATTHEWS H., MONDAL D., 2020, Wheat is an emerging exposure route for arsenic in Bihar, India, *Sci. Total Environ*, 703, 134774.
42. SYED E.H., POUDEL K.C., SAKISAKA K., YASUOKA J., AHSAN H., JIMBA M., 2012. Quality of Life and Mental Health Status of Arsenic-affected Patients in a Bangladeshi Population, *J. Heal. Popul. Nutr*., 30: 262-269.
43. THAKUR B.K., GUPTA V., 2016, Arsenic concentration in drinking water of Bihar: health issues and socio-economic problems, *J. Water, Sanit. Hyg. Dev*., 6: 331-341.
44. UN, 2000, *Millenium Development Goals*, https://www.un.org/millenniumgoals/.
45. UN, 2015, *Sustainable Development Goals*, https://sdgs.un.org/goals.
46. VAHTER M., 2009, Effects of Arsenic on Maternal and Fetal Health, *Annu. Rev. Nutr*., 29: 381-399.
47. WASSERMAN G.A., LIU X., PARVEZ F., AHSAN H., FACTOR-LITVAK P., GEEN A. VAN, SLAVKOVICH V., LOIACONO N.J., CHENG Z., HUSSAIN I., MOMOTAJ H., GRAZIANO J.H., 2004, Children's Health Article Water Arsenic Exposure and Children's Intellectual Function in Araihazar, *Environ. Health Perspect*, 112: 1329-1333.
48. WASSERMAN G.A., LIU X., PARVEZ F., AHSAN H., FACTOR-LITVAK P., KLINE J., VAN GEEN A., SLAVKOVICH V., LOLACONO N.J., LEVY D., CHENG Z., GRAZIANO J.H., 2007, Water arsenic exposure and intellectual function in 6-year-old children in Araihazar, Bangladesh, *Environ. Health Perspect*, 115: 285=289.
49. WCED, 1987, *Our Common Future*, oxford University Press, New York.
50. WHO, 2011, *Guidelines for Drinking-water Quality*: 396-397.