International Research Journal of Environment Sciences ISSN 2319–1414
Vol. **4(2),** 70-76, February **(2015)** *Int. Res. J. Environment Sci.*

Review Paper

Groundwater Arsenic Contamination in the Middle-Gangetic Plain, Bihar (India): The Danger Arrived

Sushant K. Singh
Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043, USA

Available online at: www.isca.in, www.isca.me
Received 21st November 2014, revised 25th January 2015, accepted 17th February 2015

Abstract

This study presents a review of the arsenic contamination of drinking water, soil, and the food chain in the Middle-Gangetic Plain in India's Bihar state. We identify challenges for arsenic-mitigation and recommend solutions for this problem. Approximately 46% of the geographical regions, 72 of 532 community blocks, are arsenic contaminated. More than 10 million people in rural Bihar are exposed to elevated levels of arsenic through naturally contaminated drinking water. Arsenic levels exceed the United Nations Food and Agricultural Organization's standards for irrigation water. Arsenic contamination in soil and in the food chain could be potential threats to the area's inhabitants. Children are exposed to arsenic contaminated soil while playing in their backyards. Children who do not wash their hands thoroughly may unintentionally ingest soil, which over the long term may increase the risk of developing cancer. People with several stages of arsenicosis symptoms and suspected arsenic-induced cancers were found in the state. Recently discovered arsenic contaminated areas in Bihar are far from the River Ganges, which suggests that other River basins, such as the River Ghaghara and Gandak, are potential sources of arsenic. Katihar was the most vulnerable district because of the socioeconomic and biophysical conditions, followed by Vaishali, Samastipur, Khagaria, and Purnia. Munger was the only resilient district, as it had a greater adaptive capacity. Some of the foremost challenges of arsenic-mitigation are lack of guidelines for water sampling density, a common arsenic contamination data repository, coordination among research groups, and decision-making tools for arsenic-mitigation; uncontrolled and unregulated hand pump installations, and wide spatial variation in arsenic concentrations distribution. The state needs comprehensive arsenic-mitigation policies and decision-making tools to help prioritize, which arsenic contaminated areas to pursue. A decision-making tool, such as a composite vulnerability framework for assessing and mapping vulnerability to groundwater arsenic contamination, would be an absolute necessity.

Keywords: Arsenic, groundwater, contamination, mgp, bihar, health-risk, vulnerability, mitigation.

Introduction

Naturally occurring groundwater arsenic contamination impacts millions of people globally through drinking water, irrigation water, soil, and food materials[1-3]. Inorganic arsenic is a category-I human carcinogen and a potential threat to exposed individuals, even at concentrations of 10 µg/L ingested from drinking water[4-6]. Prolonged arsenic exposure (>5 years) can cause carcinogenic and non-carcinogenic effects such as melanosis, keratosis, skin lesions, neurological disorders, hepatic damage, respiratory complications, and various cancers[5,6]. The study suggests that socioeconomic and demographic factors (age, gender, education, economic condition, and awareness), daily arsenic dose, exposure period, nutritional and health status of the exposed individual, genetic susceptibility, route of exposure (smoking, ingestion, inhalation, and dermal contact), exposure to sunlight and to arsenic containing pesticides, and sex hormones, could enhance the severity of health effects from arsenic exposure[2].

Two countries, India and Bangladesh, are the most affected by arsenic poisoning, where more than 100 million people are at risk and several hundred died between 2005 and 2013[1-4]. Many communities in these countries lack of effective arsenic-mitigation programs and have a low capacity to cope with the adverse impacts of arsenic poisoning[1-3,7]. The first case of groundwater arsenic contamination in India was reported in the late 20th century in Chandigarh[1]. Later, several other states were identified as arsenic contaminated with arsenic levels far exceeding the World Health Organization (WHO) standard of 10µg/L and the Bureau of Indian Standard (BIS) of 50µg/L in drinking water[2,7]. Severe arsenic contamination in India occurs in the Gangetic Plain, which shares its boundary with Bangladesh and Nepal, the two other severely arsenic affected countries in South Asia[7,8]. Bihar and West Bengal, located within the Middle-Gangetic plain (MGP), are the two worst arsenic contaminated states in India[2,9,10]. Chakraborti et al., 2003, first reported groundwater arsenic contamination in Bihar, with 1654 µg/L of arsenic reported in drinking water in the Semaria Ojha Patti village of Shahpur block of the Bhojpur district[11]. Elevated levels of arsenic in urine, hair, and nail samples were also observed, and several arsenicosis patients were identified in the area[11]. This study postulated that groundwater arsenic contamination in the region could be a future danger, which is now a proven fact[11]. In the last decade, several studies on groundwater arsenic contamination in the MGP were executed by different research groups[8,11-13]. These investigations revealed new arsenic contaminated habitations with arsenic concentrations exceeding the BIS standard in 16 of 37 districts and in 61 of 532 community blocks in Bihar[2].

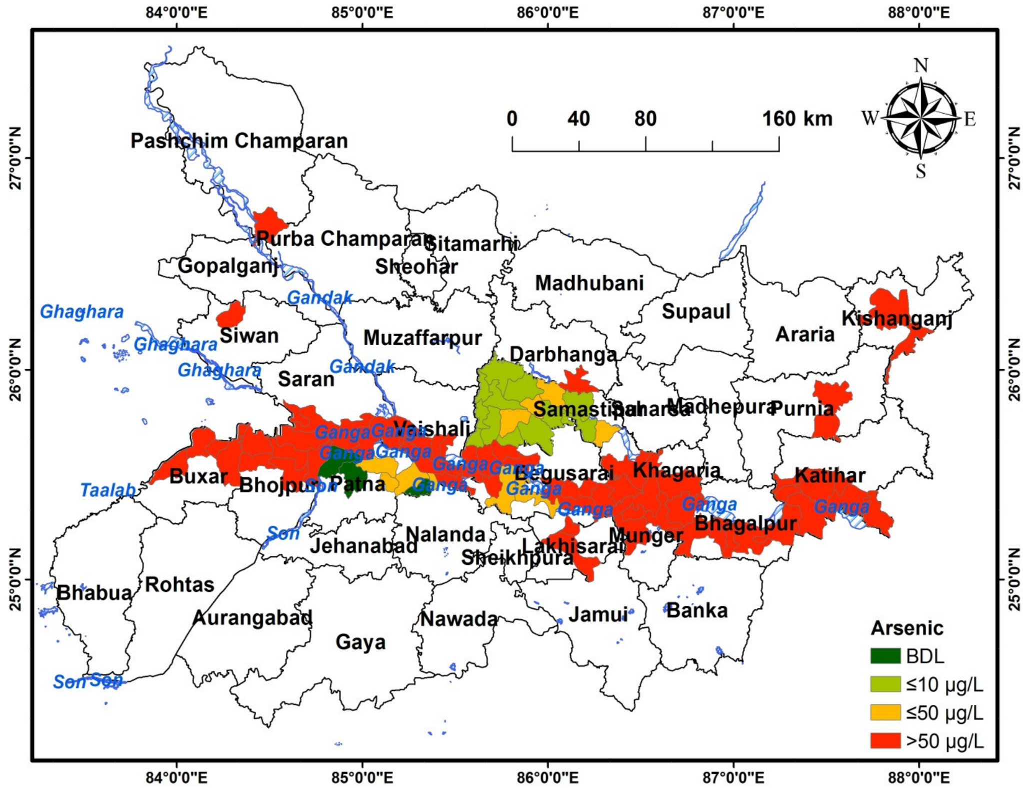
This study presents the current status of arsenic contamination in groundwater, soil, and in the food chain within the region of Bihar, examines health risks due to the arsenic consumption, and examines the vulnerability of the residents of Bihar to arsenic contamination. Furthermore, research gaps are addressed and recommendations offered to fill these gaps.

Groundwater Arsenic Contamination in Bihar: The River Ganges divides Bihar into two physiographic units, the North and the South Ganga Plains. Geologically, the state is stratified into the Holocene newer alluvium and the Pleistocene older alluvium, forming a "two tier aquifer system"[8,14]. The shallow aquifer systems (<50 m depth) and the deeper aquifer systems (between 120 and 300m depth) are separated by a 15-32 m thick aquitard composed of clay and sandy clay[8,14]. The shallow aquifer was found to be arsenic contaminated and the deeper aquifer was reported as arsenic-free[8,14,15]. A hydro-geochemical study revealed that hydraulic conductivity of the aquifer, the infiltration of irrigation water charged with fertilizers, and recharge from rainfall infiltration are all important hydro-geochemical processes shaping the groundwater chemistry of the shallow aquifers in the state[15]. In deep aquifers, leakage from shallow aquifers, ion-exchange process, and weathering of silicate minerals are found to be important factors in determining the groundwater chemistry[15]. Dug wells, which are shallow, usually 8-12 m deep, were arsenic-free, as arsenic co-precipitates with iron under oxidizing environments[8,15].

After the discovery of the first case of arsenicosis in Bihar, a blanket sampling strategy was adopted to examine government installed hand pumps, and a screening sampling strategy was implemented to analyze private hand pumps for arsenic concentrations in the state[13]. This large-scale arsenic testing of groundwater was conducted jointly by the United Nations Children's Fund (UNICEF), the Public Health and Engineering Department (PHED) of Bihar, and Anugrah Narayan College, Patna, Bihar, India[12,13]. A total of 66,623 hand pumps were investigated from eleven districts and 64 community blocks, which represents less than 30% of the approximately 60,000 government and 180,000 private hand pumps in this region (as of the year 2004)[2,3]. All 11 districts and 50 community blocks were found to be affected by arsenic contamination, with elevated arsenic levels generally restricted to sites located < 10 km from the River Ganges[13]. In 2010-2011, arsenic contamination was reported in two new villages in Vaishali and six new villages in the Bhagalpur district, with arsenic levels above the WHO standard in Vaishali and above the BIS standard in the Bhagalpur area[16,17]. The highest concentration in Vaishali was 21 µg/L, and up to 599 µg/L in the villages of Bhagalpur[16,17]. In a recent study of the Siwan community block in Siwan district, arsenic levels >50 µg/L were reported with a maximum concentration of 150 µg/L of arsenic[10,18]. The Nautan community block in West Champaran district has arsenic concentrations up to 397 µg/L in drinking water[10,18]. Likewise, new community blocks in Samastipur district have arsenic levels ranging between <10 µg/L and 60 µg/L [19]. These areas are located far from the River Ganges, for example Siwan ~ 100 km, West Champaran ~ 139 km, Darbhanga ~ 80 km, Purnia ~ 65 km, and Kishanganj ~125 km, and indicate that the arsenic distribution is not strictly confined within the 10 km of the River Ganges[14]. The nearest River in Siwan is Ghaghara, which is about ~19 km from the arsenic contaminated community block. The arsenic contaminated Nautan community block in West Champaran is close to the River Gandak (~ 6km). The River Ghaghara is the second longest tributary of the River Ganges, which is a perennial trans-boundary River that originates on the Tibetan Plateau, crosses the Himalayas in Nepal, meets the Sarda River at the Brahmaghat in India, and connects Bihar and Uttar Pradesh through Siwan[20]. The Ghaghara River basin was identified as the most severely arsenic affected region in Uttar Pradesh, a neighboring state of Bihar[21]. Higher concentrations of arsenic in Siwan could be potentially linked to the Ghaghara River basin. On the other hand, the River Gandak originates in Tibet near the Nepal border in the Himalayas. It enters the Indian Territory near the town of Tribeni in Nepal, forms the boundary between Uttar Pradesh and Bihar, flows through the West Champaran, and joins the River Ganges at Hazipur in Bihar[20]. In a recent study, arsenic levels greater than the BIS standard were reported in Muzaffarpur district (although only 2 samples), which is situated along the Budhi Gandak River[20,22]. This River originates in West Champaran in Bihar and flows through the Muzaffarpur, and drains into the River Ganges near Khagaria district[20,22]. It is too early to identify the actual source(s) of arsenic in these areas, which are far from the River Ganges. Therefore, a detailed investigation is needed of groundwater sources close to the other Rivers and their arsenic affected basins. Hydro-geochemical analysis of the aquifers and biogeochemical studies of surface soils are vital to comprehend the origin and the distribution of arsenic in Bihar.

So far, 17 of 37 districts and a total of 87 of 532 community blocks have been investigated for groundwater arsenic contamination. Three community blocks were arsenic safe, as all the sources tested in these blocks had arsenic levels below the detection limit of the measurement method used[12]. Twelve community blocks had arsenic levels below the WHO standard[19]. Ten community blocks had arsenic concentrations above the WHO standard but equal or below to the BIS standard[12,13,19]. A total of 62 community blocks had arsenic concentrations above the BIS standard of 50 µg/L[8,11-14,16,17,19]. In sum, a total of 72 community blocks were contaminated with arsenic levels above the WHO standard of 10µg/L of arsenic in drinking water[8,11-14,16,17,19].

A total of about 13 million people live in these arsenic contaminated community blocks.



Note: Muzaffarpur district is not shown on the map as only two samples from this area contain arsenic contamination.

Figure-1

Arsenic affected community blocks of Bihar, India

Table-1

Arsenic affected community blocks and at-risk population in Bihar, India

Districts	**Total no. of blocks**[a]	**Arsenic affected blocks above the WHO standard (%)**[b]	**Total population**[a]	**Rural population**[a]
Bhojpur	14	6 (43%)	1191190	932672
Bhagalpur	16	6 (38%)	1414717	1000577
Begusarai	18	6 (33%)	1230641	1123018
Buxar	11	4 (36%)	608512	525344
Darbhanga	18	1 (5%)	233029	233029
Khagaria	7	4 (57%)	805292	728965
Kishanganj	7	2 (29%)	391645	277937
Katihar	16	6 (37%)	685151	663348
Lakhisarai	6	2 (33%)	292985	215110
Munger	9	4 (44%)	675935	390902
Patna	23	10 (43%)	1654345	1170270
Purnia	14	2 (14%)	494058	296847
Saran	20	4 (20%)	790229	516140
Siwan	19	1 (5%)	272509	162590
Samastipur	20	8 (40%)	1145061	1131292
Vaishali	17	5 (29%)	922037	802625
West Champaran	18	1 (6%)	175938	175938
TOTAL	216	72 (33%)	12983274	10346604

[a]Census of India: 2001 (http://www.censusindia.gov.in/); [b]Reference ([8, 11-14, 16, 17, 19])

It is challenging to determine whether the entire area investigated or only a portion of the area is affected by arsenic contamination. Previous studies suggest that arsenic contamination is most prevalent in rural areas, and more than 10 million people live in the rural arsenic contaminated community blocks described here[2,3,7]. Among the affected districts, more than 50% of the areas in Khagaria were arsenic contaminated. In Bhojpur, Munger, Patna, and Samastipur, more than 40% of the areas were arsenic affected. The areas least affected by arsenic contamination were Darbhanga (5%), Siwan (5%), and West Champaran (6%). Fourteen percent (14%) to 38% of the areas were arsenic contaminated in the rest of the districts (table 1). The arsenic contaminated areas, in these districts, represent percentage arsenic contaminated blocks out of total blocks. However, these do not explain that the arsenic contaminated blocks were 100% arsenic contaminated. Communities' socioeconomic conditions and biophysical status of an area play vital role in shaping communities' vulnerability[7]. Adaptive capacity refers to coping capacity of a system to the socioeconomic and/or environmental consequences[7]. Singh and Vedwan[7] reported details on these concepts and vulnerability to arsenic in Bihar. Katihar was a highly vulnerable district because of the socioeconomic and biophysical conditions, followed by Vaishali, Samastipur, Khagaria, and Purnia. Munger was the only resilient district, as it had the greater adaptive capacity. Considering the higher adaptive capacity, the likelihood of success of an arsenic-mitigation policy in Bhojpur would be greater[7].

Arsenic Contamination in Soil: Arsenic concentrations in soil and sediment depend on the geological conditions as well as on anthropogenic activities[23]. Soil considered "uncontaminated" usually contains arsenic in the range of 0.2 to 40 mg/kg, whereas contaminated soil can contain up to 10,000 mg/kg of arsenic[6,23]. The average concentration of arsenic in the Earth's crust is only 1.8 mg/kg, although values between 0.1 and 80 mg/kg have been documented[6,23].

In Bihar, arsenic in soil was first reported in 2009 in Patna, Vaishali, and Bhagalpur districts[17]. A summary of arsenic concentrations in soils and other soil properties is presented in table-2. According to a United States Environmental Protection Agency (USEPA) estimate, a child can ingest an average of 100 mg/day of soil. Although the Bihar soil arsenic concentrations were within the acceptable limit of 1mg/kg, long term exposure to and consumption of contaminated soil creates an exposure risk and potentially a cancer risk to children[6,5]. In addition, agricultural activities in rural India cause incidental ingestion of contaminated soil through hand-to-mouth contact during planting and harvesting. Contaminants transferred from irrigation water to food are then incorporated into the food chain[4,6,24]. This exposure to contamination, even at low concentrations, poses a potential risk to public health for both children and adults when continued for long periods[4,6,24].

Arsenic in the Food Chain: Arsenic in food materials in Bihar was first investigated in 2009[17]. The staple foods of Bihar including rice, wheat, maize, and lentils were analyzed for arsenic concentrations. The mean arsenic concentrations range between 0.011 mg/kg in maize to 0.024 mg/kg in wheat.

Table-2
Characteristics of soil in Bihar, India

Soil properties	Districts	Min	Max	Ave	Std. Dev.
pH	Patna	6.5	6.9	6.6	0.2
	Vaishali	6.5	7.4	7.1	0.3
	Bhagalpur	6.5	7.4	7.1	0.3
Arsenic (µg/kg)	Patna	16.0	44.0	26.5	10.9
	Vaishali	50.0	77.0	61.8	11.8
	Bhagalpur	37.0	70.0	54.0	11.1
Organic matter (%)	Patna	0.74	1.49	1.11	0.34
	Vaishali	0.60	2.71	1.12	0.80
	Bhagalpur	1.02	1.70	1.24	0.28
Phosphate (mg/kg)	Patna	0.51	2.96	2.05	0.86
	Vaishali	1.04	2.60	1.65	0.73
	Bhagalpur	2.11	3.76	2.84	0.63

Source: Singh 2011

Table-3
Arsenic in food samples collected from Maner block of Patna district in Bihar, India

Food materials	Variety	Arsenic (mg/kg)
Rice-grain	Sonam	0.019
Rice-husk	Sonam	0.022
Wheat	Ub-2338	0.024
Maize	K-H-101	0.011
Lentil	NA	0.015

Source: Singh 2011

Although the concentration of arsenic in food samples was below the Australian recommended food standard of 1 mg/kg, the total intake of arsenic through drinking water, cooking water, and food exceeded 200 µg/day[9,17]. The Food and Agricultral Organization (FAO) suggested adopting Chinese food safety standards for inorganic arsenic in South Asia, as it is more relevant to Asian countries[25]. The Australian standards consider total arsenic, whereas the Chinese standards consider inorganic arsenic in food materials[25]. A summary of the food safety standards for inorganic arsenic in various products set by the Chinese Ministry of Health is presented in table 4.

On an average, children in Bihar consume 398 µg/L and elderly people consume 945 µg/L of arsenic per day through water used for drinking and cooking[9,17]. Consumption of arsenic through rice cooked in arsenic-contaminated water reaches 1,469 µg/day[9]. In the Vaishali district, wheat and banana were the dominant produce (table-2)[17]. Vaishali is known for its unique variety of banana called "Chinia kela" [chinia represents sweet (sugar) and kela is banana in Hindi], known for its small size and sweet taste. These bananas, some grown in arsenic-contaminated soil, are exported to other districts and states in India, which could be a potential threat to those consumers who live in arsenic-free areas through "migratory arsenic"[17].

Table-4
Food safety standards for inorganic arsenic in various products

Food products	Concentration of inorganic arsenic (mg/kg)
Rice	0.15
Flour	0.10
Other cereals	0.20
Vegetables	0.05
Fruit	0.05
Poultry	0.05
Egg	0.05
Milk powder	0.25
Fresh milk	0.05
Beans/pulses	0.10
Fish	0.10
Algae	1.50
Shellfish	0.50

Source: Adapted from Heikens, 2006

Health Risks: Non-carcinogenic toxicity of a substance is derived by calculating the Hazard Quotient (HQ) or Hazard Index (HI) of a substance[4]. The HQ estimates the potential health risks associated with continued exposure to chemical pollutants. A HQ or HI below 1 indicates that there is no significant risk of non-carcinogenic effects. Likewise, a cancer risk between 10^{-4} and 10^{-6} is acceptable for carcinogenic risk[4,26]. A detailed method of deriving HQ is described in the USEPA Guidelines for Carcinogen Risk Assessment (1999)[22]. A summary of non-carcinogenic health risks due to the consumption of arsenic in Bihar is presented in table-5. This table shows an average value of the HQ for children between 5 to 10 years of age. Detailed HQ values for youth, adult and elderly people in Patna, Vaishali, and Bhagalpur districts are described elsewhere[2,3].

Table-5
Average HQ and cancer risk (CR) for children between 5 to 10 years of age in arsenic contaminated areas in Bihar, India

District	HQ	USEPA chronic risk level (HQ) (1999)	CR	USEPA cancer risk (1999)	Reference
Patna	117	High	53	Very high	3
Vaishali	6.6	High	3	Very high	2
Bhagalpur	35.6	High	16	Very high	2
West Champaran	104	High	47	Very high	18

Note: HQ: <0.1= Negligible; ≥0.1<1= Low; ≥1<4= Medium; ≥4= High, Cancer risk: <1 person/1,000,000 inhabitants= Very low; >1 person/1,000,000 and <1 person/100,000 inhabitants= Low; >1 person/100,000 inhabitants and < 1 person/10,000 inhabitants= Medium; >1 person/10,000 and <1 person/1,000 inhabitants= High; and >1 person/1,000 inhabitants= Very high

During a study conducted in 2003, 50 adults and 10 children in Semaria Ojha Patti were observed with typical skin lesions[8]. 245 adults had arsenic-typical neuropathy, and women exposed to the highest levels of arsenic in their drinking water reported fetal loss and premature delivery[11]. In a more recent study, a significant correlation between arsenic concentrations in drinking water and several types of cancer (skin, breast, gall bladder, and liver) was reported[27]. Body itching, hardening of sole and skin pigmentation were also observed in Patna, Vaishali, and Bhagalpur, with a skin pigmentation prevalence rate of 4.03% in Bhagalpur, 7.55% in Vaishali, and 2.3% in Patna[2,3].

Challenges and Solutions: Wide Spatial Variation in Groundwater Arsenic Concentrations: The arsenic hotspots appear to be confined to the Newer Alluvial belt along the river Ganges, presenting a challenge for communities dependent on hand-pump based drinking water supply systems in rural areas [8]. Additionally, measured arsenic concentrations in Bihar vary by a factor of 90 over distances as small as 150 m[14]. This creates problems with identifying and taping arsenic-free aquifers for drinking water supplies. Deep tube well installations are expensive, which make them impractical for the socioeconomically deprived communities. Consequently, they rely on the more easily accessible but arsenic contaminated water sources. Renovating arsenic-free open wells could immediately solve this problem. Sharing arsenic-free hand pumps would also provide a temporary solution for this problem.

Lack of Guidelines for Water Sampling Density: There are no guidelines for the minimum number of water sources to be tested to determine a representative water quality profile in the state. A sampling density of one drinking water source per square mile has been used in previous water quality studies, which could be adopted and implemented in the state to avoid repetition of testing drinking water sources[28]. Testing 1000 water sources per district would give a more comprehensive profile of the water quality in the state[28], but this requires coordination for comprehensive and efficient data collection. Hand pumps in Bihar were tested in 2004 and marked as “blue” for safe and “red” for unsafe[12,13]. These markings are now washed-out and the pumps have not been re-labeled (field observation, 2013). Without clear labels and unique identifiers, the likelihood of redundant testing of the same water source is greater, particularly if there is no coordination among the agencies conducting tests.

Uncontrolled and Unregulated Installation of Hand Pumps: According to the Bihar Ground Water Regulation and Control of Development and Management Act of 2006, “any user of groundwater as defined under section 2(1) desiring to sink a well in the notified area for any purpose either on personal or community basis, shall apply to the Authority for grant of a permit for this purpose, and shall not proceed with any activity connected with such sinking unless a permit has been granted by the Authority. Provided that the person or persons will not have to obtain a permit if the well is proposed to be fitted with a hand operated manual pump or water is proposed to be withdrawn by manual device"[29]. Under such rules, affluent people install 2-3 hand pumps, whereas the socioeconomically disadvantage people must rely on public hand pumps installed by the PHED, which are in most cases arsenic contaminated[12,13]. The arsenic crisis in South Asia was exacerbated by the uncontrolled installation of hand pumps. Good environmental management practices such as regulating installation of private hand pumps, regular monitoring of government installed hand pumps, and metering the hand pumps to minimize misuse of water should be priorities in arsenic-mitigation policies. There are other good recommendations in the Bihar Ground Water Regulation Act, such as "spacing of groundwater abstraction structures keeping in consideration the purpose for which groundwater is to be used" and others[29]. These require more effective implementation[29].

Lack of Common Repository of Arsenic Testing Data: At present there is no common repository for arsenic contamination data in Bihar. Therefore, it is hard to follow research progress and hinders the creation of feasible arsenic-mitigation policies. More precisely, data on the local habitat is required to advance the arsenic research in Bihar, and to develop effective arsenic-mitigation policies.

Lack of a Decision Support System for Arsenic Mitigation: A decision support system would help decision makers to prioritize arsenic-mitigation policies, based on the empirical data on socioeconomic and biophysical status of the arsenic-affected communities[7]. Household level vulnerability assessment to groundwater arsenic contamination would be a prerequisite to create sustainable arsenic-mitigation policies in Bihar and in other arsenic contaminated areas in other countries as well.

Lack of Coordination among the Research Groups: Only a few research groups were active when arsenic studies in the state first began[8,11,12]. Now several local, regional, national, and international research groups are working on arsenic issues in the state, as Bihar is a region that is laying new ground for all types of arsenic research. However, most of these groups either work in isolation or in different programmatic directions. A common arsenic consortium, where all institutions and clusters could work together, is suggested. This would help regional, national, and international organizations to get benefits from the local institutions and groups, and at the same time provide opportunities to local institutions to exchange state of the art information and techniques for arsenic and environmental management research. This would build a collegial environment, advance arsenic research, and facilitate area-specific and cost-effective arsenic-mitigation techniques in Bihar.

Moreover, research focused on arsenic in the food-chain, epidemiological surveys, and vulnerability of groundwater and the arsenic-affected communities would help to create effective arsenic-mitigation policies in Bihar. In addition, environmental awareness in general, and arsenic awareness in arsenic-affected areas, would cultivate environmental protective behavior in the communities[30].

Conclusion

This review provides an overview of the current extent of arsenic contamination in Bihar, identifies challenges and suggests solutions. One decade ago, researchers expressed concerns about arsenic contamination problems in Bihar [11]. They advised scientific communities not to repeat the mistakes made during the West Bengal and Bangladesh arsenic episodes [11]. Rather communities should be proactive and apply the knowledge gained in West Bengal and Bangladesh to Bihar. In 2003, only a single village, Semaria Ojha Patti, was known to have groundwater arsenic contamination with a similar magnitude to West Bengal and Bangladesh [11]. After one decade, the problem was detected in 72 community blocks in 17 districts. This does not mean that other areas are arsenic-free, as less than 30% of all drinking water sources in Bihar have been tested for arsenic thus far[13]. Arsenic research focused on the irrigation water, the food chain, and associated epidemiological studies are largely neglected. Socioeconomic studies are still in the rudimentary stages in Bihar. Investigation of other river basins in the state is needed to determine whether they are potential sources of arsenic contamination in the state. The arsenic danger has arrived in Bihar, as predicted a decade ago[11]. If not given immediate attention and if mitigation policies are not implemented immediately, Bihar will be the host of another global mass poisoning. An arsenic-mitigation decision support system is immediately needed. This will identify the most vulnerable communities to arsenic and also prioritize the arsenic-mitigation policies.

References

1. Ravenscroft P., Brammer H. and Richards K., Arsenic Pollution : A Global Synthesis, *John Wiley and Sons.*, **28 (2009)**
2. Singh S.K, Ghosh A.K, Kumar A., Kislay K., Kumar C., Tiwari R., Parwez R., Kumar N. and Imam M., Groundwater Arsenic Contamination and Associated Health Risks in Bihar, India, *International Journal of Environmental Research.*, **8(1)**, 49-60 **(2014)**
3. Singh S. K. and Ghosh A. K., Health Risk Assessment due to Groundwater Arsenic Contamination: Children are at High Risk, Human and Ecological Risk Assessment : *An International Journal.*, **18(4)**, 751-766 **(2012)**
4. USEPA., *Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum, NCEA-F-0644 (Revised draft).* U.S. Environmental Protection Agency (USEPA) : Washington DC, USA, **(1999)**
5. USEPA., The integrated risk information system (IRIS)., U.S. Environmental Protection Agency (USPA), Environmental Criteria and Assessment Office, Cincinnati (OH), USA, **(2001)**

6. WHO., Arsenic : Environmental Health Criteria, World Health Organization (WHO), Geneva., **18 (1981)**

7. Singh S.K. and Vedwan N., Mapping Composite Vulnerability To Groundwater Arsenic Contamination : An Analytical Framework and a Case Study in India, *Natural Hazards.*, **75(2)**, 1883-1908 **(2015)**

8. Saha D., Dwivedi S. and Sahu S., Arsenic in Ground Water in Parts of Middle Ganga Plain in Bihar-An Appraisal, Editorial Board., **24(2and3), (2009)**

9. Singh S.K. and Ghosh A.K., Entry of Arsenic into Food Material–A Case Study, *World Appl Sci J.,* **13(2)**, 385-90 **(2011)**

10. Singh S.P., Spatial Relationship of Various Parameters in Drinking Water in Siwan town of Bihar (India) with Special Emphasis on Arsenic Contamination in Groundwater, *International Journal of Basic and Applied Science Research.,* **1(1)**, 01-05 **(2014)**

11. Chakraborti D., Mukherjee S.C., Pati S., Sengupta M.K., Rahman M.M., Chowdhury U.K., Lodh D., Chanda C.R., Chakraborti, A. K. and Basu, G. K., Arsenic Groundwater Contamination in Middle Ganga Plain, Bihar, India: A Future Danger? *Environmental Health Perspectives.,* **111 (9)**, 1194 **(2003)**

12. Ghosh A.K., Singh S.K., Bose N., Roy N.P., Singh S.K., Upadhyay A.K., Kumar S. and Singh A., Arsenic Hot Spots Detected in the State of Bihar (India) A Serious Health Hazard for Estimated Human Population of 5.5 Lakhs, In *Assessment of Ground Water Resources and Management*, I.K. International Publishing House Pvt. Ltd., New Delhi, India., 62-70 **(2009)**

13. Nickson R., Sengupta C., Mitra P., Dave S., Banerjee A., Bhattacharya A., Basu S., Kakoti N., Moorthy N. and Wasuja M., Current Knowledge on the Distribution of Arsenic in Groundwater in Five States of India, *Journal of Environmental Science and Health Part A.*, **42(12)**, 1707-1718 **(2007)**

14. Saha D., Arsenic Groundwater Contamination in Parts of Middle Ganga Plain, Bihar, *Curr Sci.*, **97(6)**, 753-755 **(2009)**

15. Saha D., Sahu S. and Chandra P., Arsenic-Safe Alternate Aquifers and their Hydraulic Characteristics in Contaminated Areas of Middle Ganga Plain, Eastern India, *Environmental monitoring and assessment.,* **175(1-4)**, 331-348 **(2011)**

16. Singh A. and Choudhary S.K., Arsenic in Ground Water in Five Villages under Nathnagar Block of Bhagalpur District, Bihar, *Ecoscan.,* **4(2-3)**, 213-216 **(2010)**

17. Singh S., Arsenic Contamination in Water, Soil, and Food Materials in Bihar, Lambert Academic Publishing: Germany, **(2011)**

18. Bhatia S., Guru B. and Baranwal A., High Arsenic Contamination in Drinking Water Hand-Pumps in Khap Tola, West Champaran, Bihar, India, *Frontiers in Environmental Science.,* **2 (49)**, 1-8 **(2014)**

19. Gupta V., Singh J., Kumari P., Prasad S. and Jha A., Arsenic in Hand Pump Water of Different Blocks of Samastipur District (Bihar), India, *International Journal of Basic and Applied Science Research.,* **1(1)**, 1-5 **(2014)**

20. FMIS., River Basin, Flood Management Information System (FMIS), Water Resources Department, Government of Bihar, India., available at http://fmis.bih.nic.in/riverbasin.html, accessed on September 21, (**2014)**

21. Yasunori Y., Kenichi I., Akihiko K., Koichiro S., Shigeki T., Mitsuhiro S. and Hiroshi, Y., Arsenic Polluted Groundwater and its Countermeasures in the Middle Basin of the Ganges, Uttar Pradesh State, India, *Journal of Environmental Protection,* **3 (8A)**, 856-862 **(2012)**

22. Mumtazuddin S., Azad A.K., Bharti P. and Ranjan R., Physico-chemical Analysis of Groundwater of the Budhi Gandak Belt in Muzaffarpur District, India, *I Research Journal of Environment Sciences*, **1(1)**, 7-11 **(2012)**

23. Romero-Freire A., Sierra-Aragón M., Ortiz-Bernad I. and Martín-Peinado F.J., Toxicity of Arsenic in Relation to Soil Properties: Implications to Regulatory Purposes, *Journal of Soils and Sediments*., **14(5)**, 968-979 **(2014)**

24. Rolli N., Heavy Metal Accumulation in Vegetables Irrigated with Sewage and Its Impact on Health, *Research Journal of Recent Sciences*., **3(IVC-2014)**, 81-84 **(2014)**

25. Heikens A., Arsenic Contamination of Irrigation Water, Soil and Crops in Bangladesh: Risk Implications for Sustainable Agriculture and Food Safety in Asia, RAP Publication (FAO), **(2006)**

26. Singh S., Feldman C. and Wunderlich S., Disaster Issues and Management in Farm and Urban Crop Production, *Perspectives in public health*., **134(3)**, 127-128 **(2014)**

27. Nath A., Vendan P.S., Kumar S., Kumar A. and Singh J., Toxicity Due to Arsenic in Gangetic Zone of Patna, India and its Linkage with Cancer, *J Environ Anal Toxicol*., **3(192)**, 2161-0525 **(2013)**

28. Singh S.K., Sanchez G.D. and Panigrahi S.K., Multiple Groundwater Contamination in the Mid-Gangetic Plain, Bihar, India : A Potential Threat, *International Journal of Advanced Research in Science and Technology (IJARST).,* **3(3)**, 147-151 **(2014)**

29. GoB., Bihar Ground Water (Regulation and Control of Development and Management Act) Act, 2006; Bihar, India, **29,** 2007, **(2007)**

30. Saheb S.U., Seshaiah S. and Viswanath B., Environment and Their Legal Issues in India, *International Research Journal of Environment Sciences*., **1(3)**, 44-51 **(2012)**