REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1 (2024)
http://www.veterinaria.org
Article Received:27/07/2024 Revised: 20/08/2024 Accepted: 14/09/2024

Assessing Arsenic Contamination in Groundwater: A Comprehensive Review of NCR Districts in Haryana.

Dr. Garima Sharma[1*], Sonam Thalod[2]

[1*]Associate Professor, Apex University, Jaipur
[2]Research Scholar, Apex University, Jaipur

Abstract
Arsenic contamination in groundwater is notable concern for environment and public health. This review paper is mainly focused on sources, affected areas, health impacts, and controlling strategies of arsenic contamination in groundwater across districts of Haryana, India. This review paper arrange finding from various studies of arsenic contamination in these regions and the health risks in affected areas. Also some mitigation strategies are discussed for improving water quality which contributes to arsenic safe water for future. Both natural and anthropogenic sources of arsenic in environment are discussed due to which levels of arsenic in groundwater are increasing above permissible limits. Contamination of groundwater with arsenic in it, can cause major health problem such as skin problems like hyperpigmentation, keratosis, skin lesion, cardiovascular diseases, neurological disorders, developmental delay in children's and risk of cancer in liver, bladder, skin, lungs, and extreme arsenic poisoning may lead to death mostly among rural population of the affected areas. If arsenicosis patients were provided arsenic safe drinking water and nutritious food, they will show the sign of recovery overtime. This review also includes different ways for controlling and treating arsenic contamination in groundwater in every way possible with the help of government and locals by warning them about the risk to there health in present time as well as for the future generation. The different mitigation strategies discussed in this review paper helps to mitigate arsenic from contaminated groundwater and improving water quality in areas where arsenic concentration has crossed the permissible limits or tends to cross the permissible limits. This review paper also provides foundation for future researches and protecting human health.

Keywords: Arsenic, Heavy metal, Contamination, Groundwater, Human health, Haryana.

Introduction

Arsenic is naturally occurred toxic-metalloid, it can be very toxic for living organisms in its inorganic form with drinking water it is excessive and prolonged exposure causes arsenicosis. Arsenic can contaminate environment through air, water, and soil. Arsenic contamination effects human body in different ways such as by drinking contaminated water and by eating contaminated food.

World Health Organization[WHO] guidelines regarding bearable arsenic intake level in water and air: In drinking water- 0.01 milligrams per liter/ 10 micrograms per liter, and permissible limits of arsenic if no alternative source is present- 0.05 milligrams per liter/ 50 micrograms per liter [1].

Shaji et al. (2021) [23] Examined the sources, distribution, and health risks associated with arsenic contamination, highlighting the severity of the issue in South Asia, particularly India. They discuss the geochemical processes responsible for arsenic mobilization in groundwater and the challenges in mitigating contamination. The study emphasizes the need for sustainable management practices and policy interventions to address the widespread arsenic contamination affecting millions of people globally.

Sankhla, Kumar, and Agrawal et al. (2018) [24] Discussed the overview of how arsenic enters water sources, primarily through natural geological processes and anthropogenic activities. The paper emphasizes the severe health risks associated with prolonged arsenic exposure, including skin lesions, cardiovascular diseases, and various forms of cancer. The authors also highlight the challenges in detecting and mitigating arsenic contamination in rural and urban areas of India, stressing the urgent need for effective public health strategies and governmental interventions to address this public health crisis.

Chakraborti et al. (2017) [28] Studied an in-depth analysis of arsenic distribution in groundwater across different regions, identifying areas with the highest contamination levels. The authors discuss the toxicological impact of arsenic on human health, including skin disorders, cardiovascular diseases, and various types of cancer. They also highlight the long-term public health crisis posed by chronic arsenic exposure, particularly in rural areas where people rely heavily on contaminated groundwater for drinking. The paper underscores the urgent need for comprehensive mitigation strategies, policy interventions, and public awareness campaigns to combat this pervasive issue in India.

the study by Kumar et al. (2016) [27] Highlighted the extent of arsenic presence in groundwater sources and its implications for public health. The study focuses on specific regions where arsenic levels in drinking water exceed safe limits, posing significant health risks to the population. The authors highlight the adverse health effects associated with arsenic exposure, including cancer, cardiovascular diseases, and skin conditions. The paper calls for urgent action to address this issue, recommending regular monitoring of groundwater and the implementation of effective mitigation strategies to protect affected communities.

Human body does not respond to less amount for short-period of time, but in long term of arsenic exposure can cause

many serious health problems in every age group of peoples. So, in some areas where arsenic present in excess is causing health issues. Elevated arsenic levels may occur naturally occurring events like volcanism, weathering, forest fire, and human activities that can elevate arsenic levels are coal-fired power plants, mining, arsenic containing pesticides.

In India, Arsenic contamination in groundwater has reported in several states such as West Bengal(2017, 2013, 2010, 1996) [2, 3, 4, 5], Uttar Pradesh(2019) [6], Bihar(2016) [7], Assam(2004) [8], Bengal Basin(2022) [9], Jharkhand(2022) [10], Ganga Basin(2018) [11], Manipur(2008) [12], Chattisgarh(2017) [13] and Karnatka(2017) [14] including Haryana(2021) [15] has arsenic contamination above the permissible levels.Here are few notable ones:

Sarkar, Paul, and Darbha et al. (2022) [9] discussed the extent of arsenic pollution in this region, which is one of the most severely affected areas in the world. The review highlights the sources and distribution patterns of arsenic in groundwater, the underlying geological factors contributing to the contamination, and the associated health risks for the local population. The authors also briefly examine the existing mitigation strategies and suggest areas for future research to address this ongoing environmental and public health challenge.

The paper by Kumar and Pati et al. (2022) [10] Highlighted various computational models to analyze and predict arsenic concentrations in groundwater across the region. By leveraging machine learning algorithms, the authors aim to improve the accuracy of contamination assessments and provide insights into spatial distribution patterns. The findings offer a data-driven approach to better understand and manage arsenic contamination, potentially aiding in more effective remediation and policy decisions.

Mishra et al. (2019) [6] reported widespread presence of arsenic in the region's water sources and highlights the potential health risks associated with long-term exposure. Mishra emphasizes the need for immediate attention and intervention to address the contamination and protect public health. The piece underscores the severity of the issue and the urgency of implementing effective water management and purification measures.

Chakraborti et al. (2018) [11] studied the extent of arsenic pollution in the basin and examines how it could pose significant health risks to the population. It highlights the prevalence of arsenic in groundwater sources, discusses its link to various health problems, and emphasizes the need for comprehensive monitoring and preventive measures. The authors call for urgent action to address the contamination and mitigate its health effects.

Adhikary & Mandal et al. (2017) [3] discussed sources of arsenic, its distribution across different areas, and the health impacts on the local population, such as skin lesions, cancer, and other arsenic-related diseases. The review also covers the various methods and strategies employed to mitigate arsenic contamination and suggests potential solutions to address the ongoing crisis. The paper aims to provide a comprehensive understanding of the arsenic problem in West Bengal and to raise awareness about the need for effective intervention and policy implementation.

Patel et al. (2017) [13] studied the levels of arsenic and fluoride in groundwater in Rajnandgaon District, Chhattisgarh, northeastern India. The study highlights the presence of high concentrations of these contaminants and discusses their potential health impacts on the local population. The authors analyze water samples from various sources in the district, presenting data on contamination levels and evaluating the associated risks. The findings emphasize the need for effective water quality management and public health measures to address the issues related to arsenic and fluoride contamination.

Manju, Hegde, and Keshan et al. (2017) [14] investigated the frequency of arsenic in the environment and its correlation with dental caries experience in the affected population. It provides evidence on how arsenic exposure may contribute to higher rates of dental caries in children. The authors conclude that environmental arsenic contamination is a significant factor influencing dental health, and they advocate for increased awareness and preventive measures to address this public health issue.

Chakraborti et al. (2016) [7] highlighted extent of arsenic contamination in the region and its impact on public health, including various arsenic-related diseases. The authors present data on groundwater arsenic levels and correlate these with health outcomes in the local population. The findings underscore the severe health risks associated with arsenic exposure, highlighting the need for effective water management and public health interventions to address and mitigate these risks.

In their study, Rahaman et al. (2013) [4] reported the sources of arsenic pollution in the region, particularly its presence in groundwater, which poses a significant threat to public health. The study highlights the geographical distribution of arsenic, the factors contributing to its mobilization in the environment, and the resulting health hazards, such as skin lesions, cancer, and other chronic illnesses. The paper also explores potential mitigation strategies and the importance of monitoring and managing arsenic levels to protect affected communities..

Mazumder et al. (2010) [5] investigated arsenic contamination in groundwater in Nadia district, West Bengal, India, and its health impacts on the local population. The study outlines the extent of arsenic contamination, which poses significant health risks, including chronic arsenic poisoning and related diseases. The authors analyze data from local water sources and health surveys, revealing widespread contamination and its adverse effects on health. The paper calls for increased awareness, improved water quality management, and health interventions to address the issues associated with arsenic exposure

Chakraborti et al. (2008) [12] examined groundwater arsenic contamination in Manipur, a state in northeastern India. The study assesses the extent of arsenic pollution in the region's groundwater and its potential future health risks. The authors present data on arsenic levels and discuss their implications for public health, emphasizing the need for monitoring and mitigation strategies. The findings highlight the urgent need for action to prevent health issues related to arsenic exposure and to address the contamination problem effectively.

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Singh et al. (2004) [8] studied the extent and distribution of arsenic in the region's groundwater, emphasizing the significant public health risks associated with exposure. Singh highlights the challenges in managing and mitigating arsenic contamination and calls for enhanced monitoring and remediation strategies to address the issue effectively. The presentation provides valuable insights into regional water quality issues and the need for targeted interventions to safeguard public health.
Dipeankar Das et al. (1996) [2] examines the arsenic levels found in the water sources and discusses the potential health risks associated with long-term exposure to arsenic. The study highlights the widespread nature of the contamination and it's implications for public health, emphasizing the need for remedial measures and further research to address the issue.
In Haryana, groundwater serves as primary sources of water for many purposes like agriculture and drinking, and this water is contaminated with harmful heavy metals including arsenic.

Geographical and Geological Context
Haryana, north Indian state(30°44′N 76°47′E) which is covering less than 1.4% of India's total land area. Haryana has vast geological formation which influence various groundwater quality. An estimated two million peoples in an area of 44,212 km2 in Haryana are presently drinking arsenic contaminated water. Haryana has many northeast to west flowing rivers originating form Himalayas and some southwest to east flowing seasonal rivers originating from the Aravali range which are prone to arsenic contamination due to natural and anthropogenic activities [19].

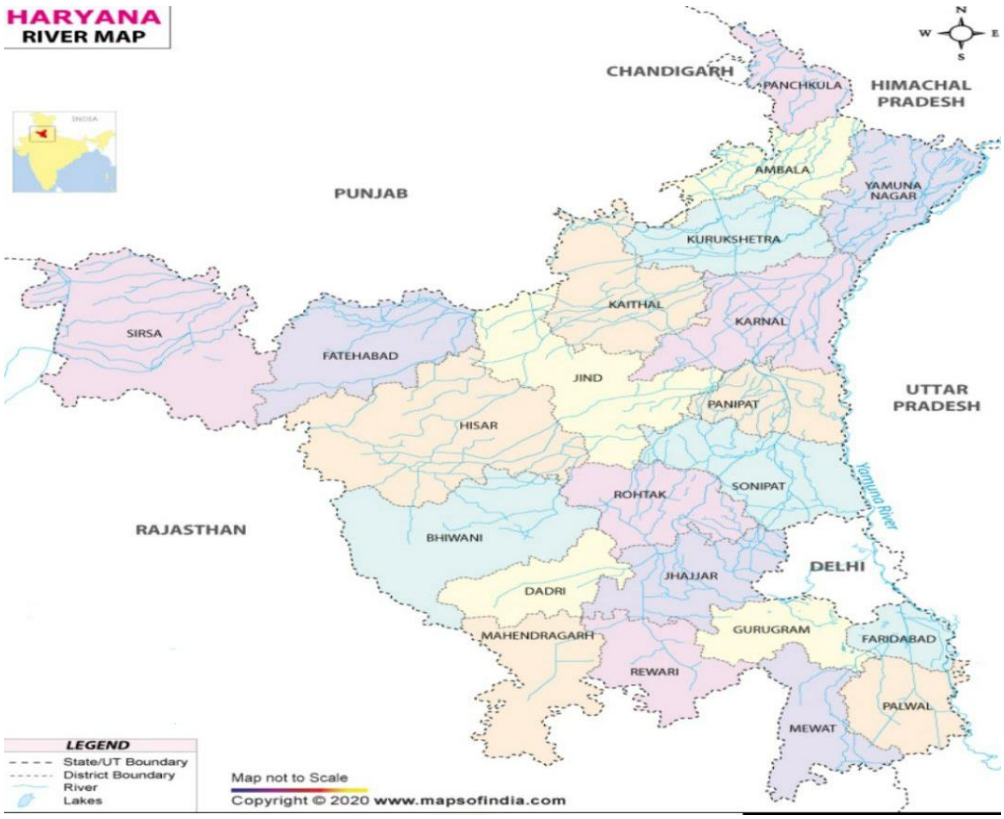

Figure.1: Map of Haryana state with district and river flowing in them.

The geological context of Haryana, India, involves these main factors:
Alluvial Deposits: Haryana's groundwater is primarily sourced from alluvial deposits of the Yamuna and Ganges rivers. These deposits can contain arsenic-bearing minerals, especially in areas where the river sediments are rich in iron and manganese.
Geochemical Conditions: Arsenic contamination often results from natural processes such as the dissolution of arsenic-rich minerals in the aquifer. In Haryana, factors like high iron content and reductive conditions in the groundwater can contribute to the mobilization of arsenic.
Hydrogeology: The region has a complex hydrogeological setup with both shallow and deep aquifers. Arsenic contamination is often more prevalent in shallow, unconfined aquifers compared to deeper, confined ones.
Agricultural Practices: Intensive agriculture and the use of arsenic-containing pesticides or fertilizers can exacerbate contamination. Runoff and leaching can transport arsenic into groundwater systems.
Industrial Activities: Historical and ongoing industrial activities can contribute to arsenic pollution. Mining and industrial waste disposal can introduce arsenic into the groundwater system.

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Haryana, is known for agricultural production and milk production, here groundwater is main requirement for almost every piece of work in day to day life. If the importance of water is this much and the water is contaminated with poisoning heavy metals in it how it will provide benefit to mortal beings.

Districts of Haryana which came under National Capital Region [NCR] are: Faridabad, Gurugram, Nuh, Rohtak, Sonipat, Rewari, Jhajjar, Panipat, Palwal, Bhiwani, Charkhi Dardri, Mahendragarh, Jind, and Karnal. Some of the researches and finding of arsenic contamination in NCR districts of Haryana:

A document by Central Ground Water Board(CGWB) [20] Highlighted affected districts with different contaminants present in groundwater state -wise, including districts of Haryana affected with arsenic: Ambala, Bhiwani, Faridabad, Fatehabad, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonepat, Yamunanagar, Mahendergarh, Palwal.

The article by Ipsita Pati et al. (2024) [35] Discussed the growing concerns over groundwater contamination in various regions, particularly in Gurgaon. The report is expected to outline the actions implemented by the CGMA to address the issue, including monitoring, regulation, and enforcement strategies. The article emphasizes the importance of protecting groundwater resources, which are crucial for drinking water and agriculture, and the need for effective pollution control measures to safeguard public health and the environment.

The article by Bhartesh Singh Thakur et al. (2024) [36] Reported the potential health risks associated with consuming contaminated water, which can lead to severe health issues such as skeletal fluorosis and arsenic poisoning(arsenicosis). The article emphasizes the urgent need for government intervention to address this public health concern, including better monitoring, public awareness campaigns, and the implementation of corrective measures to ensure safe drinking water for the affected populations.

The article by Thakur and Tandon et al. (2023) [17] reported that groundwater in 18 districts of Haryana, India, has been found to be contaminated with arsenic, while fluoride contamination is present in 21 districts. The extent of the contamination and highlights the potential health risks associated with these pollutants. It emphasizes the urgent need for intervention and improved water management to address the contamination and protect public health in the affected areas.

Malik et al. (2023) [33] Highlights in-depth analysis of inorganic contamination in groundwater with a specific focus on Haryana, India. The authors explore the sources and distribution of various inorganic pollutants in groundwater, including heavy metals and other hazardous substances. They examine the associated health risks posed by these contaminants to the local population, such as chronic diseases and toxic effects. The paper also reviews current remedial technologies and strategies for mitigating groundwater contamination. The authors emphasize the need for targeted interventions and improved water management practices to address the contamination issues effectively and safeguard public health in Haryana.

Chahal et al. (2022) [31] Studied the carcinogenic and non-carcinogenic health risks associated with heavy metals in the drinking water of Mahendergarh district, Haryana, India. The authors assess the concentrations of various heavy metals in the local water supply and evaluate their potential health impacts on the population. The study reveals significant levels of heavy metals that pose serious health risks, including cancer and other chronic conditions. The paper emphasizes the need for improved water quality management and public health interventions to mitigate these risks and safeguard community health.

Mahajan et al. (2021) [15] reported severe contamination issues affecting water quality in these districts, raising concerns about public health. The findings underscore the urgent need for remediation and improved water management to ensure safe drinking water for the affected populations.

Mahajan et al. (2021) [16] highlighted widespread contamination issues that compromise water quality and pose health risks to local communities. It underscores the need for urgent action to address these contamination problems and improve water safety and management in the affected areas.

Yadav, Garg, Singh, and Mor et al. (2020) [21] examines the levels of arsenic contamination in groundwater in southwestern Haryana and the health implications for local populations. The study highlights the significant presence of arsenic in the region's groundwater, emphasizing the risks of chronic exposure through drinking water. The authors assess the chemical body burden of arsenic in the affected individuals and discuss the potential health impacts, including the risk of arsenic-related diseases. The research underscores the need for effective mitigation strategies to address arsenic contamination and protect public health.

Mahajan (2015) [32] Highlights the growing concerns about polluted water sources and their impact on public health in the region. Mahajan discussed the sources of contamination, including industrial discharge and inadequate waste management, and the resulting health risks faced by the local population. This article underscores the urgent need for effective water management policies and interventions to ensure safe drinking water and protect community health in Haryana.

Roy et al. (2008) [34] Examines the presence of arsenic and mercury in various water sources in Haryana, India. The study assesses the levels of these toxic metals in drinking water, irrigation sources, and other water bodies within the region. The authors find that both arsenic and mercury concentrations exceed safe limits in some areas, posing potential health risks to local populations and agriculture. The paper underscores the need for regular monitoring and stringent measures to manage and mitigate the contamination, emphasizing the importance of ensuring safe water quality for both human consumption and agricultural use.

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Sources of Arsenic Contamination

Arsenic contaminant in groundwater can appear from natural sources or anthropogenic activities. The primary natural geological sources include the dissolution of arsenic containing minerals and ores and release of arsenic during volcanism, weathering, etc. The anthropogenic activities(human-made sources) like as industrial discharge, agricultural practices and inappropriate waste disposal these can lead to elevated contamination levels [34].

Table.1: Natural and anthropogenic sources of arsenic.

SOURCES OF ARSENIC
Natural sources
• Volcanic eruption.
• Arsenic rich sediments.
• Weathering of arsenic bearing ores and minerals into water.
Anthropogenic activities
• Arsenic containing industrial discharge.
• Pesticides.
• Coal combination.
• Mining.

Health Impacts of Arsenic Exposure

According to World Health Organization (WHO) guidelines, inorganic form of arsenic in drinking water is consumed for long-term even in lower concentration for several years can lead to serious health problems. This guideline is based on evidence of carcinogenic effects of arsenic on living organisms.

Arsenic contamination in groundwater can cause many serious health problems in every age groups of peoples due to prolonged ingestion of arsenic contaminated air, food or water.

Arsenic poisoning may affect human being in both acute and chronic forms such abnormalities collectively known as arsenicosis. Arsenic can have various harmful impacts on human's health:

Dermatological effects: Skin abnormalities are diagnosed such as keratosis, skin lesions, hyperpigmentation or hypopigmentation, etc.[25,29]

(a) Hyperpigmentation (b) Keratosis (c) Skin Lesions

(d) Patchy skin hyperpigmentation (e) Hyperkeratosis

Figure.2: Various dermatological abnormalities due to arsenic poisioning.

* **Cardiovascular effects:** Various cardiovascular abnormalities are discovered in past studies some are hypertension, cardiac ischemic disease, peripheral vascular disease, acute myocardial infraction, heart failure, etc.[26,29]

* **Hepatological effects:** high levels of arsenic in body results in hepatic necrosis, abnormal liver function, hepatic lesions, etc.[30]

* **Respiratory effects:** in some cases arsenic can contaminate air also which causes bronchiectasis, impaired lung disease, pulmonary tuberculosis, etc.[29]

* **Gastrointestinal effects:** Intake of arsenic contaminated water and food cause vast digestion problems such as: abdominal pain, burning in esophagus and stomach, gastrointestinal disturbance, etc.[18]

* **Neurological effects:** Arsenic poisoning cause serious damage to both peripheral nervous system(PNS) and central nervous system(CNS). Neurological impairment, neurodevelopmental defects, proinflammatory neuronal disorder,

neurodegeneration, etc.[18, 29]

* **Cancerous effects:** prolonged exposer of arsenic from various contaminated sources can cause cancer in bladder, lungs, skin, kidneys, liver, etc. [18]

* **Health effects on children:** Evidence indicates that exposure of arsenic during early states of life(less than 20 yrs) will damage vascular system. Some more danger for children's are: infant mortality, low birth weight, increased risk of cancer in future Our future generation at risk.[18, 29]

* **Other health effects and future danger:** Diabetes mellitus, chronic kidney disease, pain and weakness in muscles, etc.[29,30]

* **Rare case of extreme poisoning may lead to death.**

Mitigation Strategies

Mixed approaches are required to address arsenic contamination in groundwater:

1. **Identification and monitoring:** Testing groundwater for identification of contaminants and taking samples on regular bases for monitoring contaminant in specific areas in which arsenic contamination is known or suspected.
2. **Alternative water sources:** Supplying of safe drinking water through different sources like rainwater harvesting, surface water, or treated water.
3. **Water treatment:** Implementing treatments for removal of contaminants from groundwater such as- adsorption using activated alumina or iron-based materials, reverse osmosis, coagulation-filtration.
4. **Public awareness and education:** Awareing peoples about the risks of arsenic contaminated groundwater and water treatment technologies. Apply strict regulation against arsenic contaminating pesticides and industrial discharge to reduce arsenic.

These strategies ensure to drink arsenic-safe water and protect public health from the harmful effects of arsenic [22].

Conclusion

Arsenic contamination in groundwater is serious health concern for large population in different areas of Haryana. Level of arsenic in groundwater in Haryana is increasing as the time passes by due to both natural and anthropogenic sources. The natural sources which are causing increased arsenic level are unable to stopped by humans, but anthropogenic sources can be excluded by taking strict act by us. Government intervention is required to ensure safe drinking water in affected areas. Combination of researches and strategies are required to reduce the impact of arsenic contamination in groundwater such as monitoring, treatments, and educating public about the risks of prolonged exposure of arsenic. The mitigation strategies should be implemented according to geological context of an affected area. If arsenic in groundwater is present in higher level or in lower concentration but consumed for long-term is causing major health problem, then it is possible that there could be more such elements which can cause more health issues in the future.

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REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1 (2024)
http://www.veterinaria.org
Article Received:27/07/2024 Revised: 20/08/2024 Accepted: 14/09/2024

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