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Arsenic Contamination in the Groundwater of India and Bangladesh and Green Practices in Concrete Construction incorporating Arsenic-Laden Sludge as Admixture

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Abstract

Geogenic arsenic contamination in groundwater represents a critical public health emergency across South Asia. This study presents a comprehensive regional assessment of arsenic distribution patterns across ten Indian states and Bangladesh, synthesizing state-level contamination data with health impact trajectories and remediation technology performance. Exposure affects an estimated 22.38 million people across ~1,800 habitations in India alone. We examine both biogeochemical mechanisms driving arsenic mobilization in alluvial and hard-rock aquifers and epidemiological evidence for multi-system health effects. Critical examination of existing remediation approaches reveals significant gaps in acceptability, sustainability, and cost-effectiveness. This paper proposes an innovative circular-economy solution: stabilization of arsenic-laden sludge from treatment plants within non-structural concrete elements—a green practice that addresses the "end-of-pipe" waste challenge while adhering to environmental safety thresholds. Recommendations include staged implementation protocols prioritizing government infrastructure, rigorous long-term monitoring of leachate pathways, and comprehensive risk communication frameworks for affected communities.

Keywords: Arsenic contamination: Groundwater pollution: Drinking water standards: State-wise arsenic occurrence: Human health impacts: Water treatment technologies.

Introduction

Groundwater is the backbone of India's water supply system, meeting more than 65% of irrigation requirements, approximately half of the water demand in urban and industrial sectors, and nearly 80% of the drinking water needs of rural populations. However, in many parts of the country, especially across the Ganga–Brahmaputra–Barak alluvial plains, this essential resource is increasingly threatened by geogenic contaminants such as arsenic. The Ganga basin contributes about 171 BCM of replenishable groundwater annually, while the Brahmaputra–Barak system provides around 26 BCM (CGWB, 2011). Together, these two major fluvial basins account for nearly 45.7% of India's total renewable groundwater availability.

Over the past decades, a steady rise has been observed in the number of districts and states reporting groundwater arsenic concentrations above the limits prescribed for safe drinking water by the Bureau of Indian Standards (BIS). This trend raises significant concerns because elevated arsenic not only undermines human and livestock health but also affects agricultural productivity and soil quality. Until about 2008, reports of arsenic levels surpassing the earlier permissible threshold of 50 μg/L (revised to 10 μg/L in 2009) were largely confined to the Ganga–Brahmaputra plain spanning parts of West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, and Chhattisgarh (CGWB, 2010). The expanding geographical spread of contamination since then highlights the urgency of comprehensive monitoring and mitigation strategies.

By 2014, arsenic contamination in groundwater had been identified in ten Indian states. These included West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, Chhattisgarh, Haryana, Punjab, and Karnataka. Most of the affected regions lie within major alluvial floodplains—particularly the Ganga floodplain across West Bengal, Bihar, Jharkhand, and Uttar Pradesh; the Brahmaputra–Barak and Imphal river plains in Assam and Manipur; the Yamuna system in Haryana; and the Ravi–Beas plains in Punjab. In contrast, the contaminated zones of Chhattisgarh and Karnataka occur within hard-rock aquifer settings, differing significantly from the highly productive Quaternary alluvial aquifers found in the other states. It is noteworthy that, except for Chhattisgarh and Karnataka, the arsenic-affected states draw water primarily from extensive Quaternary aquifers, which are generally characterized by high groundwater availability but have become vulnerable to geogenic contamination.

Globally, the acceptable concentration of arsenic in drinking water has undergone substantial revision. The World Health Organization (WHO) initially set the permissible limit at 200 μg/L (200 ppb) in 1963. However, increasing evidence of severe health impacts from long-term exposure prompted WHO to lower this limit—first to 50 μg/L and later, in 1993, to 10 μg/L (10 ppb), which remains the current guideline value. Reflecting these global concerns, the Bureau of Indian Standards (BIS) also prescribes an acceptable limit of 10 ppb for drinking water and allows up to 50 ppb as a “maximum permissible limit” only in situations where safer alternatives are unavailable.

Arsenic in the Groundwater of India

Groundwater arsenic concentrations exceeding the earlier permissible limit of 50 ppb have been reported from 86 districts spread across ten states of India. The spatial distribution of contamination is highly variable, and arsenic does not occur uniformly in all groundwater sources within the affected districts. Overall, an estimated 22.38 lakh people living in nearly 1,800 habitations are exposed to arsenic-contaminated groundwater.

In India, the occurrence of arsenic in groundwater broadly falls into two distinct hydrogeological settings:

1. **Alluvial aquifers** of West Bengal, Bihar, Jharkhand, Uttar Pradesh, Assam, Manipur, Punjab, and Haryana.
2. **Hard-rock terrains** of Karnataka and Chhattisgarh.

In the latter two states, arsenic contamination is primarily associated with sulphide mineralization, especially the presence of arsenopyrite. In Karnataka, the issue is mostly confined to gold-bearing mineralized belts within parts of Raichur and Yadgir districts. In Chhattisgarh, arsenic has been linked to acid volcanic rocks along the Kotri lineament. Under suitable geochemical and hydrogeological conditions, arsenic is mobilized into groundwater through the dissolution of arsenic-bearing minerals such as arsenopyrite. State-specific details further highlight the severity of the issue. For example, in Assam, arsenic contamination has been detected in 18 of the 23 districts, affecting 76 blocks and 603 habitations.

Over 50 ppb of arsenic were discovered to be present in 1590 dwellings spread across 15 districts in Bihar. By April 2015, the number of habitations afflicted by arsenic had decreased from 1590 to 95 due to the State's mitigating actions. The nine districts of Begusarai, Bhagalpur, Buxar, Darbhanga, Lakhisarai, Munger, Patna, Sambalpur, and Saran comprise the remaining 95 afflicted habitations. The majority of these districts are situated in Bihar along the Ganga River. The quaternary alluvium-holding multi-aquifer system makes up the geological formations in the impacted areas. Medium-to-fine sands with sporadic coarse-grained sand layers interspersed with sandy clay layers are indicative of the aquifers. The flood plain regions of the Ganga, Brahmaputra, and Barak rivers, hard-rock portions of the Rajnandgaon district of Chhattisgarh State's Ambagarh Chowki block were found to be contaminated. A few hundred residents of the impacted villages were exposed to skin lesions caused by arsenic. Eleven villages are impacted by arsenic contamination, according to an analysis of groundwater samples.

Studies conducted by CGWB-NWR, Chandigarh in 2003 and 2013 under the Aquifer Mapping Programme reported that groundwater in several Haryana districts underlain by alluvial aquifers contained arsenic levels exceeding 50 ppb. The elevated concentrations were attributed to the release of arsenic from sedimentary minerals, particularly arsenic-bearing phases that dissolve under reducing geochemical conditions, allowing arsenic to migrate into groundwater. In Sahebganj district of Jharkhand, arsenic contamination above 50 ppb was detected for the first time during 2003–2004 in areas located between the middle and lower Ganga plains. The CGWB subsequently reconfirmed this contamination during detailed investigations carried out in 2006–2007. A total of 278 habitations were identified as affected, impacting approximately 2,09,060 people. The geological characteristics of this region resemble those of West Bengal and adjoining Bihar, where arsenic contamination is already well documented. In Karnataka, groundwater arsenic occurrence has been primarily associated with regions influenced by gold mining and associated geological formations. The presence of arsenic is linked to the mineral arsenopyrite in the host rocks. Notable examples include the abandoned mining zones of Shorapur taluk (now part of Yadgir district, formerly in Gulbarga) and the Hutti Gold Mine region in Lingasugur taluk of Raichur district. In these settings, arsenic enrichment is localized, with contamination typically more pronounced near the shallow phreatic aquifer where arsenic leaching takes place.

Groundwater arsenic contamination has also been identified in several parts of the Manipur valley, particularly in the districts of Kakching, Imphal East, Imphal West, and Bishnupur. These regions lie along river systems originating in the eastern Himalayan terrain, where geological conditions favour the release of arsenic. A CGWB investigation carried out in 2004 across 261 shallow groundwater samples in Punjab indicated arsenic occurrence with notable spatial variability. Elevated concentrations above 10 ppb were detected at twelve locations spread across the districts of Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, and Ropar. All of these contaminated sites are positioned along the Ravi and Beas river corridors, both of which trace their origins to the Himalayas highlighting the geomorphological control on arsenic distribution. In Uttar Pradesh, a survey undertaken in 2003 in 25 villages of Ballia district first brought arsenic contamination to light. Subsequent assessments documented similar groundwater arsenic poisoning in Varanasi and Ghazipur districts. It is significant that all arsenic-affected districts in Uttar Pradesh, as well as the twelve contaminated districts of Bihar, are located along the linear flow path of the Ganga River, pointing to a strong river-related sedimentary influence. In West Bengal, the earliest documented evidence dates back to 1983, when groundwater from 33 villages in South 24 Parganas, North 24 Parganas, Nadia, and Murshidabad was found to contain arsenic concentrations exceeding 50 μg/L. As per the joint NIH–CGWB status report (2010**)**, by 2008, arsenic contamination had been recorded in 3,417 villages across 111 blocks in nine districts, including Kolkata. To categorize the extent of contamination, these districts were classified into three severity levels—severely affected (>300 ppb), moderately affected, and mildly affected—with tube wells reporting concentrations above 300 ppb falling into the highly impacted category.

Arsenic in Groundwater of Bangladesh

Bangladesh experiences one of the world's most severe arsenic crises. Initial surveys (BGS 1999) documented contamination in 61 of 65 tested locations. Shallow tube wells with water table changes between 5 and 10 mbgl are considerably more polluted than deep aquifers (BGS, 2000). Comprehensive analysis of 6,000 water samples from a 25 km² area confirmed arsenic exceeding Bangladesh's drinking water standard (50 μg/L) across all tested zones (Van Geen et al., 2003). Maximum arsenic concentration recorded: 347 μg/L in Chandpur district, with individual tube wells ranging 6-934 μg/L. Tube wells with maximal arsenic content are found in the southern and eastern portions of Bangladesh and more than 60% of tube wells are seriously impacted (Escobar et al., 2006; Safiuddin et al., 2011).

The continued use of arsenic-laden groundwater for irrigation in Bangladesh has led to a gradual rise in arsenic accumulation within agricultural soils (Ullah, 1998). A nationwide preliminary assessment conducted by Meharg and Rahman (2003) indicated that soil arsenic concentrations could reach as high as 46 mg/kg. Across Bangladesh, their reported soil values ranged from 11.7 to 51.9 mg/kg, with an average concentration of 32.8 mg/kg—substantially higher than the global background range of 5–10 mg/kg described by Spallholz et al. (2008). Earlier findings by Uddin (1998) showed that in uncontaminated farmlands, arsenic concentrations were comparatively low, generally between 2.6 and 7.6 mg/kg. Huq et al. (2006), in a 24-upazila survey, observed that about one-fifth of soil samples exceeded 20 mg/kg arsenic, and the maximum reported level was 80 mg/kg. Over the last decade and a half, repeated irrigation with groundwater containing elevated arsenic has notably increased arsenic concentrations in the topsoil of many agricultural fields (Roberts et al., 2007). Their study found that nearly half of the 456 shallow tube well (STW) sites had topsoil arsenic levels surpassing 10 mg/kg. Most investigations have focused on the upper 15 cm of soil, although a few have examined how arsenic migrates through the entire soil profile. According to Heikens et al. (2007), irrigation water rich in arsenic contributes directly to this accumulation. However, the extent to which such contamination affects crop development and yield remains insufficiently understood, highlighting the need for further research.

Impacts of Arsenic on Human Health

By inhibiting several mitochondrial enzymes and uncoupling oxidative phosphorylation, arsenic can disrupt cellular respiration and have harmful effects. As (III) species have the ability to react with the -SH group of proteins and enzymes, rendering them inactive and increasing the amount of reactive oxygen species in cells, which can lead to cell damage. Studies have shown that 200 bodily enzymes could be inhibited by arsenic. Multisystemic non-cancer impacts have been thought to result from trivalent arsenic chemicals deactivating vital enzyme processes and causing oxidative stress to cells. Inorganic arsenic indirectly increases vulnerability to oxidative stress, cell proliferation, DNA repair process suppression, and chromosomal changes that cause cancer. Because arsenate (AsO_4^{-3}) and phosphate (PO_4) have similar structures, arsenate can replace PO_4^{-3} in adenosine diphosphate ADP).his substitution stops ADP from being converted to ATP (adenosine triphosphate), which gives the cell energy. The majority of the publications on the health effects of drinking groundwater contaminated with arsenic that are now accessible come from epidemiological studies of long-term exposure to arsenic. Compared to chronic arsenic exposure, there are very few research and cases pertaining to acute arsenic toxicity. Due to the use of groundwater contaminated with arsenic and the resulting health impacts, numerous chronic arsenic exposure episodes have been recorded from Asian countries during the past ten years. An increasing number of studies have been conducted to determine the different health impacts of long-term exposure. Four monographs (IARC, 2004) as well as several papers and special issues covering the research activities of chronic arsenic exposure and various carcinogenic and non-carcinogenic health effects have been published during the past ten years.

Exposure to inorganic arsenic deactivates the function of enzymes, various important anions, cations, and transcriptional processes in cells, among other direct or indirect consequences. Numerous epidemiological studies have confirmed that these inorganic arsenic activities are responsible for a number of illnesses. Examples of the same include impacts on the skin, heart, lungs, digestive system, endocrine system (diabetes mellitus), nervous system, reproductive and developmental system, cancer, and other areas. The primary symptoms of arsenicosis include skin lesions, hyperkeratosis, and melanosis.

Arsenic in Food Chain

Numerous studies have demonstrated that eating vegetables and commodities cultivated in arsenic-contaminated groundwater can raise daily arsenic intake in addition to drinking water. Since agriculture is the main industry in the arsenic-affected areas, particularly those in the alluvial plains, groundwater contaminated with arsenic is nevertheless used for irrigation. Furthermore, compared to leafy vegetables, tuberous vegetables have been found to absorb more arsenic. The immediate and long-term consequences of irrigating paddy fields with contaminated water are also a big concern since arsenic may transfer from water to soil. This propensity has been demonstrated by several studies. Irrigation with arsenic-contaminated water could raise soil arsenic levels by 1μg/g each year (Mehar and Rahman, 2003). Fruity vegetables come next. Potato, brinjal, arum, amaranth, radish, lady's finger, and cauliflower have been shown to have higher levels of arsenic accumulation, while beans, green chilli, tomato, bitter gourd, lemon, and turmeric have been found to have comparatively low levels. Compared to the native varieties, the high-yielding rice cultivars accumulate more arsenic. It has been found that those with inadequate nutrition are more susceptible to arsenic poisoning than those with appropriate nutrition. Groundwater poisoning with arsenic has far-reaching effects that include social issues in addition to health and environmental risks. Illiterate residents who live below the poverty line make up about 30% of the impacted population. Compared to men and adults, women, children, and newborns are more susceptible to arsenic poisoning. Social education regarding the treatment of those affected by arsenic toxicity and the negative consequences of drinking water tainted with arsenic has been scant or nonexistent.

Technological Options for Combating Arsenic

Any one of the following technological solutions, or a combination of several, can be used to counter the threat of arsenic in groundwater and guarantee an arsenic-free water supply in the impacted areas:

- Removal of arsenic from the aquifer system in situ.
- Arsenic removal technology used for ex-situ remediation of groundwater that has been tapped.
- Using surface water sources instead of tainted groundwater.
- Using other safe aquifers to obtain groundwater free of arsenic.
- Biological elimination of arsenic.

Effective remediation of arsenic requires knowledge of the physicochemical processes in groundwater as well as the aquifer framework, lithology, and groundwater flow regime of the area under consideration because the primary source of arsenic in groundwater is geogenic in origin and is closely related to the aquifer geometry and groundwater flow regime. Remedial actions can take many different forms, such as eliminating arsenic from groundwater after it has been mined, looking for other aquifers, lowering the amount of arsenic in the aquifer itself, diluting the pollutants with artificial recharge, mixing with drinkable water, etc.

Ex-situ Arsenic Treatment

This method's primary objective is to lower the water's arsenic content once it has been extracted from aquifers. A variety of treatment techniques based on oxidation, co-precipitation, adsorption, ion-exchange, and membrane processes can be used to remove arsenic from contaminated water (Bhattacharya, 2017a, b). However, there is still uncertainty regarding the efficacy and appropriateness of these techniques due to the low influent arsenic concentration and variability in source water composition. Some of these techniques are rather straightforward, but they have the drawback of producing a lot of hazardous sludge. In addition to creating concerns about the sustainability of these techniques in terms of social acceptability and economic viability, this requires additional treatment before being disposed of in the environment. Many of these technologies can be used to remove arsenic from groundwater at the home and community levels. Numerous small-scale arsenic removal systems have been created, tested in the field, and implemented in a number of nations, including India, over the past few decades. It is necessary to rank the available technological solutions according to their acceptability, cost, operation and maintenance, and effectiveness.

Arsenic-Safe Alternative Aquifers

An important mitigation approach in arsenic-affected regions is to encourage the use of safer, alternative aquifers. Much of the arsenic-impacted belt of the Gangetic plains—including the deltaic tracts of West Bengal as well as large areas of Bihar and Uttar Pradesh—contains a complex multi-aquifer system (Bhattacharya, 2017; BIS, 2009, 2012). These aquifers occur within Quaternary sedimentary formations, where layers of unconsolidated sand serve as water-bearing zones and are separated by horizons of clay or sandy clay. Owing to this stratified nature, the deeper aquifers generally show semi-confined to confined conditions (Fig. 1). Arsenic contamination is largely concentrated in the upper sedimentary layers, especially within the shallow aquifers that typically occur up to a depth of about 80 m below ground level (mbgl) (Bhattacharya, 2017). In some locations, however, the hydrogeology differs. For instance, in Malda district of West Bengal, only a single aquifer is present until bedrock is encountered at depths of roughly 70–120 mbgl. Investigations carried out by the Central Ground Water Board (CGWB) and institutions such as the Bhabha Atomic Research Centre (BARC), involving lithological logging, groundwater flow analysis, isotope tracing, and hydrochemical modelling indicate that deeper aquifers situated below 120 mbgl remain largely unaffected by arsenic. Isotope evidence and results from long-duration pumping tests in both West Bengal and Bihar consistently show that these deep aquifers have very limited hydraulic connectivity with the shallow arsenic-rich zones above them, reducing the likelihood of downward migration of contaminants. Different age groups with distinct recharging techniques make up the groundwater in the shallow and deep aquifers (Bhattacharya, 2017). This method might not work for a single aquifer system as in West Bengal's Malda district. Making an arsenic-risk map of the impacted states that shows arsenic-safe aquifers, arsenic-risk and sensitive zones, etc. is urgently needed.

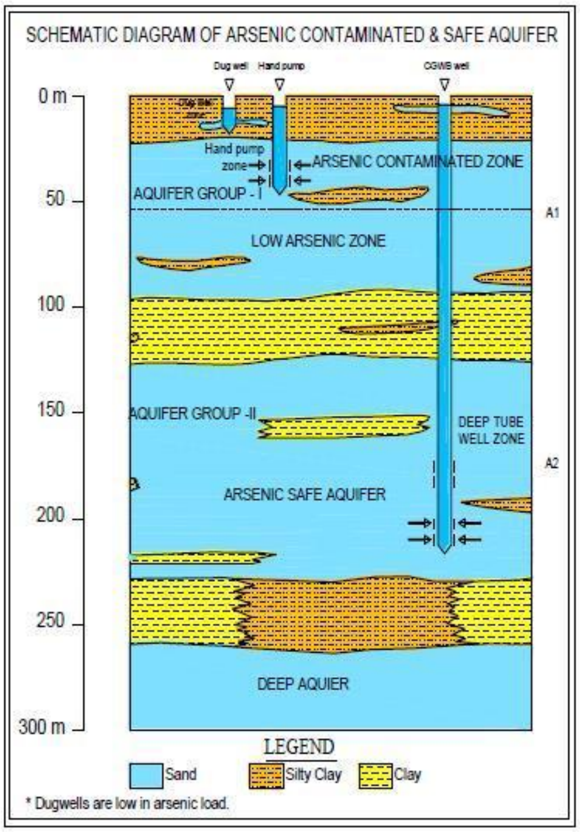

Fig. 1 Distribution of arsenic in multi-layered

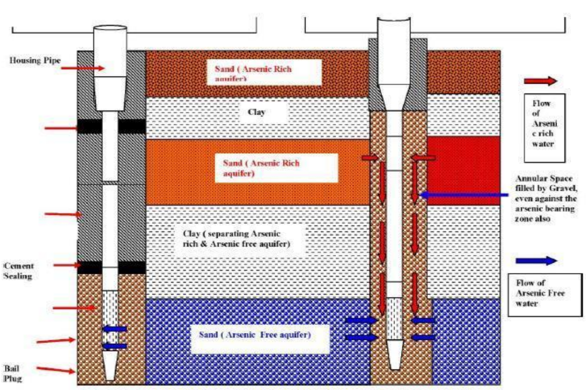

Fig. 2 Deep tube well tapping arsenic safe deeper aquifer

In-situ (subsurface) arsenic treatment enable arsenic immobilization within the aquifer itself. It might also be possible to immobilize arsenic by establishing an oxidizing environment beneath the surface of the ground, since arsenic is mobilized in groundwater under reducing conditions (Fig. 2). However, more research on arsenic's geochemistry would be required. In-situ methods for treating arsenic are (a) using atmospheric oxygen for water that is high in iron and arsenic; (b) using atmospheric oxygen and ferrous chloride for water that is low in iron and arsenic; (c) permeable reactive barriers; and (d) electro-kinetic treatment.

Biological Arsenic Removal

Microorganisms can play an important role in reducing arsenic concentrations in groundwater. Two major microbe–metal interaction pathways help remove arsenic: (a) certain microbes convert arsenite [As(III)] into the less mobile and more easily removable arsenate [As(V)], which can then be extracted using conventional arsenic-removal technologies; and (b) some microbial communities can take up arsenic directly through bioaccumulation, thereby lowering dissolved concentrations. In addition to microbial processes, aquatic plants are also used for phytoremediation, an in-situ technique applied to contaminated soils and groundwater. Species such as Azolla and Spirodela (duckweed) have shown strong arsenic-absorbing capabilities. Duckweed-based remediation has been tested with promising results in Bangladesh. Among the possible technological solutions, aquifer decontamination or in-situ treatment of arsenic within aquifer formations is theoretically the most comprehensive. However, large-scale implementation remains extremely difficult and expensive because of limited knowledge about the hydrogeological, physicochemical, and geochemical controls governing arsenic behavior within aquifers.

Using surface water instead of contaminated groundwater is often viewed as a practical option, but this requires reliable surface-water availability and a well-developed distribution network to meet irrigation and drinking-water needs. Nonetheless, this approach has been considered suitable for densely populated areas where surface-water supply schemes can be organized. Both West Bengal and Bihar governments have initiated drinking-water programs in some arsenic-impacted districts following this strategy. Another alternative is to tap deeper or otherwise safe aquifers that are free from arsenic. Several localized studies have evaluated this possibility. However, adopting this option on a wider scale demands detailed investigations on groundwater potential, long-term sustainability of freshwater reserves, and the temporal–spatial dynamics of arsenic mobilization within the aquifer system.

Providing Medical Relief to Affected People

Short-term acute arsenic exposure can result in cardiac toxicity, neurological consequences like headache, convulsions, and neuropathy, and gastrointestinal symptoms like nausea, vomiting, and diarrhea. The cornerstones of treatment for acute instances are supportive therapy and specific medicines. Skin complaints, an increased risk of diabetes, and cancer can result from long-term usage of drinking water with arsenic contents beyond allowable limits. Terminating exposure and providing symptomatic supportive care are the two main strategies for managing chronic poisoning. The following four factors made it difficult to provide the afflicted population with appropriate medical care: Inadequate database of affected/vulnerable individuals; Most affected individuals reside in rural areas with poor infrastructure; The majority of these individuals are impoverished and unable to pay for treatment; Inadequate knowledge of arsenic-related health risks among the general public and local healthcare professionals.

Green Practices in Safe Utilisation of Arsenic-Laden Sludge from Arsenic Filters

When assessing and improving techniques for disposing of arsenic-laden sludge from arsenic filters, green practices are essential. Although there are many arsenic filters on the market, they all result in sludge that is contaminated with arsenic and must be disposed of properly. It goes without saying that this sludge cannot be buried since it will seep into the groundwater and contaminate it. Additionally, plants may absorb arsenic through their roots, which implies that it will enter the food chain regardless of whether humans consume the plants directly or indirectly through consuming herbivorous animals. Because the arsenic will contaminate the air, burning sludge containing arsenic is not an option. Additionally, geosynthetic-bounded landfills are not the answer because they will eventually fill up and any geosynthetic breaking will contaminate the groundwater and soil with arsenic. It has been suggested that arsenic can be consumed by earthworms and that the arsenic can remain stable in the earthworms' bodies for generations to come. However, since the earthworms will eliminate all of the arsenic in their tissues in the event of an unintentional death, this does not seem to be a particularly practical approach. The proponents of this theory claimed to demonstrate that earthworms' excrement is devoid of arsenic and that the arsenic they consume simply persists in their body for generations to come through cannibalism of dead earthworms.

One of the most effective methods for managing arsenic-rich sludge is to incorporate it into concrete as an additive (Roy et al., 2019; Mohammadi, 2023). Because concrete behaves like an engineered rock, it can immobilize arsenic and significantly reduce the potential for leaching. Initially, such sludge should only be mixed with concrete intended for non-structural purposes—mainly architectural or finishing works. Even in these cases, the arsenic-infused concrete is recommended only for the inner core of a member, while the outer layers should be cast using conventional, arsenic-free concrete to avoid any direct contact with the environment. Before this material can be used for load-bearing applications, comprehensive studies are needed to fully assess its mechanical behavior—particularly its strength, durability, and deformation properties. Only after it is conclusively proven that arsenic-containing concrete performs comparably to standard concrete should it be used structurally. An alternative stabilization option is to incorporate arsenic-laden sludge into bricks, a method that has also shown promise in reducing leaching risks (Mahzuz et al., 2009).

Mixing with Concrete as an Admixture and with Clay for Brick Manufacturing

By enhancing the physical properties of the pollutants and reducing their toxicity and transmissivity, cement is used to treat a significant quantity of hazardous wastes. In this procedure, the waste is mixed into a cementitious binder system, either as a solid, liquid, or sludge. However, the kind of arsenic molecule present has a significant impact on how well arsenic-laden sludge is treated using cement-based solidification and stabilization. The least mobile substance is arsenate. It has been discovered that cement's calcium affects arsenic leaching and immobilization. Lower arsenic leaching often occurs with a higher Ca:As molar ratio. Arsenic-contaminated sludge can be effectively stabilized by solidification and stabilization using lime and Ordinary Portland cement (OPC). Roy et al. (2019) examined the viability of adding arsenic-bearing iron sludge, produced from electrochemical arsenic remediation systems, into concrete mixtures, makes a substantial addition to sustainable concrete practices. Because of its arsenic level, the sludge is usually regarded as dangerous, and if it is not adequately managed, it could pose long-term environmental hazards. The results supported the possible use of such stabilized concrete in low-load-bearing or non-structural construction applications close to arsenic treatment plants, offering a locally flexible and environmentally friendly alternative for managing hazardous sludge.

It has been found that utilizing up to 10% of clay by volume to stabilize arsenic-laden sludge is safe. Only up to 4% of ornamental bricks and tiles by volume can be safely treated with sludge containing arsenic. It is important to keep in mind that when the percentage of sludge increases, the bricks' compressive strength reduces at all firing temperatures. Mahzuz et al. (2009) found that beautiful bricks may be made from sludge containing arsenic. It is safe to add up to 4% sludge to clay without sacrificing its strength. Compressive strength drastically decreases with >4% sludge. For instance, the strength of a brick (1" x 6") with 0% and 4% sludge is nearly similar at 304.3 psi and 303.63 psi, respectively. Increased sludge reduces density; however, the effect is negligible up to 4%. Sludge's decreased compressive strength makes it unsuitable for use in mortar cube construction; even 0.5% sludge diminished strength. Sludge containing arsenic is currently disposed of in landfills. Because landfills are already full and new ones must be constructed, the current technique of disposing of arsenic waste in landfills is unsatisfactory. These landfills can provide environmental risks, particularly during earthquakes, and may not be geotechnically secure. Even though the geosynthetics used to build the landfills are made to bear typical loads, they may break during earthquakes and release all of the arsenic into the soil, causing an environmental disaster. Because of commercial reluctance, legal difficulties, and toxicity issues, sludge is not reused. Because arsenic is known to be toxic, the builders steer clear of utilizing concrete that contains arsenic due to concerns about public opinion, cost, and time. The construction industry is unlikely to take the chance of using arsenic in construction, even in non-structural concrete.

Conclusions

It may be concluded that significant advancements have been made in identifying areas affected by arsenic, comprehending the effects of arsenic exposure on health and the environment, and raising public and scientific awareness of the issue. In spite of this, the problem is far from solved; in fact, it would be premature to say that the spread of groundwater poisoning with arsenic has even stopped. Sustained research, stricter enforcement of regulations, and ongoing monitoring are still crucial. With an emphasis on assessing the most efficient and sustainable stabilizing techniques, this study has also investigated ecologically friendly solutions for handling waste containing arsenic produced by filtration systems. The assessment's main recommendation is to start adding arsenic-laden sludge only to government buildings' non-structural elements, where it can be securely contained and its exposure to the outside world is reduced.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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