Impact of Arsenic Contamination on Aquatic Life of North-East India

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Abstract: Environmental pollution is a threat to all living organisms, including aquatic organisms. Heavy metal pollution from substances such as lead, arsenic, cadmium, chromium, and mercury are harmful to both freshwater and marine ecosystems. Exposure to heavy metals can have detrimental effects on aquatic organisms over both short and long periods of time. Fish are often used as a model to determine the degree of aquatic pollution. This review focuses on the impact of arsenic contamination on aquatic life of North-East India. It also helps in understanding the environmental and biological fate of arsenic and different parameters responsible for posing it as an environmental pollutant. Natural sources are estimated to emit about 1.5 times more arsenic into the atmosphere than human activities. However, due to continuous emissions and accumulation, both organic and inorganic forms of arsenic have been found in higher concentrations in aquatic environments compared to terrestrial environments.

Keywords: Arsenic, Environmental pollution, Aquatic organism, Aquatic ecosystem, Heavy metals


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Introduction

Industrialisation, urbanisation and population explosion have deleterious impacts on the entire ecosystem. Globally pollution, especially in the aquatic ecosystem due to heavy metal contamination, has become a significant cause of concern for the environmentalist. The bio-life of aquatic ecosystems is adversely affected due to the constant release of heavy metals due to their characteristic of long persisting nature or longer half-life, bioaccumulation mechanism, biomagnification process and non-biodegradability (Bakshi and Panigrahi, 2018).

Even in small concentrations, heavy metals in the food chain cause cumulative harmful effects on aquatic organisms (Velma et al., 2009; Velma and Tchounwou, 2009). Heavy metals are thus considered to have an ecological, evolutionary, nutritional and environmental impact on the
ecosystem (Jaishankar et al., 2014). Recently, freshwater ecosystems have been polluted mainly by waste water released from different industries and municipalities. The most frequently available heavy metals in the waste water are Lead, Arsenic, Cadmium, Chromium and Mercury (Bakshi, 2016; Mehana et al., 2020). There is a significant impact on fish development and physiological processes such as breeding, spawning, and overall organ development, and a decline in quantity and quality of offspring production due to the contamination by heavy metals in the aquatic environment. Furthermore, due to the intake of such waterborne contamination, there seem to be abnormalities and disruption of function and structure of many tissues and organs of the aquatic life (Jezierska et al., 2001, 2008).

Arsenic is considered one of the most potent and prominent toxicants in the aquatic environment among all the known heavy metals. Arsenic has also been reported to cause severe water pollution, affecting the growth of aquatic flora and fauna (Ratnaike, 2003; Oremland et al., 2003). Furthermore, the uncontrolled influx of industrial wastes and pesticides in the aquatic environment has made this toxic metalloid widely available in rivers, canals, ponds, lakes, groundwater and seawater, thereby causing a global threat (Kumari et al., 2016).

Regarding public health arsenic has been reported to be the most dangerous chemical as per the WHO reports (Babich et al., 2019). In most countries, arsenic levels have been reported to be up to 800 and 2500 ppm (Naujokas et al., 2013). There have been several studies reporting the adverse effect of the high level of arsenic exposure resulting in diseases such as lung and skin cancer and liver and cardiovascular disorders in case of humans (Liu et al., 2008; Kundu et al., 2011; Gong et al., 2012; Bräuner et al., 2014). Previous research has demonstrated the adverse effects of Arsenic on the overall growth and development of the fishes, histopathological and genetic alteration and mortality (Hayat et al., 2007; Ahmed et al., 2013; Banerjee et al., 2015; Foley et al., 2016; Minatel et al., 2017; Han et al., 2019). Exposure to the higher concentration of Arsenic in fish have been reported to cause changes in body physiology, including effects on the overall growth, mortality, ion exchange system, immune system, reproduction, enzyme activity, histology and gene regulation (Farag et al., 1995; Pedlar et al., 2002; Datta et al., 2009).

**Arsenic and its characteristics:**

Arsenic is one of the harmful heavy metals (metalloids) in aquatic biolife. It has a metalloid property and is predominantly available in oxides (arsenate and arsenite) or sulfides or as a salt of sodium, iron, copper, calcium, etc. (Singh et al., 2007). The emissions of arsenic into the atmosphere from natural sources are estimated to be about 1.5 times higher than those from human activities (Chilvers et al., 1987). However, due to continuous emissions and accumulation, both organic and inorganic forms of arsenic have been found in higher concentrations in aquatic environments compared to terrestrial environments (IPCS, 2001). Although arsenic contamination in aquatic biological communities originates from geogenic sources, it occurs through accumulation from lower to higher trophic levels, particularly in members of the Class Pisces (Jankong et al., 2007; Grotti et al., 2008; Srivastava and Sharma, 2013; Taleshi et al., 2014; Williams et al., 2014; Oliveira et al., 2017; Han et al., 2019). The degree of accumulation and biomagnification of arsenic in aquatic flora and fauna varies based on geographical settings, such as freshwater, estuarine, transitional, and marine ecosystems, as well as across species and their trophic status within the food web, which strongly controls exposure and uptake routes (Chen and Folt, 2000; McGeer et al., 2003; Schafer et al., 2015; Oliveira et al., 2017).

Aquatic organisms, like their terrestrial counterparts, can absorb varying amounts of arsenic from their environment. They are exposed to different forms of inorganic and organic arsenic, commonly through food, water, and other environmental sources. The metabolism of arsenic
is complex due to the variety of physiochemical properties and bioavailability of each form, and is further complicated by the influence of other metals and metalloids on arsenic metabolism within and between species (Mandal and Suzuki, 2002). Organic forms of arsenic, such as arsenobetaine, have been widely observed in marine aquatic flora and fauna, but are virtually absent in most freshwater invertebrates and vertebrates (Schaefer et al., 2006).

Organic forms of arsenic are produced by algae and passed along the food chain (Wrench et al., 1979). Both microalgae and macroalgae, which form the base of lower trophic levels, may accumulate more arsenic than organisms at higher trophic levels (García-Salgado et al., 2012). In addition to algae, drifting organisms such as phytoplankton and zooplankton can also accumulate arsenic. Studies have shown that phytoplankton can accumulate large amounts of inorganic arsenic and/or convert it into other organic forms, such as arsenobetaine. Higher trophic level organisms, such as fish, crabs, prawns, and shrimps, also play an important role in the speciation of arsenic within aquatic environments (Šlejkovec et al., 2014).

The global occurrence of water-soluble arsenic concentration above the permissible limit is primarily due to excessive use of arsenical pesticides, industrial activities, mining operations and chemical laboratory exhaustion. Water soluble inorganic arsenic (iAs) is converted to methylated arsenical forms, i.e., monomethyl arsionic acid (MMA) and dimethylarsinic acid (DMA), through enzymatic activities in the organism’s body. These arsenical forms are long-term arsenic exposure’s primary end metabolites and biomarkers (Jaishankar et al., 2014; Kumari et al., 2016). The advesative impact on the hydrobiological quality of water bodies such as lakes, ponds and rivers all over the world has been due to extensive industrialization, exploitation and rapid urbanization (Praveena et al., 2013), hence it has been observed that the exposure of the aquatic biolife to arsenic may be waterborne and diet-borne. The main routes of entry for it into the aquatic organism is through gills and GI tract. After taking entry through gill, waterborne arsenic significantly accumulates in the gill, liver and intestine and manipulates the growth of the fish (Tsai and Liao, 2006; Han et al., 2019).

Inorganic Arsenic (iAs) may be present in two forms, i.e., iAs (III) and iAs (V). According to Kumari et al. (2016), after the entry of iAs (V), it converts into iAs (III). Then iAs (III) changes into MMA(V) coupled with SAM –SAH conversion (SAM: S-adenosylmethionine; SAH: S-adenosylhomocysteine). After that MMA(V) transforms into the most toxic and accumulating form MMA (III), through reduction reaction by the action of MMA(V) reductase or GSTO 1 (glutathione S-transferase omega 1). MMA (III) can also be converted into DMA coupled with a SAM –SAH conversion (SAM: S-adenosyl-methionine; SAH: S-adenosylhomocysteine). Most biotransformation reactions occur in the liver (Han et al., 2019).

When arsenic compounds come with food, they accumulate in the digestive tract. From the digestive tract, it goes to the liver, where most of the biotransformation takes place. It then accumulates in other organs or body tissues, i.e., brain, gonads, muscles either directly or through circulation and accumulate (Tsai et al., 2012). Arsenic compounds dissolved in water can also pass through the gills and be deposited directly into the brain, kidneys, gonads, and other tissues. Absorption through food shows accumulation in the gastrointestinal tract until the end of exposure, but the concentration gradually decreases during elimination. Although there are many different studies, the liver is reported as the most metal accumulating organ in most cases (Kumari et al., 2016; Han et al., 2019).

**Arsenic detection in the North-East region:**

Arsenic is one of the most available metals that can be found in soil, rocks, natural waters and organisms. It occurs through different natural processes such as weathering, microbial metabolism and volcanic eruptions which leads to
arsenic contamination. Anthropogenic activities like mining, combustion of fossil fuels, use of arsenical pesticides, herbicides and crop desiccants and agricultural additives for livestock are also responsible for exaggerating the arsenic in soil and groundwater (Buragohain et al., 2012). Though researchers have made advancements in understanding the distribution, occurrence and mobilisation of arsenic in groundwater on a global scale, on a regional extent, it still needs to be improved and needs proper knowledge and information. Most North East India people primarily depend on dug-well, ponds, and naturally occurring spring water. It has been estimated that 60% of these water sources are contaminated with arsenic concentrations. The concentration being much higher than the WHO and BIS guidelines of 10 µg/l and 50 µg/l, respectively (WHO, 1993; Shukla et al., 2010; BIS, 2013). A study conducted by the North-eastern Regional Institute of Water and Land Management (NERIWALM) found that 20 out of 24 districts of Assam have a content exceeding 50 µg/l (Bordoloi, 2012). Another study has reported that Karimganj and Dhemaji districts are the worst affected areas of Assam, where 19.1% of groundwater has arsenic concentration above 50 µg/l, and 2.1% contains more than 300 µg/l (Saikia et al., 2012). Continuous water consumption can pose serious health hazards to the local population. Though several restorative and precautionary measures have been taken to supply arsenic free water to the affected population and develop devices for arsenic removal, the effort is insignificant when looking at the larger arena of the stated problem.

The detection of Arsenic in groundwater from large areas of the North-eastern region of India few years back has rung the bell of concern for millions (Das et al., 2015). Arsenic distribution in natural water mainly depends on the geochemical characteristics of the aquifer materials. It has been observed that most of the arsenic affected floodplains in Asia are by the side of the rivers that originate in the Himalayas foothills. Hence, the Himalayas and surrounding mountains are considered to be the possible sources of Arsenic bearing minerals. For example, the sediments of Bengal Delta Plain (the 13th Largest Delta in the World) has been reported to contain high percentage of clay and organic matter deposits. This reacts with Fe and Mn - Oxyhydroxide minerals accordingly that reaches high Reduction Potential (Eh) value and strongly absorb arsenical elements for auxiliary release of the toxic in the groundwater (Selima et al., 2010; Santra et al., 2013). It has also been reported that the average arsenic content of carbonaceous matter from the North-eastern Region is 95.1 mg/kg (Mudhoo et al., 2011). The weathering sulphide content in the carbonaceous matter produces Arsenic-rich iron oxyhydroxide. This in an oxygen-deficient environment which has been reported to release arsenic to the existing sedimentary layers of Arunachal Pradesh, Assam, Nagaland and Meghalaya (Table 1).

**Different sources of Arsenic in North-East India:**

The most abundant element in the earth’s crust is Arsenic, and its traces can be found in more than 245 types of minerals. These are typically ores containing sulphide, copper, nickel, lead, cobalt

<table>
<thead>
<tr>
<th>States</th>
<th>Types of Carbonaceous materials</th>
<th>Carbon (wt %)</th>
<th>Arsenic (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Average</td>
</tr>
<tr>
<td>Assam</td>
<td>Sub-bituminous</td>
<td>70.381–71.143</td>
<td>44.0–78.0</td>
</tr>
<tr>
<td>Nagaland</td>
<td>Lignitic</td>
<td>53.825–56.124</td>
<td>56.0–68.0</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>Sub-bituminous</td>
<td>58.202–58.791</td>
<td>106.0–238.0</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>Graphitic</td>
<td>66.012–71.981</td>
<td>39.0–50.0</td>
</tr>
</tbody>
</table>
etc. The earthly profusion of arsenic is approximately 1.5-3 mg/kg. Most of the reported cases of arsenic in the Himalayan region cause sedimentary mobilisation under natural hydrogeological conditions, and few cause human extravagance. The sources of Arsenic in the environment can be subcategorised into natural and anthropogenic sources (Devi et al., 2009; Mudhoo et al., 2011).

Natural sources: Although the definite source of groundwater arsenic contamination in the Ganga-Brahmaputra basin is yet to be identified, several arsenic bearing sediments have already been reported in the Bengal delta plain, Gondwana coal seams, Bihar mica belt, pyrite bearing shale, Son valley gold belt etc. (Chakraborti et al., 2004; Barringer et al., 2013; IARC, 2014). The Ganges-Brahmaputra River system which covers the North-eastern states, had over the time several sediment deposits that functions as a reservoir of Arsenic, and the concentration of the element in these deposits can reach to as high as 490 mg/kg.

Anthropogenic activities: The extensive use of pesticides, application of fertilisers, agricultural additives for livestock, crop desiccants burning of coal and leaching of metals from coal-ash tailings are the major causes of human caused contamination. The average Arsenic content in Indian coal ranges up to 3.72 mg/kg. Whereas a maximum value of 40 mg/kg has also been reported in North-eastern regions. Thus coal combustion is considered to be one of the most important sources of anthropogenic arsenic emission in the environment in North eastern India. In addition, several metallurgical plants, cement factories, incinerators and chemical plants also pose a threat to the pollution to the environment in this region (Chakraborti et al., 2013; Barringer et al., 2013; IARC, 2014).

Adverse effect of Arsenic on Aquatic life:
Among the aquatic organisms, fish can serve as a model to study arsenic toxicity, as they are continuously exposed to arsenic through gills and get accumulated in various tissues. The accumulation of arsenic compounds basically takes place in the digestive tract once it enters through food. It takes it course through and goes to the liver, where the major biotransformation takes place. Inorganic arsenic, potent carcinogen is methylated in the body by altering the reduction of pentavalent arsenic (Arsenate, AsV) to trivalent (Arsenite AsIII) with an addition of methyl group from S-adenosylmethionine. Although it has been reported that the site of arsenic methylation is the liver, however, there are also reports that most organs also show arsenic methylation activity. Methylarsonic (MMA) and dimethylarsinic acid (DMA) may be less reactive organic arsenic and readily excreted in the urine, they may form reactive immediate such as MMA III and DMA III which might be absorbed in the body and results in toxicity (Vahter et al., 2002).

After arsenic enters aquatic systems, it exerts detrimental effects on aquatic organisms directly through inhalation and drinking or indirectly by uptake through the food chain (Rahman et al., 2012). It is then accumulated in the body tissues and organs such as muscles, brain, gonads etc. (Tsai et al., 2012). Kumari et al. (2016) has also reported in one of the purification experiments that a small amount of metal traces has also been observed in faeces. Different biological and environmental factors (Zhang et al., 2022) also play an important role in arsenic bioaccumulation in aquatic organisms. Absorption of Arsenic is also influenced by various parameters such as type of species, body size, age, pH, salinity, dissolved organic matter levels, moulting, food density, prey types, pre-exposure, presence of phosphate etc. From lower-level microorganisms to marine fish, many enzymes take significant roles in the biotransformation of inorganic arsenic to less toxic organic arsenic species. Although there are several reports on influence of various factors on arsenic bioaccumulation in aquatic organism, however, no comprehensive and systematic information related to entire bioaccumulation process have been reported.
Once ingested the Arsenic compounds are reported to be deposited in different organs and tissues of the aquatic organisms. This leads to various physiological and biochemical disorders such as poisoning, enzyme activity, immune function, liver lesions, cell and tissue damage, decreased fertility and cell death too (Ribeiro et al., 2005; Bears et al., 2006). Bioaccumulation of arsenic may also trigger a change in water temperature which can cause metabolic disorder in some aquatic organisms. The rise in the temperature accelerates the process of oxygen consumption which can induce stress and immunity degradation too (Lushchak and Bagnyukova, 2006; Bagnyukova et al., 2007). As a result of toxicity, it has also been reported that the feed intake rate and metabolic rate decreases which in turn results in the overall growth rate of the fishes (Farkas et al., 2002; Hayat et al., 2007).

The haematological characteristics as a result of arsenic toxicity have also been extensively studied in case of fishes. There are several reports on decrease of haematological parameters such as RBC counts, haematocrit (Ht), and haemoglobin (Hb). The striking decrease in RBC count was observed at the highest arsenic concentration regardless of temperature. Arsenic toxicity have also been demonstrated to be associated with bone marrow damage and arsenic-induced anaemia due to haemolysis of intravascular erythrocytes (Cockell et al., 1991; Carvalho and Fernandes, 2006; Ferrario et al., 2008).

Protein synthesis disorder due to decreased plasma proteins is associated to be the result of Arsenic accumulation in the liver (Lavanya et al., 2011). Kavitha et al. (2010) have elaborated the effect of arsenic on glucose metabolism due to changes in the cellular metabolism and metal complexes formation that ultimately affects the carbohydrate metabolism such as glucose, glycogen and lactate.

Fishes when exposed to arsenic for a longer period has been reported to develop lesions in the liver, gall bladder and kidney which further results in the damage of the hepatic and renal functions (Pedlar et al., 2002, Roy and Bhattacharya, 2006). In an experiment conducted by Pedlar et al. (2002), the feeding of lake whitefish (Coregonus clupeaformis) with arsenic resulted in histopathological alterations, inflammation and necrosis of the liver, gallbladder etc. Abdel-Hameid (2009) reported substantial increases in GOT and GPT of catfish (Clarias gariepinus), exposed to arsenic, and elevated levels of these parameters may reflect liver damage due to arsenic toxicity.

**Conclusion**

Arsenic in the environment can significantly affect aquatic organisms. It can accumulate in these organisms through processes such as solute absorption and dietary assimilation. Both biological and environmental factors affect arsenic absorption and assimilation. Inside the body, arsenic can change to another species. Many enzymes play an important role in the conversion of inorganic arsenic to less toxic organic forms in organisms from microorganisms to marine fish. However, many processes such as AsB synthesis and degradation pathways are still not fully understood. Elimination is another important factor in determining arsenic bioaccumulation. Through this review, we tried to understand the mechanisms of arsenic intake, its biotransformation, adverse effects on aquatic organisms and the whole environment. Arsenic contamination has become an environmental hazard and strategies must be implemented to control it. Effective legislation, guidelines and regular monitoring must be prioritized to combat this environmental menace. If the pollution is not controlled, it can lead to serious complications in the future due to the harmful effects of such heavy metals. Monitoring exposure and release of heavy metals and implementing measures to reduce further exposure to the environment are critical to addressing this problem. Cooperation at the national and international levels is essential to develop effective strategies to prevent the negative effects of heavy metal toxicity.
References


