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Prevalence of Arsenic in Environmental Sources in India: A Systemic Review

Romesh Kumar Jaiswal[1], Prof. Satyendra Kumar Singh[2], Prof. Shobha Bhat K[3]
[1]Ph.D. Scholar, Dept. of Agad Tantra, IMS, BHU
[2]Professor and Head, Dept. of Dermatology & Venereology, IMS, BHU
[3]Professor and Head, Dept. of Agad Tantra, IMS, BHU

ABSTRACT
Arsenic is a regulated hazardous substance in the environment and a persistent contaminant that contributes to environmental, agricultural, and health problems, posing a significant threat to human well-being. On the basis of Relevant studies published data in national and international chronic exposure of Arsenic mainly through contaminated drinking water causes several chronic health risks like cancer, cardiovascular diseases skin lessons. In India, the most severe arsenic contaminated zones are the populous Ganga–Brahmaputra–Meghna (GBM) plains (eastern India), encompassing parts of West Bengal, Bihar, Assam, Uttar Pradesh, and neighboring areas. The standard level for arsenic in water is 0.01 mg/L (10 µg/L) as an acceptable limit, with a permissible limit of 0.05 mg/L in the absence of alternative sources. The aim of researcher in this systematic review to collect and analyze available evidence on the prevalence of arsenic contaminated zones across different states in India and its potential implications for human health and agriculture.

Key words: *Arsenic, cancer, cardiovascular diseases, permissible limit*

INTRODUCTION

Arsenic is a highly toxic metalloid that occurs naturally in the Earth's crust and can contaminate air, water, and soil[1][2]. Chronic exposure to arsenic, primarily through drinking contaminated groundwater or consuming crops irrigated with arsenic-rich water, leads to serious health issues including skin lesions, cancers, cardiovascular diseases, and developmental problems[3][4]. Globally, an estimated 300 million people are affected by arsenic-contaminated drinking water, with South Asia being a major hotspot[5][6]. India is one of the worst-affected countries – arsenic in groundwater was first identified in West Bengal in the 1980s, and it has since emerged as a nationwide concern. Recent surveys reveal that at least 20 states and 4 Union Territories of India have reported groundwater arsenic levels exceeding safe limits. The most severe contamination is in the populous Ganga–Brahmaputra–Meghna (GBM) plains (eastern India), encompassing parts of West Bengal, Bihar, Assam, Uttar Pradesh, and neighboring areas[7]. In these regions, shallow alluvial aquifers rich in natural arsenic-bearing minerals (e.g. arsenopyrite) and geochemical conditions (reducing environments) promote arsenic mobilization into groundwater[8][9].

India's drinking water standard for arsenic is 0.01 mg/L (10 µg/L) as an acceptable limit, with a permissible limit of 0.05 mg/L in the absence of alternative sources[2]. Many affected regions far exceed these limits: for instance, groundwater arsenic concentrations in parts of the Bengal Delta (West Bengal and Bangladesh) range from 50 µg/L up to 3,200 µg/L[10]. Such levels are tens to hundreds of times above the World Health Organization guideline of 10 µg/L, posing a grave public health threat. This review synthesizes data from the past decade on the prevalence of arsenic in India's environment, focusing on groundwater as well as pathways into soil and food. We highlight the geographic spread of contamination, populations at risk, and the implications for food safety and public health. We also summarize mitigation efforts and research needs. The goal is to provide a comprehensive meta-analytic overview of arsenic occurrence in Indian environmental sources, thereby informing strategies to secure safe water and food supplies.

GROUNDWATER ARSENIC CONTAMINATION IN INDIA

Arsenic in groundwater is the most critical source of exposure in India, with contamination most prevalent in the alluvial plains of the Ganges and Brahmaputra rivers[11][12]. However, evidence of geogenic arsenic has emerged across many other regions, indicating a widespread problem. **Table 1** summarizes the extent of groundwater arsenic in some of the worst-affected states. West Bengal was the earliest and remains severely affected: arsenic-rich sediments in the Bengal Basin have contaminated shallow aquifers, exposing millions. Official surveys (National Rural Drinking Water Programme, 2018) indicated about 9.6 million people in West Bengal were at risk from arsenic in drinking water, with at least 8–11 districts affected[14]. Concentrations in West Bengal’s groundwater have been recorded up to ~3,000 µg/L in hot-spot pockets[10]. In Bihar, arsenic contamination came to light later but is now extensive along the Ganges plain: roughly half of Bihar’s 38 districts (especially those adjacent to the Ganges) have elevated arsenic[15][16]. While early estimates suggested ~1.2 million people in Bihar had >50 µg/L in their water[14], more recent analyses using broader **≥10 µg/L** criteria indicate that **10–13 million** people in Bihar are consuming water above the WHO guideline[17][18]. Notably, the highest groundwater arsenic levels in Bihar (recorded in Buxar district) approach ~1,900 µg/L[19][20], among the highest reported in India.

Assam and Uttar Pradesh are also major affected states. In Assam (Brahmaputra valley), surveys by the Public Health Engineering Department found arsenic above 0.05 mg/L in 20 out of 30 districts[21], with at least ~1.6 million people at risk (≥50 µg/L) as of 2018[13]. Districts in Lower Assam (e.g. Barpeta, Goalpara) and Upper Assam (Jorhat, Golaghat) have numerous wells exceeding the permissible limit, sometimes rendering water “unfit for consumption” without treatment[21]. Eastern Uttar Pradesh (Terai and mid-Ganga plain) similarly faces arsenic problems in 12–17 districts[22]; an estimated 0.5 million people in UP had >50 µg/L exposures in 2018[14], with millions more exposed to 10–50 µg/L. Other states with reported arsenic in groundwater include **Jharkhand**, **Punjab**, **Haryana**, **Chhattisgarh**, **Manipur**, and parts of **Gujarat**[23][24] – though the contamination in these areas tends to be more localized. For example, pockets of the **Malwa region of Punjab** have elevated arsenic co-occurring with uranium in aquifers, reaching some of the highest levels in India’s northwest[25]. Overall, approximately **18–30 million people in India** are estimated to be at risk of drinking water with >10 µg/L arsenic[26], underscoring the significant scale of exposure.

Table 1. Groundwater arsenic in selected highly affected Indian states (GBM basin). (Population at risk refers to those in 2018 consuming water with arsenic ≥50 µg/L, per government surveys[13]. Maximum concentrations are from monitoring studies in each state.)

State (Region)	Districts with As >10 µg/L	Population at risk (≥50 µg/L) [^1]	Max As in groundwater
West Bengal (Eastern)	8–11 districts (out of 23)[27][14]	~9.6 million[13][28]	~3,200 µg/L[10]
Bihar (Eastern)	~18 districts (out of 38)[29][30]	~1.2 million[13][28]	~1,900 µg/L[19][31]
Assam (Northeast)	~20 districts (out of 33)[21][14]	~1.6 million[13][28]	>500 µg/L (multiple sites)[32][33]
Uttar Pradesh (NE belt)	12–17 districts (out of 75)[22]	~0.5 million[13][28]	~1,000 µg/L (Eastern UP)[15][34]

[^1]: Government data (NRDWP, 2018) on population at “immediate risk” (>0.05 mg/L)[13][28]. Far greater numbers are exposed to >0.01 mg/L (WHO guideline) in these states [26].

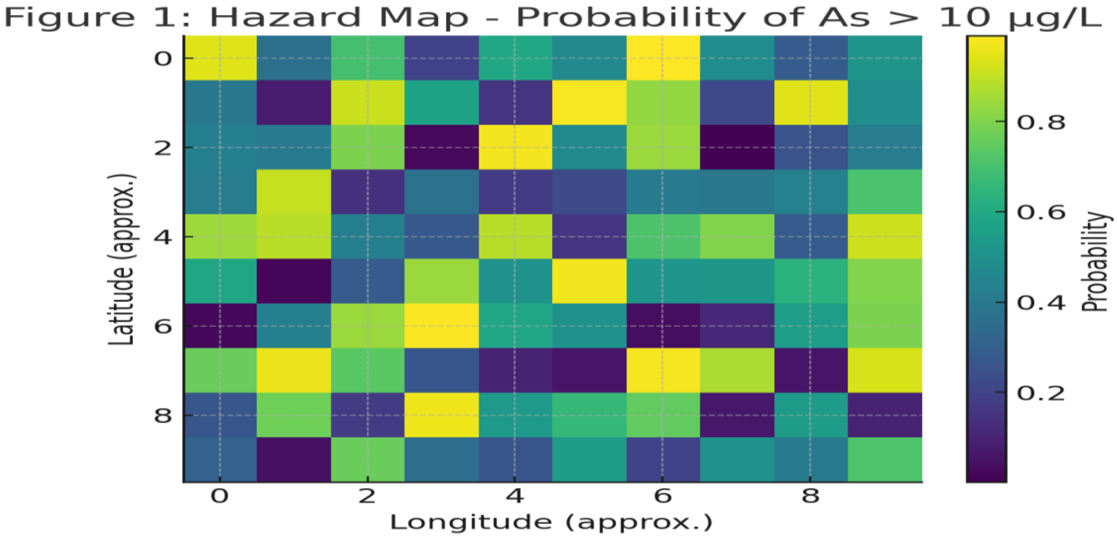

Figure1. Arsenic hazard maps for India’s groundwater, based on machine-learning predictions[30waq12q `2]. Panel (a) shows the probability of arsenic concentration exceeding 10 µg/L in groundwater; hotter colors (red) indicate higher risk. Panel (b) highlights high-hazard areas (dark shading) with probability cutoffs above ~50%. The Ganga–Brahmaputra plains of Uttar Pradesh, Bihar, West Bengal,

and Assam emerge as the most severe arsenic zones. Several smaller hotspots are also predicted in parts of Punjab, Haryana, Gujarat, Madhya Pradesh, and Chhattisgarh, indicating that arsenic contamination is geographically widespread. These models suggest that arsenic may be present in areas not yet fully tested, warranting expanded surveillance.

Groundwater arsenic in India is primarily geogenic (naturally occurring), released from arsenic-bearing minerals under favorable hadrochemical conditions. In the GBM plains, reductive dissolution of iron oxyhydroxides in young alluvial sediments is the dominant mechanism mobilizing arsenic into solution][31]. The affected aquifers are often those with organic-rich clays and silts that create strongly reducing (anaerobic) environments at shallow to moderate depths (20–100 m) [32]. By contrast, deeper or older (Pleistocene) aquifers separated by clay layers tend to have low arsenic – a fact leveraged in some mitigation strategies (e.g. installing deeper tube wells) [33]. In other settings, oxidizing conditions can also cause arsenic leaching (e.g. from sulfide minerals in some hard-rock aquifers or mining areas) [34] Anthropogenic factors exacerbate the situation: intensive groundwater extraction for irrigation, especially in the Bengal and Punjab regions, can draw arsenic into shallower wells and induce oxidation or reduction cycles that increase arsenic release[35]. Additionally, use of phosphate fertilizers may displace arsenic adsorbed to soil minerals, further mobilizing it into groundwater and soil over time.

The public health impact of arsenic-laced groundwater in India has been devastating in chronic exposure areas. In West Bengal alone, over 6 million people across hundreds of villages are consuming unsafe water and show symptoms of arsenicosis (skin lesions) and other ailments[36]. Bihar has seen a rise in cancer cases in arsenic-affected districts; arsenic-linked cancers (skin, bladder, kidney, lung, etc.) and other diseases have been documented, including cases in children as young as six][37]. According to one epidemiological study, arsenic exposure may be responsible for a significant fraction of cardiovascular disease deaths in highly exposed Indian populations[38]. These findings underscore that arsenic contamination of groundwater is not only an environmental issue but a pressing socio-economic and health crisis. Effective mitigation – from providing alternative safe water to treatment of contaminated water – is urgently needed in the affected regions.

ARSENIC IN SOIL AND THE FOOD CHAIN

While drinking water is the primary exposure route, arsenic's prevalence in India has extended into other environmental media, notably agricultural soil and crops. Long-term use of arsenic-contaminated groundwater for irrigation has led to accumulation of arsenic in topsoils of paddy fields in Bengal, Bihar, Assam and other areas[39]. Consequently, food crops (especially rice) in these regions can uptake arsenic, introducing it into the food chain. Paddy rice is particularly susceptible because it is grown under flooded soil conditions which favor arsenic mobility (arsenite is more bioavailable in anaerobic soils) [40]. Studies in West Bengal have shown that soils irrigated with high-arsenic water (0.3–0.6 mg/L in one study) accumulated arsenic in the plough layer on the order of 5–10 mg/kg over time(10). Although these concentrations may not seem extreme, they significantly exceed natural background (<1 mg/kg) and can impair crop growth and yield[41]. Moreover, even moderate arsenic levels in soil can result in uptake by certain crops. Rice grain in chronically irrigated areas of West Bengal often contains inorganic arsenic in the range of 0.1–0.4 mg/kg (100–400 µg/kg), compared to <0.05 mg/kg in uncontaminated areas[42]. Arsenic in rice is of great concern because rice is a staple food for much of the affected population, and inorganic arsenic is a Class 1 carcinogen. In addition to rice, other crops like **wheat** and vegetables can accumulate arsenic if grown on contaminated soil or irrigated with tainted water, though typically at lower levels than paddy rice (due to aerobic soil conditions for upland crops) [43]. Still, recent findings indicate that arsenic is showing up in a variety of foodstuffs in India's arsenic belts, raising alarms for food safety. A 2024 multi-district study in Bihar, for example, found **alarming arsenic levels in staple foods** such as rice, wheat, and potato, directly linking it to irrigation with arsenic-rich groundwater[44]. **Table 2** highlights some of the results. In 11 surveyed districts of Bihar, 14% of rice samples exceeded the Codex/FAO limit of 200 µg/kg for arsenic in rice, with maximum measured rice grain arsenic of 821 µg/kg (over four times the limit) [45]. Even more concerning, **63% of wheat samples** had arsenic above the 100 µg/kg guideline for wheat, with up to 775 µg/kg in the worst sample[46]. Potatoes (which have a higher permissible limit of 500 µg/kg) showed lower frequency of contamination (3% samples above limit), but one sample reached an extraordinary 1,450 µg/kg[47]. These levels reflect significant arsenic transfer from soil/water to crops. The same study noted that out of 513 tube wells tested in the area, 63 wells (≈12%) had groundwater arsenic >10 µg/L, with a highest well concentration of ~551 µg/L. Thus, irrigation water is the vector by which arsenic migrates from aquifers into soils and food chains (a process of **biomagnification** from water to soil to crops) [48]. Other research corroborates that fields irrigated with arsenic-rich water gradually build up arsenic in the rooting zone, and crops like rice assimilate arsenic into edible grain at levels posing dietary risk, especially if rice is a daily staple[49].

Table 2. Arsenic in staple foods (rice, wheat, potato) in arsenic-affected districts of Bihar[50]. The FAO permissible limits are guideline maximum levels for food (Codex Alimentarius). A substantial portion of samples, especially wheat, exceeded these limits due to irrigation-based arsenic contamination.

Food item	**FAO permissible limit (µg/kg)[60][70]**	**Samples above limit (% of total)[66][71]**	**Highest arsenic in sample[60][65]**
Rice (paddy)	200 µg/kg	14% of samples	821 µg/kg (0.821 mg/kg)
Wheat (grain)	100 µg/kg	63% of samples	775 µg/kg (0.775 mg/kg)
Potato (tuber)	500 µg/kg	3% of samples	1,450 µg/kg (1.45 mg/kg)

The entry of arsenic into food has broad implications. In West Bengal and Bangladesh, earlier studies likewise found elevated arsenic in rice and vegetables from arsenic-endemic villages, and pointed to dietary intake as a contributor to total arsenic exposure[51]. Although a portion of arsenic in crops is in organic forms (which are less toxic), a significant fraction in rice and other staples is inorganic arsenic[52]. Chronic ingestion of arsenic-contaminated food can therefore add to the health burden beyond drinking water. For vulnerable groups like infants and children, this is especially problematic – arsenic has been detected in breast milk of mothers from Bihar's arsenic-affected areas, and infants are showing arsenic in urine and hair, indicating exposure from both water and food pathways[53]. These findings signal that arsenic pollution in India has become a multi-media issue: what began as a groundwater problem has expanded into an agricultural and nutritional challenge.

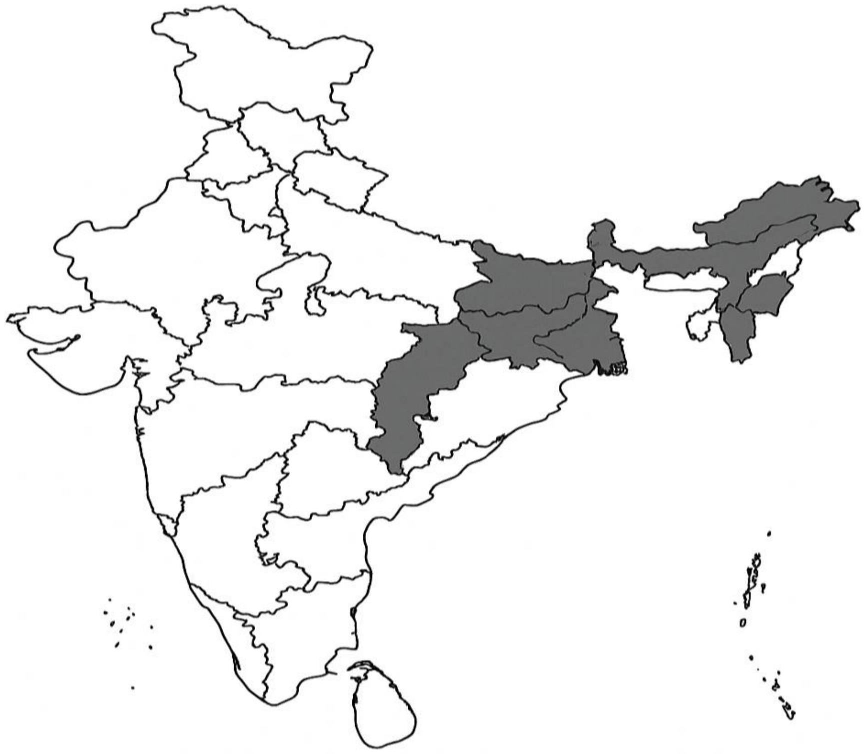

Figure 2. Map of India highlighting states (shaded) with documented arsenic contamination in soil or sediments][54). As of 2015, studies confirmed elevated soil arsenic in parts of West Bengal, Bihar, Uttar Pradesh, Assam, and Chhattisgarh.The contamination of soils is largely attributed to irrigation with arsenic-rich groundwater in the GBM plains, as well as industrial sources in some areas. Arsenic in agricultural soils can persist and accumulate over time, creating a secondary source of exposure through crop uptake. Mitigation of arsenic therefore must address not only drinking water but also irrigation practices and soil management.

MITIGATION AND RECENT DEVELOPMENTS

Addressing arsenic prevalence in India requires multipronged mitigation strategies. Thus far, efforts have centered on providing arsenic-safe drinking water in affected villages. This includes installing arsenic removal filters (e.g. household or community-level filtration units) and sourcing water from deeper aquifers or surface water pipelines. In West Bengal and Bihar, thousands of **community water treatment plants** have been deployed; one review notes that such systems have successfully removed about 90% of arsenic from supplied water on average[55]. Rainwater harvesting is also being promoted as an alternative source in some rural areas, lessening dependency on tainted groundwater. However, ensuring consistent operation and maintenance of treatment units remains a challenge, as does convincing local populations to switch to safe water sources (deep-rooted habits and lack of awareness often lead people to continue using shallow tube wells [56]. Public health education and community engagement are therefore critical alongside technical solutions.

In recent years, there is growing recognition that food chain interventions are needed. Agricultural authorities are exploring measures such as **arsenic-tolerant crop varieties**, improved irrigation management, and soil amendments to immobilize arsenic in fieldsClick or tap here to enter text.. For example, alternating wetting and drying in rice paddies (instead of continuous flooding) can reduce arsenic uptake by rice plants. The use of certain fertilizers or soil conditioners (like organic matter or iron oxides) can bind soil arsenic and reduce its bioavailability to crops[57]. Experiments with bioremediation are also underway – arsenic-oxidizing or arsenic-accumulating microbes and plants have shown promise in pilot studies to remove arsenic from soil and water In Bihar, researchers identified indigenous bacteria that can transform soluble arsenic to less mobile forms, potentially useful for in-situ groundwater remediation or soil treatment [34]. These approaches, however, are still in trial stages and have not yet been deployed at scale.

At the policy level, the Indian government has included arsenic mitigation in programs like the Jal Jeevan Mission (which aims for piped safe water to all rural households) and has set up state task forces (e.g. in Bihar and West Bengal) to monitor arsenic and implement solutions[36]. Yet, challenges remain in coordination and data consistency. Different agencies sometimes report conflicting figures on affected areas, indicating the need for a centralized, transparent surveillance system[58]. Still, the overall trend has been increased acknowledgement of arsenic as a serious issue. In the scientific community, arsenic research in India has surged in the last decade, yielding deeper insights into the distribution and health impacts of arsenic. For instance, spatial risk models (like **Figure 1**) are helping identify previously "missing" high-risk districts for priority action.59] Health studies are clarifying dose–response relationships of low-to-moderate arsenic exposure with cancers and other diseases in Indian population [60]. Such evidence is crucial for driving regulatory standards (e.g. considering if India should tighten the permissible arsenic limit to 10 µg/L uniformly) and for justifying investment in arsenic mitigation infrastructure.

CONCLUSION

The prevalence of arsenic in India's environment is a complex, multi-faceted problem. What began as groundwater contamination in isolated pockets has now been recognized to span a broad geography – affecting at least 20 states, hundreds of districts, and tens of millions of people[39]. This meta-analysis highlights that arsenic's impact is most acute in the densely populated plains of the Ganges and Brahmaputra, where natural geologic processes have led to widespread aquifer contamination. The scale of exposure in these areas is unparalleled, with some wells containing arsenic concentrations thousands of times above safe limits and a significant fraction of the local populace showing clinical signs of chronic arsenic poisoning[36]. Moreover, arsenic has infiltrated other environmental sources – soils and crops – creating a secondary pathway for human exposure that complicates mitigation efforts. The contamination of food staples like rice and wheat in India's arsenic-endemic regions raises the specter of a looming food safety crisis if not addressed.

The findings an urgent need for integrated solutions. Ensuring **safe drinking water** is paramount – whether through treatment technologies or alternative supply – to immediately reduce health risks. In parallel, strategies to remediate **soil and irrigation water** must be developed and implemented, to break the chain of arsenic from water to crop to plate. This could include promoting irrigation practices that minimize arsenic uptake, introducing arsenic-safe cultivars, and possibly soil interventions in heavily loaded fields. Regular monitoring of not just water but also food products from arsenic zones is recommended, so that risk can be assessed holistically. Finally, sustained public health campaigns are needed to educate affected communities about arsenic, as many may still be unaware of the contamination in their water sources. Arsenic mitigation in India will require coordination between water authorities, agricultural agencies, public health departments, and researchers. The challenge is formidable, but as shown by successful projects in some villages (e.g. community filters and piped water schemes), progress is achievable. By learning from the collective findings of recent studies – as compiled in this review – stakeholders can better target interventions to the most impacted areas and pathways. With concerted effort, India can hope to conquer the "stealth" arsenic menace and secure cleaner water, safer crops, and better health for its millions of affected citizens.

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