Green Practices involved in the Stabilisation of Arsenic-Laden Sludge from Arsenic Filters of India

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Abstract

The present chapter starts by presenting an overview of the Arsenic contamination in the groundwater in different parts of India. The chapter goes on to present standards regarding Arsenic in drinking water and then proceeds to give a state-wise status of Arsenic contamination. Adverse effects of Arsenic on the health of human beings, accumulation of Arsenic in the food chain and ill-effects of using Arsenic-laden water for irrigation are elaborated upon in the chapter. The chapter proceeds to explore technological options to deliver Arsenic-free water by various ways and means. Providing medical relief to affected people is also included. Green practices are vital in evaluating and fixing up methods for disposal of Arsenic-laden sludge from Arsenic filters. While there are a number of Arsenic filters available in the market, they all produce Arsenic-laden sludge. Arsenic is a carcinogen and is not an input element in any industry. Fixing Arsenic in concrete is indubitably a green practice but it also has its fair share of issues.

Introduction

Groundwater plays a vital role in India to meet water demands of various sectoral uses. About 80% of rural domestic needs and 50% of urban and industrial needs and about 65% of irrigation water requirements are met by groundwater. groundwater quality deterioration from the contaminants of geogenic origin, in which Arsenic is the one, in many States, mainly in the Ganga-Brahmaputra-Barak fluvial plains, has emerged as a major concern to this important resource. The groundwater potential of the Ganges and Brahmaputra Barak basin in India has been assessed 171 BCM (Billion Cubic Metre) and 26 BCM, respectively, which is about 45.7% of the total annual replenishable groundwater resources of India (CGWB, 2011). Increased number of contaminated districts and States, where the contamination is reported beyond the acceptable limit for drinking use as prescribed by the BIS (Bureau of Indian Standards) is a matter of grave concern from different viewpoints, which include: (a) risk apprehended on human and animal health due to the exposure to Arsenicosis by the uses of Arsenic-contaminated groundwater; (b) scope and infra-structural facilities available to detect and diagnose Arsenic impacted patients; (c) alternative source and other remedial measures for supply of Arsenic safe water in the affected and vulnerable areas; (d) reliance and dependency of rural people more on groundwater for drinking and irrigation purposes; (e) risk exposed to the agricultural sector due to the uses of Arsenic-contaminated groundwater and biomagnification of Arsenic content in the agricultural products; (f) possible damage caused to the soils health by the use of Arsenic-contaminated water on agricultural lands; (g) impact on socio-cultural and socio-economic aspects and (h) technological solutions available to resolve the issues and provide Arsenic-free water. Until the year 2008, occurrence of high Arsenic content in groundwater in excess to the limit of 50 µg/L or 50 ppb (BIS standards prevailed until 2009, later modified to 10 µg/L) was mainly reported in the Ganges-Brahmaputra fluvial plains covering pockets of seven states namely, West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur and Chhattisgarh (NIH and CGWB, 2010, Bhattacharya et al., 2016, Bhattacharya, 2017a, Bhattacharya, 2017b). Until the year 2014, the count of number of groundwater Arsenic-exposed States has increased from 7 to 10. The reported States are: West-Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, Chhattisgarh, Haryana, Punjab, and Karnataka. In West Bengal, Bihar, Jharkhand and Uttar Pradesh, the Arsenic-exposed areas are mostly located in the floodplain of the Ganga River; in Assam and Manipur the exposed areas are mainly in the floodplains of the Brahmaputra-Barak and Imphal rivers, respectively; in Haryana these areas are in the plains of Yamuna river and its tributaries; in Punjab the exposed areas are mainly in the floodplains of Ravi and Beas rivers; in Chhattisgarh and Karnataka the Arsenic-exposed areas are in hard-rock areas, which have different characteristics than the alluvium plains of Ganges and Brahmaputra. Ironically, except Chhattisgarh and Karnataka, all other States represent Upper Quaternary aquifers which are otherwise potential from groundwater point of view.

Standards for Arsenic in Drinking Water

Different countries have set different standards of Arsenic content for drinking water quality. World Health Organisation's (WHO) norms for drinking water quality go back to 1958; in that year, the international Standard for drinking water was established at 200µg/L (i.e, 200 ppb; ppb : parts per billion) as an allowable concentration for Arsenic. In 1963, the standard was re-evaluated and reduced to 50µg/L(50 ppb). The WHO guidelines have been revised during the recent past and the permissible limits have been reduced from 50µg/L to 10µg/L (10 ppb) in the year 1993 due to the adverse health reports that arose from different parts of the world, where Arsenic has caused severe health problems. Until 2009, in India the acceptable limit for Arsenic in drinking water was 50 ppb. After the year 2009, Bureau of Indian Standards (BIS) has set the desirable limit of Arsenic in drinking water as 10 ppb and in the absence alternative sources, 'maximum permissible limit' in drinking water has been set to 50 ppb.

Arsenic in Groundwater of India

Isolated pockets in 86 districts in ten States have been reported affected by groundwater Arsenic content beyond BIS maximum permissible limit of 50 ppb. Occurrence of Arsenic in groundwater in those affected areas has been highly sporadic in nature and not necessarily all the sources were

contaminated. As per IMIS (Integrated Management Information System) data of Ministry of Drinking Water and Sanitation, about 22.38 lakh population is affected by Arsenic in 1800 habitations.
Arsenic occurrences in groundwater in India can broadly be put into two categories: (i) occurrence in parts of West Bengal, Bihar, Jharkhand, Uttar Pradesh, Assam, Manipur, Punjab, and Haryana in the alluvial terrain, and (ii) in parts of Karnataka and Chhattisgarh in the hard-rock terrain. In general, worldwide large-scale groundwater Arsenic-contamination is reported from Late Quaternary fluvial and deltaic deposits. However, there are exceptions, such as in Chhattisgarh and Karnataka, where it is very limited in areal extent and site specific. In these two states, Arsenic is reported to be associated with sulphide mineralisation especially Arsenopyrite. In Karnataka, it is mainly restricted to the gold mineralisation areas covering parts of Raichur and Yadgir districts and in Chhattisgarh, it has been reported from the acid volcanic associated with Kotri lineament. Arsenic from Arsenic-bearing minerals like Arsenopyrite, which is common in those settings, has been released into groundwater under favourable geological conditions.

Technological Options

Technological options to combat Arsenic menace in groundwater to ensure supply of Arsenic-free water in the affected areas can be one of the followings or a combination of more than one options :

- In-situ remediation of Arsenic from aquifer system.
- Ex-situ remediation of Arsenic from tapped groundwater by Arsenic removal technologies.
- Use of surface water source as an alternative to the contaminated groundwater source.
- Tapping alternative safe aquifers for supply of Arsenic-free groundwater.
- Biological Arsenic removal.

Since the major source of Arsenic in groundwater is of geogenic origin and is intricately linked to the aquifer geometry and groundwater flow regime, its effective remediation warrants understanding of physicochemical processes in groundwater and aquifer framework, lithology and groundwater flow regime of the area. The remedial measures includes variety of options, ranging from removing Arsenic from groundwater after it is extracted, searching alternative aquifers, reducing Arsenic level within the aquifer itself, dilution of the contaminants by artificial recharge, blending with potable water, etc.

Ex-situ Arsenic Treatment

This method primarily targets to lower the concentration of Arsenic after the water is extracted from aquifers. A variety of treatment technologies, based on oxidation, co-precipitation, adsorption, ion-exchange and membrane process, have been developed and are available for removal of Arsenic from contaminated water (Bhattacharya et al., 2016, Bhattacharya, 2017a, Bhattacharya, 2017b). However, question, regarding the efficiency and applicability/appropriateness of the technologies, remains, particularly because of low influent Arsenic concentration and differences in source water composition. Some of these methods are quite simple, but the disadvantage, associated with them, is that they produce large amounts of toxic sludge. This needs further treatment before disposal into the environment, besides the sustainability of these methods in terms of economic viability and social acceptability. Many of these technologies can be adopted in household and community scale for the removal of Arsenic from groundwater. During the last couple of decades, many small scale Arsenic removal technologies have been developed, field tested and used in various countries including India. There is a need of prioritising available technological solutions based on their effectiveness, cost, operation and maintenance, and acceptability. Various technologies available for removal of Arsenic from contaminated water are based mainly on five principles:

i) **Oxidation and filtration**
ii) **Co-precipitation:** Oxidation of As (III) to As (V) by adding suitable oxidising agent followed by coagulation, sedimentation and filtration (co-precipitation).
iii) **Adsorption:** Activated Alumina, Iron filings (zero valent iron) and hydrated iron oxide.
iv) **Ion exchange** through suitable action and anion exchange resins.
v) **Membrane technology**: Reverse osmosis, nanofiltration and electrodialysis.
The details about the processes of these techniques are available in many literatures (NIH and CGWB, 2010). Arsenic is normally present in groundwater in As (III) and As (V) states in different proportions. Most treatment methods are effective in removing Arsenic in pentavalent state and hence, include an oxidation step as pretreatment to convert As (III) to As (V).

Arsenic-Safe Alternative Aquifers

This technique advocates tapping safe alternative aquifers right within the affected areas. In the vast affected areas in the Gangetic Plains covering Bihar and Uttar Pradesh as well as Deltaic Plains in West Bengal is characterised by multi-aquifer system (CGWB, 1999, Acharya, 2005, Shah, 2007, Bhattacharya et al., 2016, Bhattacharya, 2017a, Bhattacharya, 2017b). The sedimentary sequence is made up of Quaternary deposits, where the aquifers have unconsolidated sands, which are separated by clay/sandy clay, making the deeper aquifer/aquifers semi-confined to confined in nature. The Arsenic-contamination is mainly in the upper slice of the sediments, particularly in the shallow aquifer system within 80 metre below ground level (CGWB, 1999, Bhattacharya et al., 2016, Bhattacharya, 2017a, Bhattacharya, 2017b). However at places, like Maldah district in West Bengal, single aquifer exists till the bedrock is encountered at 70-120 mbgl. The lithologic, groundwater flow, isotope and hydrochemical modeling carried out by CGWB along with other agencies like BARC has indicated that the deep aquifers (>120 mbgl) underneath the contaminated shallow aquifer have been reported Arsenic-free. Long duration pumping tests and isotopic studies carried out in West Bengal and Bihar indicated that limited hydraulic connection between the contaminated shallow and contamination free deep aquifers, and the groundwater belong to different age groups having different recharge mechanisms (CGWB, 1999, CGWB and BARC, 2009, Bhattacharya et al., 2016, Bhattacharya, 2017a, Bhattacharya, 2017b). Deep aquifers in West Bengal, Bihar and Uttar Pradesh have the potential to develop for community-based water supply. For single aquifer system, as reported in Malda district of West Bengal, this technique may not be useful. These eventually advocate that there is an immediate need of preparing Arsenic risk map of affected States indicating Arsenic risk and vulnerable zones, Arsenic-safe aquifers, etc.

In-situ (Subsurface) Arsenic Treatment

In-situ remediation refers to all such techniques that make Arsenic immobilisation possible within the aquifer itself. As Arsenic is mobilised in groundwater under reducing conditions, it may also be possible to immobilise the Arsenic by creating oxidized conditions in the sub-surface. However, further investigations on geochemistry of Arsenic and its speciation would be necessary. Some of the in-situ treatments applied successfully elsewhere for Arsenic treatment are mentioned here :
(a) Use of atmospheric O_2 for iron and Arsenic-rich water,
(b) Use of atmospheric O_2 and ferrous chloride for low Iron and Arsenic-rich water,
(c) Permeable Reactive Barriers (PRB),
(d) Electro-kinetic treatment.

Biological Arsenic Removal

Arsenic in water can be removed by microbiological processes. Two main types of metal-microbe interactions which can potentially be used for the removal of Arsenic from groundwater are: (a) microbial oxidation of Arsenic (III) to Arsenic (V) to facilitate its removal by conventional Arsenic removal processes, and (b) bioaccumulation of Arsenic by microbial biomass. In addition to the techniques mentioned above, Phytoremediation, which is an in-situ technology applicable to contaminated soil and groundwater, uses aquatic plants to accumulate Arsenic and thus remove Arsenic from groundwater. Azolla and Spirodela (duckweed) species have the highest efficiency to remove Arsenic. A study on duckweed was carried out in Bangladesh and found to be efficient. The results indicated that a complete cover of plant could accumulate about 175 g of Arsenic from a pond of one hectare area per day. In-situ remediation of Arsenic from aquifer system or decontamination of aquifer is the best technological option. However, in-situ remediation of Arsenic-contaminated aquifer would be very expensive and may be a difficult task because of the size of the plan and absence of complete understanding of the physico-chemical and geochemical processes and behavior of aquifer system. Although the use of surface water sources, as an alternative to the supply of treated contaminated groundwater, seems to be a logical proposition, it would require availability and supply of surface water flow and organized water supply system for ensuring supply of both drinking and irrigation water. To meet requirement of potable water in Arsenic-affected areas, this approach can prove to be a potential alternative in areas having thick population. Based on this approach, Governments of West Bengal and Bihar have developed some schemes to supply drinking water to some of the Arsenic-affected areas. Tapping alternative safe aquifers, for supply of Arsenic-free groundwater, could also prove to be a logical proposition. This has also been explored in many areas on a local scale. However, this approach would require extensive studies and analyses for mapping of groundwater availability, freshwater reserves and to examine mobilisation of Arsenic in the aquifer, both on spatial and temporal scale.

Arsenic-Removal Technologies

The major issues which need to be factored-in while adopting Arsenic-removal technologies are given below:

a. Development of cost effective and efficient materials for Arsenic-removal based on locally available resources,
b. Cost effective detection techniques with technical performance better or comparable to currently available alternatives,
c. Development of household and community Arsenic-removal systems based on indigenously developed materials,
d. Field demonstration of developed systems to assess their suitability in specific social context,
e. Popularisation of cost-effective techniques,
f. Capacity-building at appropriate levels for installation, operation and maintenance of Arsenic-removal plants.
g. Safe disposal of sludge.

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

Green practices are vital in evaluating and fixing up methods for disposal of Arsenic-laden sludge from Arsenic filters. While there are a number of Arsenic filters available in the market, they all produce Arsenic-laden sludge which needs to be safely disposed of. Obviously, this sludge cannot be dumped into the ground as it will then leach into the groundwater making the groundwater unsuitable for drinking. Also, plants may take in the Arsenic through their roots and thus the Arsenic will make its way into the food chain irrespective of whether the plants are directly eaten by human beings or indirectly by means of human beings eating herbivorous animals.

Incineration of Arsenic-laden sludge is rendered out of the question because the Arsenic will pollute the air. Nor are geosynthetic-bounded landfills the solution because such landfills will get filled-up sooner or later and, furthermore, any breakage of the geosynthetic will result in the Arsenic contaminating the soil and groundwater.

It has been mooted that earthworms can devour Arsenic and the Arsenic can continue to be stabilised in the bodies of earthworms generation after generation. However, this does not appear to be a very practical solution as the earthworms will dispose all the Arsenic in their tissues in case of accidental death. The floaters of this idea purported to show that the excreta of earthworms do not contain any Arsenic and the Arsenic ingested by the earthworms simply continues in the bodies of the earthworms for generation after generation by means of earthworms cannibalising the bodies of dead earthworms.

Used rubber tyres have been safely disposed of by mixing them in the bitumen used for road construction. Kilometres after kilometres of roads have been constructed using used rubber tyres as an admixture to the bitumen. However, this method cannot be used for disposal of Arsenic for two reasons. Firstly, when the bitumen is heated prior to its being used in roads, Arsenic will vapourise and pollute the air. Secondly, roads, by their very nature, are always subject to intense wear and tear and Arsenic will escape and partly pollute the air and partly pollute the soil and groundwater.

Therefore, the preferred option of the author is to dispose of the Arsenic-laden sludge by using this sludge as an admixture to concrete. Since concrete is an artificial rock, Arsenic is stabilised and does not leach out to the outside environment from the concrete. To start with, the Arsenic-laden sludge can be used for that concrete which is not intended to be used for structural purposes, that is, for that concrete that is intended to be used for architectural finishing only.

Even then, concrete containing Arsenic should be used only in the core portion of the total concreting with the exterior being cast in ordinary Arsenic-free concrete so as to eliminate the possibility of Arsenic getting in contact with the exterior. Only after intense research has been conducted on load-bearing and deformation characteristics of concrete having Arsenic-laden sludge as a part of the admixture and it has been conclusively proved that Arsenic-bearing concrete is not inferior to ordinary concrete in terms of strength and stiffness, can such concrete can be used for structural purposes. Arsenic-laden sludge can also be stabilised by using it in bricks. These two methods are elaborated below.

Mixing with Concrete as an Admixture in a Controlled Ratio

Cement is used to treat a large amount of harmful wastes by improving the physical characteristics of the contaminants and by decreasing the toxicity and transmissivity of contaminants. This process involves mixing the waste, either in form of a sludge, a liquid or a solid, into a cementitious binder system. However, the effectiveness of Arsenic-laden sludge treatment through cement-based solidification and stabilisation is strongly influenced by the type of Arsenic compound present. Arsenate has the lowest mobility. It is found that Ca of cement influences the leaching and immobilisation of Arsenic. With higher Ca:As molar ratio, lower Arsenic leaching generally results. Solidification and stabilisation with lime and Ordinary Portland cement (OPC) is an effective means of stabilisation of Arsenic-contaminated sludge.

Mixing with Clay for Brick Manufacturing

When Arsenic-laden sludge is stabilised using clay, it is observed using Arsenic-laden sludge is safe when used upto 10% of clay by volume. In the case of ornamental bricks and tiles, Arsenic-laden sludge can be used safely only upto 4% of ornamental bricks and tiles by volume. It must be remembered that the compressive strength of the bricks decreases at all firing temperatures with increase in percentage of sludge.

Issues relating to Disposal of Arsenic Sludge from Arsenic Filters

However, there are certain issues that need to be considered when considering the disposal of Arsenic sludge from Arsenic filters. Arsenic is well known to be a poisonous element and the construction industry is unlikely to risk using Arsenic in construction, even in non-structural concrete, because if word gets out that a certain builder is using Arsenic sludge in his construction, then his product, be it apartments or any other products that the builder may be building, will not be sold due to public fear of Arsenic and the builder will be left with huge losses. Also, the owners of neighbouring buildings may go to court against this particular builder on the ground that the builder is polluting the atmosphere by using Arsenic in his construction and secure and an injunction halting the construction from the court and the builder will have to fight a legal case, which may go on for a few years, in his attempt to vacate the injunction. All this combined, would bring endless trouble, problem wastage of time and money and mental worry and distress to the builder.

Because rumours spread fast among the public, even if one builder uses Arsenic in construction, the entire construction industry will suffer because the public will suspect that the other builders are also using Arsenic in their construction.

Therefore, a public awareness campaign needs to be carried out for a period of years to build awareness among the public that civil engineers are going to use Arsenic sludge safely in construction and there will be no danger to occupants of the buildings that are going to be constructed with Arsenic mixed with non-structural concrete. This public awareness campaign must be carried through all possible channels like radio, television, newspaper, banner advertisements on roads and other public places, social media and so on. Because the construction industry carries out its business for a profit and there is very intense competition within the construction industry with builders trying their level best to lower costs of construction so as to get projects, this short of advertisement for public awareness would add an extra cost which builders would be loath to take. Therefore, the government must bear a large portion of the cost of this public awareness campaign. The medical professional, media, social welfare organisations and the general public all have a very vital role to play in building up this public awareness.

After the construction industry is of the opinion that sufficient public awareness has been generated, the construction industry can join hands to build a single pilot project with Arsenic mixed in non-structural concrete and carefully observe the public response to their construction. If it is found that the public reaction is negative, then the public awareness needs to be carried on for some more time and another pilot project constructed later. In the meantime, the entire construction industry bears the losses for the failed pilot project and in this way the loss is shared by several builders and the situation of any one single builder facing huge losses is avoided.

Even with the above steps, there is a tough problem remaining. This pertains to casting concrete in two stages with the Arsenic-laden concrete in the core part and the Arsenic-free concrete in the exterior. This sort of two-stage construction will necessarily increase construction time. That means that the builder will have to pay more wages to the workers and more rental costs for construction equipment will also occur. If other builders save time and cost by constructing with Arsenic-free concrete, no builder is going to willingly incur greater cost by two-stage construction with Arsenic-laden concrete knowing fully well that this step is going to make him uncompetitive in a highly competitive market. Also, owners of residential apartments and other types of structures typically pay a large booking amount to the builder and go on paying various sums of money at periodic intervals to the builder until such time as they physically occupy the construction. Therefore, the money of the owners gets blocked up without giving any benefit to the owners until such time as the owners physically occupy the construction for which they are paying. Naturally then, owners, that is the general public, will want the pace of construction to be fast so that their money is blocked up for a shorter period. Hence, any modification in the construction method which results in a longer period of construction will be unpopular with the general public.

There is no easy solution to the above problem. The only solution is for the government to make laws making it mandatory for all builders to use Arsenic-laden concrete so that all builders have a level-playing field. But this is again going to add an another layer to the government bureaucracy because the government is going to need a set of government inspector to visit each and every construction site for ensuring that every builder is complying with government laws. Moreover, such a government law is going to increase the cost of construction for the construction industry as a whole and, therefore, the already-high housing costs are going to rise even higher. This would put a greater financial strain on the buyers of residential apartments and other types of construction and, thus on, society as a whole. Any law which is going to increase purchase costs is going to make the government extremely unpopular with the public and opposition political parties are going to seize the opportunity in the next election. Hence, the government would also not like to risk by making such a law.

In view of all these, there appear to be severe problems in using Arsenic for construction.

What is the solution then? That is indeed a very difficult question to answer and no satisfactory solution has yet been found. Arsenic is not the raw material of any industry and therefore, unlike Chromium which is widely used in the leather industry and also in some other industries, it cannot be input as the raw material in any industry. The current practice of dumping Arsenic waste in landfills is also not a satisfactory solution because landfills filled up and new landfills have to be built. Also, if geosynthetics are used to construct the landfills, even if the geosynthetics are designed to withstand normal load, they may break during earthquakes leaching the entire Arsenic to the soil thus resulting in an environmental catastrophe. However, it seems that, considering all factors connected with all possible disposal methods, landfills are not going away anywhere in a hurry.

Arsenic can be used in concrete structures built and owned by the government along with an intensive campaign to generate public awareness about the safety of such structures to the public from a public health point of view. Arsenic can also be used as an alloy with Aluminium for Aluminium products that are fully manufactured in the factory and are only sold outside. For Aluminium products which need cutting at site, it is not desirable to use Arsenic-blended Aluminium as Arsenic will pollute the atmosphere when the Aluminium alloy is being cut at site.

It must be kept in mind that the issue of green practices in the safe disposal of Arsenic waste, including the generation of public awareness, must be tackled unitedly by various professionals like environmental engineers, structural engineers, architects, doctors, lawyers, journalists, etc.

Conclusions

It may be concluded that plenty of work has been done in the areas of diagnosis of Arsenic-affected areas, the harmful effects of Arsenic and in sensitising the scientific community and the people at large about the baneful effects of Arsenic. However, it may be mentioned that much more needs to be accomplished before it may be said that the problem of Arsenic in groundwater has been arrested, let alone solved. Some green practices in the disposal of Arsenic-laden waste from Arsenic filters have also been examined in this chapter and the most effective methods considered in detail.

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