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Review Paper

Arsenic in Groundwater: A Demon Moving Towards the North India

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ABSTRACT

Water is life. A very significant part of total fresh water available on this planet is in form of groundwater. It is one of the Nation's most important natural resource. As groundwater is less prone to any contamination in comparison to surface water, so people hardly doubt on the quality of groundwater. But on estimation, it is found that worldwide more than 140 million people drink arsenic contaminated groundwater. A study of National Geophysical Research Institute reveals that the depletion of groundwater largely happening in North India. While ten years back studies showed that contamination of ground water by arsenic largely happened only in some parts of Bihar and West Bengal, which is now being seen moving forward in northwest direction. Studies in different parts of the world have suggested that over pumping is a potential cause of arsenic contamination of groundwater. So, it is an alarming situation where we must find a way to manage our groundwater resources in a sustainable way. In this paper we have reviewed the mechanism of arsenic contamination of groundwater, future danger of arsenic contamination in North India states, health related impacts of groundwater arsenic contamination, psychological and socioeconomic impacts of arsenicosis and some solutions to the problem of groundwater arsenic contamination.

Introduction

Water is no doubt the most important natural resource on this planet. It is required for household, industrial and agricultural activities. The oldest civilizations of this world were located near the fresh water sources. The production of food resources whether plant products or animal products largely depend on availability of freshwater in the area. For industrial activities in an area also water is required in such large volumes that no one can afford arranging it from anywhere else. Out of the total water available on mother Earth, less than even one percent is the freshwater. A very significant amount of the freshwater (around 97.58 %) is available in form of groundwater. So, the importance of the underground water is much more than the surface water. Also, the groundwater is less prone to any contamination in comparison to the surface water. This is the reason why we hardly doubt on the quality of groundwater and use it even for drinking without any prior treatment. But what if we came to know that the groundwater that we were using for a long time is toxic and contaminated with heavy dose of a toxic metal.

Water pollution is one of the most complex worldwide environmental problems. When we talk about groundwater pollution, it can be a result of human activities or sometimes can even have a natural phenomenon responsible for it. The groundwater pollutants can be organic compounds or even the inorganic metal ions. The commonly found heavy metals in soil and groundwater are Cd, As, Cr, Zn, Ni, Pb, V and Hg. In water these are diluted easily and found as sparingly soluble precipitates of metal sulfates, sulfides or carbonates. When the adsorption capacity of sediments is exhausted, it results in an increase in the concentration of these metal ions (Zhu et al., 2020, Ravindra and Mor, 2019, Tutic et al., 2015). The presence and vital levels of hazardous pollutants in underground water can be predicted by using appropriate methodological principles. Using statistical information system, laboratory methods and appropriate technology it is possible to attenuate the toxic level and effects of heavy metals (Ustaoğlu and Tepe, 2019, Jusufranic et al., 2014). Arsenic comprises of over 200 naturally occurring minerals in the earth's crust (Smedley and Kinniburgh, 2002).Arsenic adsorbs into mineral surfaces. Groundwater arsenic contamination is a result of dissolution of these minerals into water or desorption of arsenic from such mineral surfaces. Sometimes human activities like mining also become a cause of groundwater arsenic contamination.

Oxidation of sulfides having arsenic has also been considered for the increased arsenic concentration in underground water (Peters and Burkert, 2008, Tuttle et al., 2009). Recent studies propose that reductive dissolution of arsenic loaded glauconite can also be accountable for arsenic contamination of groundwater(Mumford et al., 2012).

In groundwater, presence of arsenic is considered as a serious problem. In ecological environments arsenic is found in two broad forms viz. organic arsenic and inorganic arsenic. Main source of organic arsenic consumption is food and is comparatively less toxic. While, inorganic arsenic is more toxic and usually derived from our environment. It is observed in many studies that exposure to even very low concentration of inorganic arsenic can lead to many acute and chronic health effects(Tsai et al., 2003, Tchounwou et al., 2019). Many studies show that risk of cancer increase due to exposure to inorganic arsenic. Therefore, arsenic and its compounds are classified as group 1 carcinogens by the International Agency for Research on Cancer (IARC). The US Environmental Protection Agency (USEPA)has also listed arsenic as a group A carcinogen. The cancerous nature of arsenic in potable water has also been reported globally(Tsuji et al., 2019).

Studies have revealed that groundwater samples having arsenic concentrations more than 1 µg/L were accountable for skin cancer (Knobeloch et al., 2006). Hence, WHO and USEPA have decreased the permissible limit of total arsenic concentration in drinking water from 50 µg/L to 10 µg/L(Post, 2021).Increased levels of arsenic ground water are observed in parts of Bangladesh(Serre et al., 2003),West Bengal (Halder et al., 2013), the United States(Kim et al., 2011) and Taiwan(Lin et al., 2013). Hyperpigmentation, hypopigmentation and hyperkeratosis are initial skin symptoms of chronic arsenic exposure(Guo et al., 2001). Exposure to high levels of arsenic (<100 µg/L) may lead to lung cancer, skin cancer, bladder cancer and non-carcinogenic effects like peripheral neurotoxicity, skin lesions, keratosis, vascular and neuromuscular abnormalities. But exposure to even very low levels of arsenic can be responsible for high blood pressure, obesity, hyperglycemia, bone damage, metabolic syndrome and anemia (Yu et al., 2017).

Now-a-days use of arsenic contaminated groundwater is avoided for drinking purpose but this is not the complete solution of the problem. Arsenic contaminated underground water is still used for aquaculture. Arsenic can accumulate in the tissue of farmed fish and thus consumption of fish becomes a route for exposure to arsenic(Ling et al., 2014).Other than this, a major source of arsenic exposure is through regular consumption of rice cultivated with underground water contaminated with arsenic(in comparison to other cereals, rice has a higher tendency for arsenic uptake as it is grown in submerged soil conditions) (Sandhi et al., 2017).This implies that it is a very complicated problem and thus cannot have very simple straightforward solutions.

Also, the spatial distribution of arsenic in the underground water is generally not homogeneous and can vary significantly from place to place. This further increases the complexity of the problem. The implication of this is that the human health risk may also vary from place to place corresponding to variations in the amount of arsenic in groundwater and the quantity of this water used for drinking.

The main objectives of this review article are:

1. To review the mechanism of contamination of groundwater with hazardous arsenic
2. To review and analyse the future dangers of arsenic contamination in North India states
3. To review and discuss the health effects of arsenic in groundwater, psychological and socioeconomic influences of arsenicosis and to suggest the possible solutions to this problem.

History of Groundwater Arsenic Contamination in North India

In North India arsenic contamination of groundwater was initially noticed in 1976 in Chandigarh and in some villages of the Haryana and Punjab (Datta Dv Fau - Kaul and Kaul). Significant attention was not given to this information at that time. In West Bengal arsenic poisoning was reported in 1983(Garat et al., 1984). In 1999, high level of arsenic was reported in the underground water of Rajnandgaon district in MP (now in Chhattisgarh) (Chakraborti et al., 1999). In 2003 high arsenic concentration was reported in Bihar (Chakraborti et al., 2003) and UP(Ahamed et al., 2006), in Jharkhand in 2004(Das et al., 2008) and along the Allahabad-Kanpur trail in 2009 (Chakraborti et al., 2009). Arsenic levels upto 100 µg/L were reported in underground water of Delhi, the capital city of India. Arsenic in the underground water of Rajasthan in four districts viz. Hanumangarh, Gangapur, Churu and Sikar was reported by Duggal et al(Duggal et al., 2012). Himachal Pradesh, Uttarakhand and the other states in India have not been surveyed yet for the existence of arsenic in underground water(Chakraborti et al., 2018).

Mechanisms of Arsenic Contamination of Underground Water

Many different theories are put forwarded for the origin of arsenic in groundwater and its flow from that source(Islam et al., 2004**).** In an organic matter rich environment like aquifer sediments it is believed that arsenic has been released by reductive dissolution driven by microbes(Islam et al., 2004, Stuckey et al., 2016). The precise mechanisms for the flow of arsenic are still not fully explored(Stuckey et al., 2016). It is reported that in Chhattisgarh, ground water arsenic contamination occurred naturally due to the deposition of the pyrite rich in arsenic, and further its movement due to respiration of organic carbon by

microbes (Acharyya et al., 2005). Arsenic containing sediments in the Himalayan Mountains and the Tibetian plateaus are responsible for the arsenic contamination of water in the North Indian rivers(Das et al., 2008). Reduction of iron-oxyhydroxides and degradation of organic substances are found to be responsible for arsenic contamination of the underground water in Bangladesh(Ahmed et al., 2004).The main challenge in understanding the mechanism of arsenic contamination of the ground water is the non-uniform distribution of arsenic in the Ganga river basin. So aquifer-specific are required to realize the actual mechanism of arsenic contamination of underground water in a particular area(Singh et al., 2016).

Table 1. Districts in India having arsenic contaminated groundwater(Mishra et al., 2016)

Sr.No.	Name of State in India	Total number of districts	Number of districts having Arsenic contaminated ground water
1	Uttar Pradesh	75	25
2	Jharkhand	24	03
3	Bihar	38	22
4	Haryana	22	14
5	Rajasthan	33	03
6	Delhi	11	01
7	West Bengal	23	14
8	Chhattisgarh	27	02

Overpumping as a Cause of Arsenic Contamination

When the aquifers are stressed from over pumping, high vertical hydraulic gradients cause a large amount of water to be drawn from the less permeable clays, inducing the release of water which is highly contaminated with arsenic(Smith et al., 2018). Thus over exploitation of groundwater must be prevented. But in North India groundwater is used on a large scale for agricultural activities and the farmers depend largely on the groundwater for irrigation.

Movement of Arsenic contamination towards North India

New research by National Geophysical Research Institute (NGRI) illustrates that the largest depletion of groundwater in the world is happening in North India. Ground water is being pumped out with a rate of 70% fast than what was predicted earlier. Delhi, the capital city of India is the epicenter of this fast developing crisis. From Delhi, Punjab, Haryana, Rajasthan and western UP, 32 cubic Km of groundwater is being lost every year which is only being recovered partially in successive monsoons. Drying up of ground water by using bigger pumps from deeper bore wells is also one important reason of large scale contamination of ground water.

Ten years ago arsenic contamination in groundwater was only seen in some parts of Bihar and West Bengal. But now it is moving towards North West direction. Out of the two big aquifers of Ganga basin, the upper aquifer has already shown arsenic contamination It is found that deep aquifers generally have low arsenic level with a very few exceptions (Choudhury et al., 2016). As people have started over exploiting both the aquifers, this lead to an increased cross contamination. Studies have shown that arsenic have already infected paddy cropon large scale(Sandhi et al., 2017).Arsenic will also affect other crops in future and will have a terrible impact on human health.

Health related impacts of groundwater arsenic

Arsenic exposure become responsible for a number of health effects(Smoke and Smoking, 2004, Organization, 2001) appearance of skin lesions is the red signal which is expressed by the body after severe internal damage (Chakraborti et al., 2011). No medicine is available to cure arsenic toxicity yet. As a preventive measure nutritious food and arsenic free water are only suggested (Chakraborti et al., 2018).

(a) Skin Related Effects

These types of effects are observed mainly in UP, Jharkhand, Bihar and West Bengal states of India and Bangladesh (Das et al., 2008, Ahamed et al., 2006, Chakraborti et al., 2011). Usually, the initial skin symptom may be the diffuse melanosis (darkening of the skin). Spotted pigmentation (spotted melanosis) is considered as the second stage and which generally appears on the limbs, chest and back. When the individuals having spotted melanosis prevent the intake of arsenic contaminated water there may be development of white and black spots on their bodies after which is known as Leucomelanosis. Arsenic toxicity can also leads to mucous membrane melanosis on gums, lips or tongue. The signs of acute arsenic toxicity are nodular keratosis on the dorsal side of legs, feet and hands(Das et al., 2008, Chakraborti et al., 2011). Melanosis, keratosis and leucomelanosis are the manifestation of arsenicosis which is actually the illness that happens due to chronic arsenic exposure. Arsenicosis is common among population exposed to the water contaminated with arsenic and having poor socio-economic environment. No particular medicine is available to treat arsenicosis. Preventing the use of water contaminated with arsenic is only suggested(FAO, 2010).

Fig. 1: Different types of skin symptoms of arsenic toxicity: (**a**) Diffuse melanosis; (**b**) Spotted melanosis; (**c**) Leucomelanosis; (**d**) Tongue melanosis; (**e**) Diffused & nodular keratosis on palm; (**f**) Spotted keratosis on sole; and (**g**) Dorsal keratosis(Chakraborti et al., 2018).

(b) Gastrointestinal Problems

Gastrointestinal effects were noticed in West Bengal as well as in Bangladesh(Das et al., 2008). Dyspepsia (acute and regular pain in upper abdomen), symptoms of nausea, diarrhea and anorexia are the main gastrointestinal effects which are observed.[16,50A]

(c) Cardiovascular Effects

Studies show that prolonged arsenic exposure may cause ischemic heart disease, black foot disease, gangrene, systemic arteriosclerosis and hypertension. Many cases of gangrene affected legs are observed in India and Bangladesh(Rahman et al., 2009).

(d) Respiratory Issues

Studies prove that chronic exposure to arsenic can result in many respiratory disorders like cough, noisy chest while breathing, shortness of breath, malignant and non-malignant lung diseases(Das et al., 2008). Increased arsenic concentration can also become responsible for bronchitis and chronic cough.

(e) Neurological Effects

Latest studies have identified several arsenic exposed individuals with different peripheral neuropathy symptoms like hyperpathia, limb pain, distal paresthesia, distal limb symptom, calf tenderness etc(Das et al., 2008).

(f) Reproductive Issue

Adverse pregnancy outcomes like premature birth, increased still birth, abortion, low birth weight and declined intelligence quotient among the children are observed in arsenic exposed populations (Islam et al., 2004, Acharyya et al., 2005).

(g) Cancer due to Arsenic Exposure

Initially it was thought that arsenic toxicity can cause only the skin cancer but now it is declared by USEPA, WHO as well as the International Agency for Cancer Research that the other types of cancer like skin, liver, lung, urinary tract, kidney and bladder cancer can be caused by arsenic(Organization, 2001, Smoke and Smoking, 2004). Ecological investigations, case controlled and cohort studies provide evidences of arsenic induced cancers from arsenic contaminated drinking water (Chakraborti et al., 2003).

Arsenic as a part of Food Chain

If a toxic substance once enters in a food chain, it becomes very difficult to remove it. Such is the case with arsenic. Groundwater used for drinking and cooking is not the only source of exposure to arsenic. When the groundwater contaminated with arsenic is used for agricultural activities it enters in the plant body and consequently affects the organisms at the higher tropic levels. [G] Due to the process of bio magnification the organisms at higher tropic levels face the highest toxic effect of arsenic. Studies in the past showed that when arsenic contaminated groundwater is used for aquaculture, it gets accumulated in the tissues of fish and thus adversely affect the humans (Kar et al., 2011). In most developing countries

ground water is exploited for drinking and agricultural activities without informing the concerned authorities or the government. [A] So it is very difficult to completely prevent the arsenic exposure in the areas where the groundwater is contaminated with arsenic. Providing arsenic free water for drinking in such areas is not the complete solution to the problem.

Psychological and Socio-economic Impacts of Arsenic Contaminated Groundwater

Studies about the arsenic affected areas reveal that arsenicosis cause physical weakness which adversely affects the family income. When the breadwinner of a poor family is affected, it becomes difficult for the whole family to survive. At macro level arsenic poisoning adversely affect the GDP of a country and puts a supplementary financial load on the government.

The victims of arsenicosis suffer from social isolation, social hatred and extensive psychological trauma. Cases of suicides due to fear of social isolation are observed in the patients suffering from arsenicosis. Those who are suffering from arsenicosis face problem in finding employment because they are rejected due to skin lesions which are easily visible on their body. Boys and girls having arsenicosis are rejected for marriage proposals. Reproductive failure like stillbirth, abortion and early neonatal death cause serious psychological trauma in the arsenic affected females.

Solutions to the Problem of Groundwater Arsenic Contamination

The ground water arsenic contamination is a major public health issue which needs to be solved by adopting a multispectral approach. The main challenges in solving this problem are providing arsenic free water for drinking in arsenic affected areas, providing proper care to the arsenicosis patients, constant monitoring of arsenic exposed population and encouraging the research on ground water arsenic issues.

There is a need to increase social awareness about arsenic poisoning so that the victims of arsenic poisoning can be identified and suitable actions can be taken within the right time. To ensure this the health ministry and the NGO's should work actively and specially in the rural areas. For the areas of high population density it is difficult to provide arsenic free water so arsenic removal technologies must be developed. Different technologies based on oxidation, adsorption, co-precipitation, membrane separation and ion exchange processes has been developed and are available for removal of arsenic from the contaminated groundwater. But the appropriateness and efficiency of these technologies is still in question due to different arsenic concentrations in different areas. Some of these methods are quite simple but they produce a large amount of toxic sludge. The disposal of this toxic sludge is an issue. More research is required to develop an eco-friendly and cost effective technique for removal of arsenic from ground water. The ion exchanger based on conducting polymers and conducting polymer based thin membranes/ sheet / adsorbents which have been used for various applications (Kumar et al., 2015, Kumar et al., Joon et al., 2015a, Joon et al., 2015b, Kour et al., 2021) are now find applications for removal of heavy metals from ground water.

Conclusion

The present study established an organized and systematic review of the groundwater contamination with arsenic. It reviewed the mechanism of arsenic contamination of groundwater, health effects of arsenic present in groundwater, psychological and socioeconomic outcomes of arsenicosis.

This study reveals that arsenic in ground water is a demon moving towards the north India states.This study also suggested some possible solutions to the problem of groundwater arsenic contamination.

Possible recommendations

The review study recommends that a lot of research is still required for actual estimation of arsenic contamination of the groundwater. To study the movement of arsenic in ground water continuous research is required in the future and to prevent the arsenic contamination of the ground water the recommended possible solutions must be analysed and implemented practically.

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