Arsenic Contamination in Groundwater: Mechanisms, Global Distribution Patterns, Health Risks, and Risk Mitigation

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Abstract:
Groundwater serves as a crucial resource for drinking water worldwide, yet it faces increasing threats from contamination. Arsenic is one of the significant contaminants that contaminate groundwater. While arsenic concentrations in natural surface and groundwater are typically around 1 part per billion (ppb), contaminated areas can have concentrations exceeding 1,000 ppb. Groundwater contamination by arsenic is a widespread problem across the globe with an estimated 300 million people affected by the consumption of arsenic-contaminated water. The United States Agency for Toxic Substances and Disease Registry (ATSDR) considers arsenic the pollutant posing the greatest threat to human health, primarily due to high geogenic concentrations in groundwater. This paper explores the properties, uses, and environmental impact of arsenic, with a focus on how it contaminates groundwater through both natural and human-induced processes. The global distribution of arsenic contamination is explored, particularly in heavily affected regions across Asia, South America, North America, and Europe. The health risks of arsenic exposure are significant, ranging from severe toxicity to carcinogenic effects, such as skin, lung, and bladder cancers, and non-carcinogenic outcomes, like neurological disorders, cardiovascular diseases, and diabetes. It emphasizes the urgent need for mitigation strategies to address the growing threat of arsenic contamination in groundwater and protect public health.

Keywords: *Arsenic contamination, Hydrogeochemical processes, Distribution, Carcinogenic effects, Public health*

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1. The Importance of Groundwater and Emerging Contamination Risks

Groundwater is an essential source of fresh water for populations around the world, supporting household needs, agriculture, and industrial processes. Nearly one-third of people globally rely on groundwater for their drinking water supply. (International Association of Hydrogeologists, 2020). In some areas, groundwater is the only reliable year-round water supply, and it often becomes the main source when sufficient energy and technology are available for extraction. Furthermore, groundwater plays a crucial role in buffering against seasonal in surface water availability caused by climate variability. Currently, it supplies nearly half of the world's drinking water, about 40% of irrigation needs, and a significant portion of industrial water (United Nations Water, 2018). As such, its importance as a resource cannot be overstated, particularly in the face of growing environmental and climate challenges. The degradation of groundwater quality has emerged as a major global issue, with concerns intensifying since the Industrial Revolution (Burri et al., 2019; Saqib et al., 2023). Contaminants, including both chemical and microbial agents, frequently threaten water safety. Among the harmful substances, toxic heavy metals and metalloids Among the harmful substances, toxic heavy metals and metalloids, such as arsenic (As), mercury (Hg), cadmium (Cd), chromium (Cr), and lead (Pb), present significant health risks.

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2. Arsenic: Its Properties, Uses, and Environmental Impact

Arsenic is a naturally occurring element commonly found in the Earth's crust. It is a crystalline metalloid positioned below phosphorus and above antimony in group 15 and period 4 of the periodic table, with an atomic number of 33 and an atomic mass of 74.92. Arsenic predominantly exists in four oxidation states: –3, 0, +3, and +5. Though chemically classified as a metalloid due to its characteristics of both metals and nonmetals, it is often referred to as a metal. In its pure form, arsenic appears as a steel-grey solid, but in the environment, it is usually bound with elements like oxygen, chlorine, or sulfur, forming inorganic arsenic compounds. When combined with carbon and hydrogen, it forms organic arsenic compounds (Agency for Toxic Substances and Disease Registry, 2007).

Arsenic and its compounds have broad applications, ranging from agriculture and medicine to electronics, metallurgy, and chemical warfare. However, the element's environmental and health impacts are of particular concern, especially as rock-water interactions in aquifers contribute to its release, degrading groundwater quality. As the 12th most abundant element in the earth's crust, arsenic exists in three different allotropic forms: black, yellow, and grey. Upon heating, it oxidizes rapidly to form arsenic trioxide (As_2O_3), emitting a garlic-like odor (Shaji et al., 2022). Due to its highly toxic nature, arsenic has earned the title "king of poison" and ranks first on the World Health Organization's 2001 list of hazardous substances. Since 1993, the acceptable limit for arsenic in drinking water has been set at 10 µg/L, reduced from 50 µg/L (prior to 1993). It is classified as a carcinogen, mutagen, and teratogen, and the International Agency for Research on Cancer (IARC) categorizes arsenic as a Group 1 human carcinogen.

Table. 1 Overview of Arsenic

Aspect	Details
Name	Arsenic
Chemical Symbol	As
Classification	Metalloid (having both metal and non-metal properties)
Physical State	Solid (Elemental form: Steel grey)
Color	Steel grey (Elemental arsenic); white or colorless powders (Compounds)
Sources	Naturally found in soil, minerals, and ores; released during smelting of copper, lead, gold
Uses	Wood preservatives, agricultural chemicals, semiconductors, animal feed additives
Primary Exposure Routes	Ingestion (contaminated food/water), inhalation (arsenic dust), skin contact (contaminated soil)
Health Effects	Carcinogenicity: skin cancer, lung cancer, bladder cancer, liver cancer and prostate cancer
	Non-carcinogenic effects: neurological effects, cognitive function, diabetes, skin disorders, cardiovascular disorders and reproductive effects
Regulatory Guidelines	WHO and EPA[1] set arsenic levels in drinking water at a maximum of 10 µg/L, OSHA[2] permissible limit: 10 µg/m³ in workplace air

In water, arsenic predominantly exists in two toxic inorganic forms: trivalent arsenic (As^{3+}, arsenite) and pentavalent arsenic (As^{5+}, arsenate), with arsenite being significantly more toxic. High arsenic levels in groundwater, especially in unconsolidated sediment aquifers, have been linked to severe health problems (Smedley and Kinniburgh, 2013). Globally, arsenic contamination in groundwater is estimated to affect

[1] EPA denotes Environmental Protection Agency
[2] OSHA stands for Occupational Safety and Health Administration.

around 500 million people, with prolonged exposure leading to skin pigmentation, hyperkeratosis, ulcers, skin cancer, and damage to vital organs such as the liver, kidneys, heart, and lungs.

Arsenic naturally occurs in soil and minerals, potentially entering the air, water, and land through wind-blown dust or runoff and leaching into water bodies. Consequently, people are exposed to arsenic through food, water, and air, with children also potentially ingesting arsenic through soil. While arsenic concentrations in natural surface and groundwater are typically around 1 part per billion (ppb), contaminated areas can have concentrations exceeding 1,000 ppb. Groundwater is much more likely to contain elevated arsenic levels compared to surface water. The United States Agency for Toxic Substances and Disease Registry (ATSDR) considers arsenic the pollutant posing the highest risk to human health, primarily due to high geogenic concentrations in groundwater (ATSDR, 2019). Arsenic has been classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) (Martinez et al., 2011).

3. Understanding Arsenic Contamination in Groundwater: Primary Causes and Processes

According to the International Groundwater Resources Assessment Centre (2004), most groundwater has arsenic concentrations below 10 µg/L. While the conditions promoting arsenic mobilization in aquifers are varied, complex, and not fully understood, several key factors are known to contribute to elevated arsenic levels. Arsenic in aquifers typically exists in three forms: bound to iron and manganese oxides, organic matter and sulfide, or silicate phases. These phases are thought to develop through a three-stage process. Researchers from the British Geological Survey attribute the high arsenic content in groundwater to hydrogeochemical processes (Smedley and Kinniburgh, 2013). Under strongly reducing conditions, arsenic—primarily in the form of As (III)—is released through the desorption or dissolution of iron oxides. However, immobilization can also occur under reducing conditions. Some sulfate-reducing microorganisms can convert As (V) into an arsenic sulfide (As_2S_3) precipitate, and immobilization may also result from the formation of iron sulfides (Plant et al., 2004).

Reducing conditions favorable for arsenic mobilization are often reported in young (Quaternary) alluvial and deltaic sediments. Complex sedimentation patterns driven by tectonic, isostatic, and eustatic forces have led to the rapid burial of large amounts of sediment and fresh organic matter during delta formation. Such sediments frequently contain groundwater with high arsenic concentrations. Additionally, groundwater extraction for public supply or irrigation has increased groundwater flow, potentially enhancing arsenic transport (Harvey et al., 2002).

Elevated arsenic levels are also found in oxidizing conditions where groundwater pH exceeds 8. In these environments, inorganic As (V) is predominant, and arsenic concentrations are positively correlated with other anionic species like HCO_3^-, F^-, H_3BO_3, and $H_2VO_4^-$. These high-arsenic regions are often arid or semi-arid, where groundwater salinity is elevated, and evaporation has been suggested as an additional cause of arsenic buildup. In certain regions, high arsenic concentrations are found in groundwater near areas with bedrock or placer mineralization, often associated with mining activities. For example, groundwater in the Ron Phibun area of Peninsular Thailand—once a site of tin mining—has been found to contain arsenic levels as high as 5000 µg/L, likely originating from the oxidation of arsenopyrite (FeAsS) (Plant et al., 2004).

4. International Standards for Arsenic Levels in Drinking Water

Over time, regulations on the permissible levels of arsenic in drinking water have become stricter as its toxicity has been more clearly understood. In 1903, the UK's Royal Commission on Arsenic Poisoning established a limit of 150 µg/L. Later, in 1942, the U.S. Public Health Service set a standard of 50 µg/L for interstate water carriers. In 1993, the World Health Organization (WHO) reduced its guideline for arsenic in drinking water from 50 µg/L to a provisional level of 10 µg/L, a limit that has since been adopted by most Western nations (Yamamura, 2003). However, many countries where arsenic contamination is prevalent continue to maintain the 50 μg/L standard due to inadequate testing infrastructure.

5. Global Distribution of Arsenic Contamination in Groundwater

Groundwater contamination by arsenic is a widespread problem across the globe with an estimated 300 million people affected by the consumption of arsenic-contaminated water (Hassan, 2018). The occurrence of arsenic contamination in groundwater varies by continent, with the majority of cases occurring in Asia.

5.1 Asia

Arsenic contamination is a particularly pressing issue in Asia, accounting for approximately 94% of the global population affected by this problem. Millions of people are exposed to arsenic through their drinking water, primarily due to natural contamination. This has led to severe public health crises, including skin conditions and an increased risk of cancer. Several Asian countries are significantly impacted, including:

- **Bangladesh:** Bangladesh is one of the most severely affected countries. Many rural residents rely on groundwater, which often contains dangerously high levels of naturally occurring arsenic, causing widespread health issues. Approximately 27% of the 11 million wells used for drinking and domestic purposes are contaminated with arsenic, with levels reaching up to 4600 μg/L. Arsenic levels above 10 μg/L have been detected in 59 out of Bangladesh's 64 districts, affecting between 35 to 77 million people, or 21–48% of the population (Huq et al., 2020).
- **India**: Arsenic contamination is an increasing issue in India, especially in the Ganges-Brahmaputra delta region, with West Bengal and Bihar being the most affected areas. Over the past seven years, arsenic contamination in the country has risen by 145%. Major incidents of arsenic contamination occur in the Ganga, Brahmaputra, and Meghna (GBM) river basins, including West Bengal, Uttar Pradesh, Jharkhand, and Bihar. Other affected regions include Assam, Manipur, and Chhattisgarh (Mazumder & Dasgupta, 2011).
- **Pakistan:** In Pakistan, arsenic contamination is a significant problem, particularly along the Indus River and its tributaries. Around 50 to 60 million people are at risk, especially in areas around Lahore and Hyderabad (Podgorski et al., 2017). The most affected regions include Khairpur, Jamshoro, and Tharparkar in Sindh, as well as Lahore, Kasur, Muzaffargarh, and D.G. Khan in Punjab.
- **China**: In China, arsenic contamination has been reported in 20 out of 34 provinces, affecting about 2.3 million people. Areas facing high arsenic concentrations include Taiwan, Xinjiang, Yunnan, and Inner Mongolia. The contamination is particularly prevalent in river deltas and inland basins, such as Datong, Yinchuan, and the Pearl, Yellow, and Yangtze River basins (Zhou et al., 2017).

5.2 South America

Several countries in South America face severe arsenic contamination in groundwater:

- **Argentina**: In Argentina, approximately four million people are exposed to dangerous levels of arsenic in their drinking water. Particularly high concentrations, exceeding 1000 μg/L, have been detected in the Chaco-Pampean Plains and Cuyo region of the Andes, located in central and northwestern Argentina. Groundwater arsenic levels in the studied areas range from 5.9 to 535.1 μg/L, with an average of 114 μg/L (Alcaine et al., 2020).
- **Chile**: Northern Chile, particularly in regions like Atacama and Antofagasta, suffers from arsenic contamination, primarily driven by mining activities. This contamination poses risks not only to human health but also to local ecosystems, highlighting the need for sustainable mining practices (Bundschuh et al., 2012).
- **Bolivia**: In Bolivia, arsenic contamination is particularly problematic in areas with a history of mining, such as the Cerro Rico Mountain in Potosí. The mining of silver, tin, and other minerals has led to arsenic pollution in soil and water, while industrial and agricultural activities further contribute to contamination. Recent reports indicate that groundwater arsenic concentrations in Bolivia can reach 45.9 μg/L (Alcaine et al., 2020).

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- **Peru**: Arsenic contamination in Peru is prevalent in mining regions like the Andean highlands and the Amazon rainforest. The extraction of copper, gold, and other minerals has contributed to environmental arsenic pollution. Additionally, informal artisanal and small-scale gold mining (ASGM) activities have exacerbated the problem, leading to arsenic contamination in both soil and water (Costa et al., 2024).

5.3 North America

Both the United States and Canada have experienced significant geogenic arsenic contamination in groundwater, although the concentrations are generally lower than those reported in Asia (Kobya et al., 2020).

- **The United States:** While arsenic contamination is not widespread across the U.S., certain regions, particularly in the American Southwest, have reported elevated arsenic levels in groundwater due to geological factors. Historically, arsenic pollution has also been linked to mining activities in Western states like Arizona and California. These areas have seen contamination in water supplies, affecting local communities and emphasizing the need for stringent regulations and ongoing remediation efforts. Over two million people in the U.S. rely on private wells with arsenic concentrations that exceed the regulatory limit of 10 μg/L (Schreiber, 2021). About 7% of tested wells showed arsenic levels above the maximum contaminant level (MCL), with the highest concerns in the Southwest, where around 16% of wells exceeded the MCL for arsenic (USGS, 2019).
- **Canada:** In Canada, regions such as British Columbia and the Yukon Territory face arsenic contamination linked to mining operations. Although geographically limited, these instances underscore the importance of continued monitoring and mitigation efforts. The Canadian government has implemented policies to track and address arsenic contamination in affected areas (Ravenscroft et al., 2009).

5.4 Africa

Arsenic contamination in Africa presents a serious health risk, with elevated levels reported in both surface and groundwater across several countries, including Botswana, Burkina Faso, Ethiopia, Ghana, Morocco, Nigeria, South Africa, Tanzania, Togo, and Zimbabwe. Though documented sporadically, arsenic contamination poses a significant threat in many African regions already grappling with water quality and scarcity challenges. Ahoulé et al. (2015) compiled research on arsenic distribution in African waters, showing a wide range of arsenic concentrations, from 0.02 to 1760 μg/L in groundwater and up to 10,000 μg/L in surface water.

- **Botswana:** Botswana is one of the few well-studied cases of geogenic arsenic contamination in Africa. Elevated arsenic levels, reaching up to 116 μg/L, were reported in deep groundwater near the Okavango Delta. Later studies recorded even higher concentrations, up to 3.2 mg/L, in shallow groundwater on Camp Island. Mladenov et al. (2013) also detected arsenic levels as high as 180 μg/L in the Okavango Delta.
- **Burkina Faso:** In central Burkina Faso, where groundwater serves as the primary water source, arsenic concentrations in some areas reach up to 1630 μg/L (Smedley et al., 2013).
- **Ghana:** Kusimi and Kusimi (2012) reported arsenic concentrations up to 1760 μg/L in groundwater in Ghana. Mining activities in the country primarily impact surface waters rather than groundwater.
- In other parts of Africa, such as Togo, surface water arsenic concentrations have been recorded as high as 6460 μg/L near urban areas (Rezaie-Boroon et al., 2011). In rural regions across the continent, including South Africa, borehole water contaminated with arsenic levels up to 1000 μg/L has resulted in cases of severe arsenic poisoning.

5.5 Europe

Arsenic contamination in groundwater is a widespread issue across Europe, with several countries, including Greece, Hungary, Romania, Croatia, Serbia, Turkey, and Spain, being significantly affected. The sources of contamination vary, often linked to industrial, agricultural, and mining activities, emphasizing the need for ongoing monitoring and remediation (Medunić et al., 2020; FSAI, 2023). The most severely impacted countries include:

- **Hungary:** In Hungary, arsenic contamination primarily affects the north-eastern region, particularly the Great Hungarian Plain in Csongrád County. This area is a major hotspot, with arsenic in drinking water impacting about half a million people across five towns and 54 villages (Rowland et al., 2011).
- **Romania:** Arsenic contamination is a concern in Romania, especially in areas with a history of mining, such as Maramures. Environmental disasters like the 2000 Baia Mare cyanide spill have exacerbated the issue. Ongoing efforts focus on stricter regulations and remediation in affected areas (Kanthak, 2000).
- **Croatia:** Croatia's Pannonian Basin, particularly in regions like Sisak-Moslavina County, faces significant arsenic contamination, often linked to historical mining activities. Industrial areas near Osijek and Vukovar also experience arsenic pollution. Groundwater arsenic levels in eastern Croatia can reach up to 610 μg/L, affecting approximately 200,000 people (Romic et al., 2011).
- **Serbia:** In Serbia, the Pannonian Basin, particularly around the Bor mining complex in the east, suffers from substantial arsenic pollution due to historical mining. Industrial zones in cities like Belgrade and Novi Sad also contribute to arsenic contamination. Remediation efforts are underway, particularly in the Vojvodina region, where more than 600,000 people are affected by high arsenic levels in groundwater (Jovanovic et al., 2011).
- **Greece:** Arsenic contamination in Greece is linked to geothermal activity, river alluvial deposits, and mining. Geothermal waters show arsenic levels between 30 and 4500 μg/L, while regions near alluvial deposits and mining areas have concentrations between 15 and 100 μg/L and 20 to 60 μg/L.

5.6 Oceania

- **Australia:** Arsenic contamination in Australia is prevalent, particularly in areas affected by mining activities. Arsenic levels in surface and groundwater across various states range from 1 to 5000 μg/L, with particularly high concentrations reported in rural Victoria. In Perth's Gwelup groundwater management area, arsenic levels have reached up to 7000 μg/L due to pyritic sediment exposure, a result of reduced rainfall, groundwater abstraction, and urban construction (Appelyard et al., 2006).
- **New Zealand:** Arsenic is a significant groundwater quality issue in New Zealand. Weathering of arsenic-bearing rocks in mountainous areas leads to arsenic accumulation in estuarine deposits near the coast. Reduced groundwater conditions increase arsenic mobility, limiting its adsorption by iron oxides. Additionally, old industrial activities, such as wood treatment plants and sheep dips, contribute to contamination. In regions like Woodend and Sefton, arsenic levels in groundwater frequently exceed the Provisional Maximum Acceptable Value (PMAV) of 10 μg/L (Davies et al., 2001).

6. Health Impacts of Arsenic Exposure: Toxicity, Carcinogenicity, and Non-Carcinogenic Effects

Arsenic enters the body primarily through inhalation or ingestion. Once ingested, approximately 90% of arsenic is absorbed in the gastrointestinal tract, a higher rate than for many other heavy metals. Even at low to moderate concentrations (10–300 μg/L) in drinking water, arsenic exposure can lead to a variety of health problems, including skin lesions, circulatory disorders, neurological issues, diabetes, respiratory complications, liver and kidney dysfunction, and chronic disease-related mortality (Chen et al., 2009). After being absorbed, arsenic binds to red blood cells and is distributed to organs like the liver, kidneys, muscles, bones, hair, skin, and nails, though it is primarily excreted through urine. Inorganic arsenic compounds inhibit key enzymes responsible for cellular respiration, glutathione metabolism, and DNA synthesis, and they can cross the placenta, potentially impacting fetal nervous system development (Hanlon and Ferm, 1977). Arsenic is a known carcinogen, though the exact mechanisms through which it induces cancer remain unclear. Arsenic toxicity is influenced by factors such as its oxidation state and solubility, alongside numerous internal and external variables (Centeno et al., 2005). Research shows that arsenic's toxic effects depend on the dose, duration of exposure, biological species, age, sex, genetic predisposition, and nutritional factors. One well-known mechanism of arsenic toxicity involves disrupting cellular respiration by interfering with oxidative phosphorylation through the inhibition of mitochondrial enzymes. Most cases of arsenic toxicity in humans are linked to exposure to inorganic arsenic compounds.

7. Toxicity and Carcinogenicity

Arsenic is unique among carcinogens, as it can cause cancer through both respiratory and gastrointestinal exposure (Centeno et al., 2006). In the 1980s, arsenic was officially recognized as a carcinogen and listed by the International Agency for Research on Cancer (IARC) (IARC, 1980). Numerous studies conducted in countries like the United States, Taiwan, Bangladesh, India, Argentina, and Chile have confirmed the link between arsenic exposure and cancer, reinforcing earlier findings (Kapaj et al., 2006). Inorganic arsenic compounds have been classified as definite carcinogens (group 1) or potential carcinogens (group 2B). The IARC has identified strong evidence linking arsenic exposure to cancers of the skin, lungs, and bladder, though evidence for liver, kidney, and prostate cancers remains limited.

- **Skin Cancer**: Several studies have demonstrated a connection between arsenic exposure and skin cancer. A cohort study involving 654 residents in Taiwan found an incidence rate of 14.7 skin cancer cases per 1000 person-years. Additionally, more recent research has reported a link between skin cancer and vascular diseases. In another study conducted in Hungary, Romania, and Slovakia, researchers assessed the carcinogenic risks of long-term exposure to low concentrations of arsenic in drinking water (Leonardi et al., 2012).
- **Lung Cancer**: Research by Hopenhayn-Rich et al. (1998) observed a marked increase in lung cancer-related deaths associated with arsenic exposure. Multiple studies have confirmed a dose-dependent relationship between arsenic intake and lung cancer, making it one of the most strongly linked cancers to arsenic exposure. Epidemiological studies consistently show higher lung cancer rates among populations exposed to arsenic compared to the general population. A recent study in Taiwan showed high mortality rates and elevated standardized mortality ratios for lung cancer in people who consumed arsenic-contaminated drinking water for 50 years (Chen et al., 2004).
- **Bladder Cancer**: Studies in Taiwan and Bangladesh have verified the association between arsenic exposure in drinking water and bladder cancer, but only at high concentrations. No clear link has been established at lower arsenic exposures (100 to 200 µg/L). It is believed that the latency period for arsenic exposure leading to bladder cancer can be more than 40 years (Steinmaus et al.).
- **Liver Cancer**: While studies in Argentina, Chile, Denmark, and other countries have suggested a connection between arsenic exposure and liver cancer, no consensus has been reached due to limited representative data. A 20-year cohort study in Taiwan reported an increased incidence of liver cancer in both men and women at arsenic concentrations above 0.64 mg/L, but no association was found at lower levels (Lin et al., 2013).
- **Prostate Cancer**: High arsenic exposure has been linked to prostate cancer in Taiwan (IARC, 2004). However, the link between low arsenic exposure and prostate cancer remains unclear due to limited epidemiological data. A recent study involving 3932 Native Americans aged 45 to 74 years found a high hazard ratio for prostate cancer mortality associated with low to medium inorganic arsenic exposure (Garcia-Esquinas et al., 2013).

8. Non-Carcinogenic Effects of Arsenic Exposure

- **Neurological Effects and Cognitive Function**: Research conducted in Mexico found that higher urinary arsenic concentrations were linked to lower verbal IQ scores and impaired long-term memory in children. Chronic exposure to arsenic, especially in individuals with poor nutrition, has been associated with deficits in attention, memory, and speech comprehension (Calderon et al., 2001). Wasserman et al. also demonstrated that children's intellectual development could be adversely affected by increased arsenic exposure. Arsenic accumulation during childhood may lead to neurobehavioral disorders during puberty and adulthood. Additionally, arsenic exposure can exacerbate the effects of lead toxicity. Neuritis, or inflammation of peripheral nerves, is a well-documented consequence of arsenic toxicity. Studies on Mexican children found a dose-dependent relationship between arsenic exposure and lower verbal IQ and long-term memory, with children exposed to 50 μg/L performing worse than those exposed to 5.5 μg/L (Wasserman et al., 2004).

- **Diabetes**: Recent studies suggest a potential link between arsenic exposure and the onset of type 2 diabetes, particularly in individuals over 40 years of age who are obese. Research in Taiwan showed that residents in areas with high arsenic concentrations in drinking water were 2 to 5 times more likely to develop diabetes compared to unexposed populations.
- **Skin Disorders**: Arsenic exposure has been linked to several skin conditions, including melanosis and keratosis. In Bangladesh, 13.9% of residents exposed to drinking water with arsenic levels at or below 10 μg/L developed these conditions. A larger study of 11,746 people in Bangladesh reported that the risk of skin disorders increased with higher arsenic exposure, with odds ratios of 1.91, 3.03, 3.71, and 5.39 for exposure ranges of 8.1–40.0, 40.1–91.0, 91.1–175.0, and 175.1–864.0 μg/L, respectively (Ahsan et al., 2006).
- **Cardiovascular Disorders**: Studies have shown that arsenic may influence the behavior of thrombocytes, cells that play a crucial role in cardiovascular health. Lee et al. (2002) observed that in the presence of thrombin, trivalent arsenite increased thrombocyte agglutination. Animal studies also indicated that arsenic exposure through drinking water could lead to arterial thrombus formation, which may contribute to cardiovascular diseases. However, more research is needed to confirm these findings in humans (Kapaj et al., 2006).
- **Reproductive Effects**: Arsenic exposure has been linked to pregnancy complications, including increased rates of fetal mortality and preterm birth. Research also indicates that exposure to arsenic during pregnancy affects urine excretion and metabolite distribution, potentially impairing fetal development. The specific effects of arsenic exposure may vary depending on the stage of pregnancy (Hopenhayn et al., 2003).

9. Strategies for Reducing Arsenic Exposure: Risk Mitigation and Public Health Recommendations

To mitigate arsenic exposure from drinking water and food, especially in regions with naturally high arsenic levels in groundwater, the World Health Organization (WHO, 2018) has outlined several key actions:

1. Provision of Safe Drinking Water

- **Goal**: Ensure drinking water contains arsenic levels below the WHO provisional guideline value of 10 μg/L.
- **Measures**:
  - **Test water sources**: Regularly test water for arsenic concentrations and communicate the results to the public.
  - **Install arsenic removal systems**: Deploy centralized or domestic systems to remove arsenic, ensuring proper disposal of the extracted arsenic.
  - **Use alternative water sources**: Replace high-arsenic groundwater with safer options such as rainwater or treated surface water for drinking, cooking, and irrigation. High-arsenic water should only be used for non-consumptive purposes like washing or bathing.
  - **Differentiate water sources**: Mark water sources based on arsenic levels (e.g., color-coded tube wells or hand pumps—red for unsafe, green for safe).

2. Raise Public and Health Sector Awareness

- Educate both the general public and healthcare workers on:
  - The harmful effects of high arsenic intake.
  - Sources of exposure include drinking water and using high-arsenic water for irrigation and food preparation.
  - Strategies to avoid arsenic exposure.

3. Monitor High-Risk Populations

- **Early Detection**: Track high-risk populations for early signs of arsenic poisoning, such as skin issues.

- **Testing**: Use arsenic speciation tests to differentiate between toxic inorganic arsenic and less harmful organic arsenic.

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