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Review Article

A systematic review on arsenic toxicity and its impacts on fish species

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Arsenic is found globally in both freshwater and marine ecosystems, posing a threat to aquatic life. It exists in organic and inorganic forms, with the inorganic variant being more toxic. While most water bodies contain inorganic arsenic, organic forms are often prevalent in fish. Both natural and human activities contribute to arsenic contamination in water. The bioaccumulation of arsenic and its transfer through the aquatic food chain highlight its significance as an environmental concern. Prolonged exposure to low levels of arsenic in fish can lead to accumulation, impacting higher trophic levels, including larger fish and humans who consume them. This review aims to enhance our understanding of arsenic sources, its bioaccumulation, food chain transfer, and effects on fish health. It underscores the urgent need to tackle arsenic contamination in water bodies to protect aquatic ecosystems and the well-being of wildlife and human populations reliant on these resources.

Keywords: *arsenic, fish health, bioaccumulation, biotransformation, arsenic speciation*

Introduction

Arsenic threatens aquatic life in both freshwater and marine ecosystems. It exists in organic, inorganic forms, and arsine gas. While most water bodies contain mainly inorganic arsenic, fish are believed to predominantly have organic arsenic (Chandel et al., 2024). In both marine and freshwater environments, inorganic arsenic (iAs) is predominant, but aquatic organisms convert it to methyl and organoarsenic species (Rahman et al., 2012). Despite being well-known as a cancer-causing agent, inorganic arsenic is considered much more toxic than its organic counterpart and it can be found naturally in water, rock and soil (Briffa et al., 2020). Whereas considerable knowledge exists about marine organisms, less is known about freshwater organisms. Arsenic toxicity in aquatic organisms depends on its concentration and speciation. Fish are essential to aquatic ecosystems and help mobilise arsenic. They contribute to the food chain and provide protein for human diets. Some fish serve as bioindicators of aquatic pollutants (Kumar et al., 2018; Sharma et al., 2018). Arsenic can accumulate in fish through the gills, skin, or by consuming prey. Studies have examined how different fish species affect arsenic toxicity from various sources (Magellan et al., 2014). Recent years have seen an increase in arsenic contamination of aquatic environments, primarily due to anthropogenic sources, causing adverse effects on aquatic biota. Thus, arsenic has gained global recognition as a leading toxin and is deposited in different tissues with the greatest rate being muscles>liver>gill (Srivastava & Prakash, 2019). So, the main objective of this study is to provide a comprehensive understanding of arsenic toxicity in fishes, highlighting the sources of arsenic in fishes and its toxicological effect on fishes.

Methodology

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Sarkis-Onofre et al., 2021). Relevant literature was retrieved from major

databases: Google Scholar, PubMed, and Scopus, encompassing studies published up to 2025. The search employed combinations of the following keywords: "Arsenic", "Fish health", "Bioaccumulation", "Biotransformation", and "Arsenic speciation" using Boolean operators (AND/OR) to ensure comprehensive coverage. Studies were included in the review if they met the following criteria: published in renowned peer-reviewed journals, articles focused on experimental or observational research related to arsenic toxicity in aquatic organisms, particularly fish, bioaccumulation, biotransformation, or arsenic speciation in aquatic environments and Available in English. Documents such as Erratum, editorials, letters to the editor, duplicate articles, and conference proceedings were excluded from the review (Shekhar et al., 2024).
Data identified: 1200
Inclusion: 900
Exclusion: 300
Included: 64

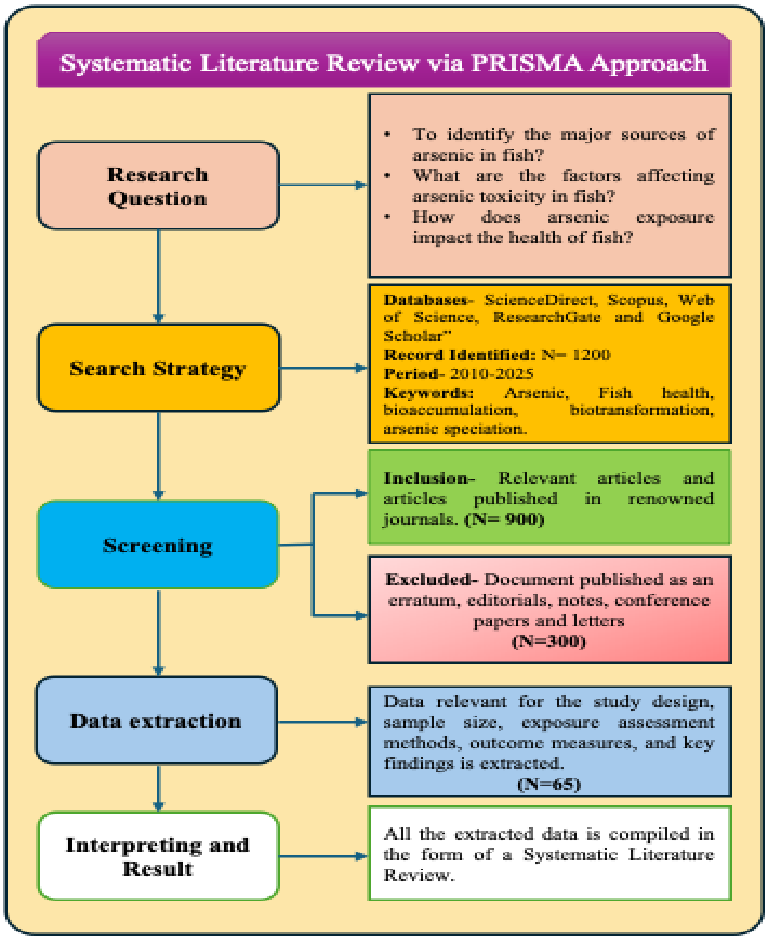

Figure 1. Systematic literature review framework using the PRISMA methodology (Shekhar et al., 2025)

Sources of arsenic in fish

Arsenic can enter the environment through natural processes, such as leaching from bedrock aquifers and volcanic emissions, as well as through human activities, including industrial operations and the use of fertilizers (Babich & Van Beneden, 2019). It exists in four distinct oxidative states: arsine (As-III), arsenate (AsV), arsenite (AsIII) and elemental arsenic (As). Among these arsenate and arsenite are the dominant forms found in the aquatic environment as they are highly soluble in water (Byeon et al., 2021). Fishes are more susceptible to arsenic contamination because of their direct contact with water and sediments which serve as reservoirs of heavy metal contamination including arsenic (Ali et al., 2021). Constant exposure of arsenic to fish changes their morphology, behavior, growth pattern, histopathology and even their molecular mechanisms (Rabbane et al., 2022).

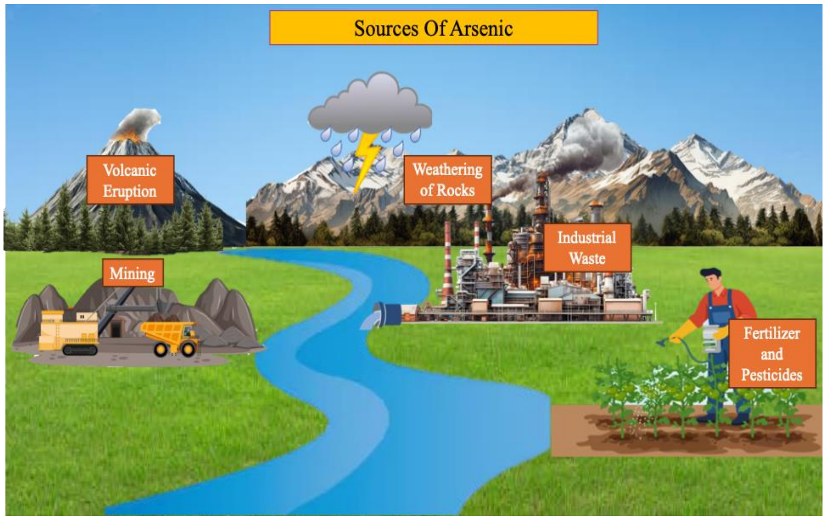

Figure 2. Major natural and anthropogenic sources of arsenic in aquatic

(i). Natural sources

Arsenic is present in ore minerals, with arsenopyrite being the most common ore mineral, followed by orpiment and realgar. These minerals typically form in Earth's crust under high temperature and pressure (Smedley & Kinniburgh, 2002). These mineral ores are prone to oxidation, releasing arsenic into the sediments. Further reductive dissolution of arsenic-bearing Fe(III) oxides and sulfide oxidation releases arsenic into groundwater, which subsequently enters surface water. The mobilisation of arsenic in groundwater is influenced by its adsorption on metal hydroxides and clay minerals (Herath et al., 2016). Volcanic eruption and geothermal emissions also release arsenic in gaseous form as well as matter which get transported over long distance and sooner or later it enters in aquatic environment by way of precipitation (Bundschuh et al., 2020). Arsenic and other trace elements are released when they meet water, and once they are released, they interact with sediments (Bia et al., 2014). Research reveals that arsenic contamination is strongly correlated with the active plate tectonics, magmatism and hydrothermal activity. Microbial activity also increases the arsenic level by facilitating the oxidation and reduction of arsenic minerals (Masuda, 2018). Arsenic is absorbed from (hydro)oxides (such as iron, aluminum, and manganese oxides) and released from geothermal water because of natural geochemical processes. There are also cases of arsenic leaching from sulfides, oxidation of arsenic-bearing sulphides, and desorption from (hydro)oxides that contain arsenic (Malik et al., 2023).

(ii). Anthropogenic sources

Arsenic can be released into the environment by a number of human activities, including as the mining and smelting of nonferrous metals, the processing of fossil fuels, combustion, wood preservation, the manufacture and use of pesticides in agriculture, and the dumping and incineration of industrial and municipal trash (Alonso et al., 2020; Nasser et al., 2020; Slimak & Delos, 1983). Coal combustion also release arsenic in aquatic environment. Volatilization of arsenic during coal combustion is controlled by temperature, composition of coal and availability of elements such as calcium, sulphur and chlorine. Later on after combustion it transform into solid forms and capture in fly ash and from here it enter in aquatic environment (Wang et al., 2018). Although the arsenic based pesticides are banned and not widely used in agriculture because of their harmful impacts but studies reveals that historic use of pesticides contributes to legacy pesticide residue in soil and is considered a potential nonpoint source of arsenic contamination (Higgins et al., 2021). Incineration of solid waste that contains chlorine facilitates the formation of volatile arsenic chlorides. Rain washes off arsenic from the atmosphere and results in its deposition in nearby waterbodies (Shen et al., 2018). Industrial byproducts also affect the leaching and mobility of arsenic. Various byproducts such as waste gypsum boards, steel abrasive and other residues are mixed with soil and thermally treated. Results show that thermal treatment negatively affects arsenic-contaminated soil as it increases arsenic leaching (Kumpiene et al., 2016). Arsenic enters the groundwater and water bodies in its most soluble forms through runoff and leaching (Pongratz, 1998).

Factors affecting arsenic toxicity in fishes

Several biological and environmental factors impact the bioaccumulation of arsenic in aquatic species. In addition to environmental factors, including phosphorus levels, pH, salinity, and the concentration of dissolved organic matter (DOM), these also include the species, size, and age of the organisms (Kamboj et al., 2022; Tomar et al., 2022). Furthermore, the rate at which arsenic is absorbed from food depends on several variables, including species density, ambient pH, gut environment, gut transit length, the presence of iron oxides, and the nature of the food or living prey. Furthermore, the organism gets rid of arsenic through physiological functions such molting, excretion, and reproduction (Zhang et al., 2022).

(i). Arsenic speciation in fish

The level of oxidation and both its forms namely inorganic and organic decides the toxicity of Arsenic in the aquatic organisms (Canivet et al., 2001). Arsenic contamination of fish occurs in several forms, including arsenobetaine (AsB), ascorbic acid (AsIII), arsenite (AsV), monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA) (Hoy et al., 2023). Living organisms excrete inorganic Arsenic via metabolites like arsenocholine (AsC) and arsenobetaine (AsB), which are less toxic than organic Arsenic (Camacho et al., 2022). Inorganic Arsenic accumulates more rapidly in tissues than organic Arsenic, therefore, it accumulates in tissues more quickly (Byeon et al., 2021). Two most common inorganic arsenic forms are trivalent meta-arsenite (As^{3+}) and pentavalent arsenate (As^{5+}) (Ganie et al., 2023).

(i). Biotic and abiotic factors

Ardini et al. (2019) state that various biotic and abiotic elements, such as exposure duration, arsenic speciation, water temperature, pH levels, organic content, phosphate concentration, suspended particles, and the presence of other chemicals and toxins influence toxicity and related factors. Anthropogenic and geogenic sources are the two main ways that arsenic enters water bodies. Although gaseous arsenic can also enter water bodies through precipitation, it is added to surface waters by direct discharge. Arsenic present in soil and water can leach into groundwater, impacting aquatic life. Research indicates that the median survival time of fish typically decreases with rising temperature and arsenic concentration. Although different arsenic species have varied origins and levels of toxicity, it is essential to identify them when researching exposure to arsenic (Kretsinger et al., 2013). Hazardous inorganic arsenic is changed by the biomethylation process into less dangerous pentavalent forms such dimethylarsenate (DMAv), trimethylarsine (DMAIII) and monomethylarsonate (MMAv). Nevertheless, biomethylation produces dimethylarsenite (DMAIII), trimethylarsonic oxide (TMAOv), and monomethylarsenite (MMAIII), which are more hazardous than inorganic arsenic (Neff, 1997).

(iii). Bioaccumulation

In fish, arsenic bioaccumulates mainly in the retina, liver, and kidney tissues, leading to a reduction in various antibodies within the fish's immune system. When metalloid arsenic accumulates to toxic levels in these tissues, it can ultimately result in several diseases (Kumar et al., 2023). The patterns of distribution and accumulation of toxic metals in fish tissues are influenced by their rates of absorption and excretion. When these metals accumulate to significantly high levels, they can lead to various physiological issues and even death (Kalay & Canli, 2000). Arsenic bioaccumulation includes uptake, assimilation, biotransformation, and elimination. Accumulation levels in aquatic organisms are influenced by biological, physicochemical, and environmental factors (Thomas, 2007).

Toxicological effects of arsenic on fish

Arsenic is harmful to fish, mainly by resulting in oxidative stress, storing in their bodies and interrupting their metabolism and body functions (Sevcikova et al., 2011). In fish, the way toxic metals accumulate and are distributed in their tissues relies on their uptake and elimination rates and can result in several health issues and mortality when levels become very high (Kumari et al., 2016). Even a very small amount of some toxins can change the way fish behave by making them less sensitive to their surroundings. Many irregular behaviours, for example erratic movement, rapid opercula movement, leaving the test medium, swimming to one side and losing balance were seen in fish exposed to sodium arsenate (Chételat et al., 2019). Because of these harmful effects, fish are harmed, aquatic ecosystems can be threatened, and food safety is put at risk. Information on how arsenic affects fish is summarised in Table 1.

Table 1. Arsenic effects on aquatic organisms with associated impacts

Affected organisms	Impact on organisms	Reference
Danio rerio	Increased eye size, Hinder retinogenesis, Hepatotoxicity	(Babich & Van Beneden, 2019)
Oryzias latipes	Bioaccumulation Biotransformation Altered muscle development	(Rahman et al., 2012; Gaworecki et al., 2011)

Clarias batrachus	Altered epidermal histomorphology Behavioral stress, Degeneration of club cells	(Khan et al., 2022; Sahu & Kumar, 2021)
Hetero pneustisfossilis L.	Hypo- and hyperpigmentation	(Singh et al., 2008)
Oreochromis mossambicus	Desquamation Edema and necrosis Aneurism and hyperplasia of epithelial cells in gills	(Ardini et al., 2019)
Tilapia mossambica	Nuclear hypertrophy Irregularly shaped nuclei	(Kretsinger et al., 2013)
Channa punctatus	Degenerative reactions in hepatopancreas, Oxidative stress	(Orloff et al., 2009)
Catla catla L. *rohita* *Cirrhinus mrigala*	Hyperglycemic impact	(Pedlar et al., 2002)
Oryctolaguscuniculus	Decreased hemoglobin levels	(Celino et al., 2009)
Gambusia holbrooki	Behavioral changes (more aggressive)	(Magellan et al., 2014)
Mystus vittatus	Decreased in alkaline and acid phosphatases level	(Prakesh et al., 2020)
Fundulus heteroclitus	Reduced muscle fibers	(D'Amico et al., 2013)
Salmo trutta	Oxidative stress	(Greani et al., 2017)
L. *rohita*	Cause hematology, Immunobiochemical and histological shortcomings	(Raza et al., 2021)
Mystus vittatus	Metabolism of organic molecules was affected.	(Srivastava & Prakash, 2019)
Sparus aurata	Cause histopathological alterations in liver	(Guardiola et al., 2013)
Sperata sarwari	Bioaccumulation in kidney	(Aamir, 2020)
Carassius auratus	Oxidative stress Alteration of antioxidant system	(Guardiola et al., 2013)
Sebastes schlegelii	Bioaccumulation and alteration in antioxidant enzymes	(Kim & Kang, 2015)
Cyprinus carpio	Negative impact on antioxidant enzymes	(Altikat et al., 2014)

Discussion

When fish are exposed to an arsenic-contaminated environment than it enters their body through multiple routes, including absorption by gills, skin and ingestion of contaminated water, sediments and dietary sources. Once it enters the bloodstream then it tends to accumulate in vital organs such as the liver, gills, kidneys, etc (Garai et al., 2021). Increased concentrations of these toxins in fish cause various kinds of physiological and biochemical problems. Mekkawy et al. (2020) exposes African catfish, *Clarias gariepinus* to levels of arsenic below lethal concentration (19.2 or 38.3 mg/L) caused serious changes in the blood and biochemical make up such as drop in RBC count, hematocrit, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH) and variations in white blood cells in the results. Changes in alkaline phosphatase, glucose, uric acid, creatinine, albumin, globulin and the albumin/globulin ratio due to arsenic exposure indicate that several organs were put under stress. Similar results were observed by Kumar & Banerjee (2016) when *Clarias batrachus* was exposed to sodium arsenite. Along with this decline in serum protein level were also observed, which indicates systemic toxicity with and physiological stress. Research shows that when *Danio rerio* fish are repeatedly exposed to arsenic and chromium, separately and combined, they suffer more abnormal nuclear changes in their red blood cells. Altered expression of base excision repair genes (ogg1, apex1, creb1, polb) and mismatch repair genes (mlh1, msh2, msh6) indicates DNA repair inhibition. A decrease in tumour suppressor genes was also observed, which promotes apoptosis, pointing to a higher risk of cancer (Kamila et al., 2025). Acute toxicity and its histopathological impacts on the gill and liver tissue of *Oreochromis mossambicus* was observed by Ahmed et al. (2013) Remarkable gill changes were noticed in the form of epithelial hyperplasia, lifted epithelium, accumulated fluid, lamellar fusions, ballooning, cell loss and tissue death, while the liver tissue revealed inflammation, jamming of the vessels, hepatocyte shrinkage, widened venules, watery swelling, dilation of the cells, spotty cell mortality and nuclear swell. *Dawkinsia tambraparniei* exposure to arsenic trioxide and sodium arsenite for 42 days, stress-responsive genes (Mt, p53 and SOD) in the brain, heart and liver express themselves differently. As_2O_3 raised p53 levels in brain tissue, but $NaAsO_2$ increased them in heart and liver which suggests that each tissue responded to the stress differently (Sakthivel et al., 2022). Behavioral changes were also observed in As exposed fishes such as increase in aggression, decrease in operculum movement along with reduction in food capturing capacity (Magellan et al., 2014).

Conclusion

Freshwater environments have very different arsenic levels because of their sources, availability, and chemical properties. There are a lot of arsenic inputs from land and other environmental factors that can cause high arsenic levels in estuaries and coastal waters. It has a lot of bad effects on aquatic organisms if exposed to arsenic and it leads to bioaccumulation. It serves as a call to action to take steps to protect our aquatic environments, preserve biodiversity, and ensure the welfare of future and present generations. Although studies on arsenic are many, we need more information about its continuous and moderate impacts, especially in important species of fish. Future work should choose to use genomics, transcriptomics and proteomics to help in discovering biomarkers for early detection. It will be necessary to examine how arsenic reacts with other pollutants and environmental changes related to climate. Apart from these, setting tougher environmental laws, managing wastewater better and educating people are vital actions to reduce arsenic pollution. Efforts involving science, technology and policies must be combined to protect aquatic environments from the lasting harm of arsenic. Arsenic's Silent Assault on Fish Health serves as a call to action. We can only combat arsenic's silent assault through collaboration and a shared commitment to sustainability, to provide a healthier and more resilient aquatic ecosystem by working together.

Author contributions

All the listed authors have contributed significantly to the paper and are eligible for authorship. Parul Sharma and Priya Ranot collected the literature and wrote the manuscript. Mansi Raingnia and Parul Sharma had proposed the systematic methodology, Amit Kumar Sharma revised the manuscript and formatted it, suggested the idea and designed the study and supervised, edited, and approved the final version.

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Conflict of interest

The author declares no conflict of interest. The manuscript has not been submitted for publication in other journal.

Ethics approval

Not applicable.

AI tool usage declaration

The authors did not use any AI and related tools to write this manuscript.

References

Aamir, S. (2020). Heavy metals (Cadmium, Mercury and Arsenic) accumulation in different organs of *Sperata sarwari* collected from Indus River, Head Taunsa, Dera Ghazi Khan, Punjab, Pakistan. *Pure and Applied Biology*, *9*(2). https://doi.org/10.19045/bspab.2020.90153

Ahmed, M. K., Habibullah-Al-Mamun, M., Parvin, E., Akter, M. S., & Khan, M. S. (2013). Arsenic induced toxicity and histopathological changes in gill and liver tissue of freshwater fish, tilapia (*Oreochromis mossambicus*). *Experimental and Toxicologic Pathology*, *65*(6), 903–909. https://doi.org/10.1016/j.etp.2013.01.003

Ali, M. M., Ali, M. L., Rakib, M. R. J., Islam, M. S., Habib, A., Hossen, S., Ibrahim, K. A., Idris, A. M., & Phoungthong, K. (2021). Contamination and ecological risk assessment of heavy metals in water and sediment from hubs of fish resource river in a developing country. *Toxin Reviews*, *41*(4), 1253-1268. https://doi.org/10.1080/15569543.2021.2001829

Alonso, D. L., Pérez, R., Okio, C. K., & Castillo, E. (2020). Assessment of mining activity on arsenic contamination in surface water and sediments in southwestern area of Santurbán paramo, Colombia. *Journal of Environmental Management*, *264*, 110478. https://doi.org/10.1016/j.jenvman.2020.110478

Altikat, S., Uysal, K., Kuru, H. I., Kavasoglu, M., Ozturk, G. N., & Kucuk, A. (2014). The effect of arsenic on some antioxidant enzyme activities and lipid peroxidation in various tissues of mirror carp (*Cyprinus carpio carpio*). *Environmental Science and Pollution Research*, *22*(5), 3212–3218. https://doi.org/10.1007/s11356-014-2896-6

Ardini, F., Dan, G., & Grotti, M. (2019). Arsenic speciation analysis of environmental samples. *Journal of Analytical Atomic Spectrometry*, *35*(2), 215–237. https://doi.org/10.1039/c9ja00333a

Babich, R., & Van Beneden, R. J. (2019). Effect of arsenic exposure on early eye development in zebrafish (*Danio rerio*). *Journal of Applied Toxicology*, *39*(6), 824–831. https://doi.org/10.1002/jat.3770

Bia, G., Borgnino, L., Gaiero, D., & García, M. (2014). Arsenic-bearing phases in South Andean volcanic ashes: Implications for As mobility in aquatic environments. *Chemical Geology*, *393–394*, 26–35. https://doi.org/10.1016/j.chemgeo.2014.10.007

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Bundschuh, J., Armienta, M. A., Morales-Simfors, N., Alam, M. A., López, D. L., Quezada, V. D., Dietrich, S., Schneider, J., Tapia, J., Sracek, O., Castillo, E., Parra, L. M., Espinoza, M. A., Guilherme, L. R. G., Sosa, N. N., Niazi, N. K., Tomaszewska, B., Allende, K. L., Bieger, K., . . . Ahmad, A. (2020). Arsenic in Latin America: New findings on source, mobilization and mobility in human environments in 20 countries based on decadal research 2010-2020. *Critical Reviews in Environmental Science and Technology*, *51*(16), 1727-1865. https://doi.org/10.1080/10643389.2020.1770527

Byeon, E., Kang, H., Yoon, C., & Lee, J. (2021). Toxicity mechanisms of arsenic compounds in aquatic organisms. *Aquatic Toxicology*, *237*, 105901. https://doi.org/10.1016/j.aquatox.2021.105901

Camacho, J., De Conti, A., Pogribny, I. P., Sprando, R. L., & Hunt, P. R. (2022). Assessment of the effects of organic vs. inorganic arsenic and mercury in *Caenorhabditis elegans*. *Current Research in Toxicology*, *3*, 100071. https://doi.org/10.1016/j.crtox.2022.100071

Canivet, V., Chambon, P., & Gibert, J. (2001). Toxicity and bioaccumulation of arsenic and chromium in epigean and hypogean freshwater macroinvertebrates. *Archives of Environmental Contamination and Toxicology*, *40*(3), 345–354. https://doi.org/10.1007/s002440010182

Celino, F. T., Yamaguchi, S., Miura, C., & Miura, T. (2009). Arsenic inhibits in vitro spermatogenesis and induces germ cell apoptosis in Japanese eel (*Anguilla japonica*). *Reproduction*, *138*(2), 279–287. https://doi.org/10.1530/rep-09-0167

Chandel, M., Sharma, A. K., Thakur, K., Sharma, D., Brar, B., Mahajan, D., Kumari, H., Pankaj, P. P., & Kumar, R. (2024). Poison in the water: Arsenic's silent assault on fish health. *Journal of Applied Toxicology*, *44*(9), 1282–1301. https://doi.org/10.1002/jat.4581

Chételat, J., Cott, P. A., Rosabal, M., Houben, A., McClelland, C., Rose, E. B., & Amyot, M. (2019). Arsenic bioaccumulation in subarctic fishes of a mine-impacted bay on Great Slave Lake, Northwest Territories, Canada. *PLoS ONE*, *14*(8), e0221361. https://doi.org/10.1371/journal.pone.0221361

D'Amico, A. R., Gibson, A. W., & Bain, L. J. (2013). Embryonic arsenic exposure reduces the number of muscle fibers in killifish (*Fundulus heteroclitus*). *Aquatic Toxicology*, *146*, 196–204. https://doi.org/10.1016/j.aquatox.2013.11.010

Ganie, S. Y., Javaid, D., Hajam, Y. A., & Reshi, M. S. (2023). Arsenic toxicity: sources, pathophysiology and mechanism. *Toxicology Research*, *13*(1). https://doi.org/10.1093/toxres/tfad111

Garai, P., Banerjee, P., Mondal, P., Ch, N., & Saha, R. (2021). Effect of heavy metals on fishes: toxicity and bioaccumulation. *Journal of Clinical Toxicology*, 1–10.

Gaworecki, K. M., Chapman, R. W., Neely, M. G., D'Amico, A. R., & Bain, L. J. (2011). Arsenic exposure to killifish during embryogenesis alters muscle development. *Toxicological Sciences*, *125*(2), 522–531. https://doi.org/10.1093/toxsci/kfr302

Greani, S., Lourkisti, R., Berti, L., Marchand, B., Giannettini, J., Santini, J., & Quilichini, Y. (2017). Effect of chronic arsenic exposure under environmental conditions on bioaccumulation, oxidative stress, and antioxidant enzymatic defenses in wild trout Salmo trutta (Pisces, Teleostei). *Ecotoxicology*, *26*(7), 930–941. https://doi.org/10.1007/s10646-017-1822-3

Guardiola, F., Gónzalez-Párraga, M., Cuesta, A., Meseguer, J., Martínez, S., Martínez-Sánchez, M., Pérez-Sirvent, C., & Esteban, M. (2013). Immunotoxicological effects of inorganic arsenic on gilthead seabream (*Sparus aurata* L.). *Aquatic Toxicology*, *134–135*, 112–119. https://doi.org/10.1016/j.aquatox.2013.03.015

Herath, I., Vithanage, M., Bundschuh, J., Maity, J. P., & Bhattacharya, P. (2016). Natural arsenic in global groundwaters: distribution and geochemical triggers for mobilization. *Current Pollution Reports*, *2*(1), 68–89. https://doi.org/10.1007/s40726-016-0028-2

Higgins, M. A., Metcalf, M. J., & Robbins, G. A. (2021). Nonpoint source arsenic contamination of soil and groundwater from legacy pesticides. *Journal of Environmental Quality*, *51*(1), 66–77. https://doi.org/10.1002/jeq2.20304

Hoy, K. S., Davydiuk, T., Chen, X., Lau, C., Schofield, J. R. M., Lu, X., Graydon, J. A., Mitchell, R., Reichert, M., & Le, X. C. (2023). Arsenic speciation in freshwater fish: challenges and research needs. *Food Quality and Safety*, *7*. https://doi.org/10.1093/fqsafe/fyad032

Kalay, M., & Canli, M. (2000). *Elimination of Essential (Cu, Zn) and Non-Essential (Cd, Pb) Metals from Tissues of a Freshwater Fish Tilapia zilli*. TÜBİTAK Academic Journals. https://journals.tubitak.gov.tr/zoology/vol24/iss4/11

Kamboj, V., Kamboj, N., Sharma, A. K., & Bisht, A. (2022). Fish Diversity Associated with Environmental Parameters in Impacted Area of Ganga River, India. *Proceedings of the National Academy of Sciences India Section B Biological Sciences*, *93*(1), 79–90. https://doi.org/10.1007/s40011-022-01393-9

Kamila, S., Dey, K. K., Das, T., & Chattopadhyay, A. (2025). Mixture effects of arsenic and chromium on erythrocytic nuclear abnormalities and expression of DNA repair, tumor suppressor and apoptotic genes in liver of zebrafish. *Environmental Toxicology and Pharmacology*, *114*, 104640. https://doi.org/10.1016/j.etap.2025.104640

Khan, M. I., Ahmad, M. F., Ahmad, I., Ashfaq, F., Wahab, S., Alsayegh, A. A., Kumar, S., & Hakeem, K. R. (2022). Arsenic Exposure through Dietary Intake and Associated Health Hazards in the Middle East. *Nutrients*, *14*(10), 2136. https://doi.org/10.3390/nu14102136

Kim, J., & Kang, J. (2015). The arsenic accumulation and its effect on oxidative stress responses in juvenile rockfish, Sebastes schlegelii, exposed to waterborne arsenic (As3+). *Environmental Toxicology and Pharmacology*, *39*(2), 668–676. https://doi.org/10.1016/j.etap.2015.01.012

Kretsinger, R. H., Uversky, V. N., & Permyakov, E. A. (2013). *Encyclopedia of Metalloproteins*. https://bwtest.upwr.edu.pl/info/book/UPWr4b359cbe3fea4eb3b062fcae2d310bbe?ps=20&title=Publikacja%2B%25E2%2580%2593%2BEncyclopedia%2Bof%2BMetalloproteins%2B%25E2%2580%2593%2BUniwersytet%2BPrzyrodniczy%2Bwe%2BWroc%25C5%2582awiu+title&lang=pl&pn=1

Kumar, N., Chandan, N. K., Bhushan, S., Singh, D. K., & Kumar, S. (2023). Health risk assessment and metal contamination in fish, water and soil sediments in the East Kolkata Wetlands, India, Ramsar site. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-28801-y

Kumar, R., & Banerjee, T. (2016). Arsenic induced hematological and biochemical responses in nutritionally important catfish *Clarias batrachus* (L.). *Toxicology Reports*, *3*, 148–152. https://doi.org/10.1016/j.toxrep.2016.01.001

Kumar, V., Malik, D. S., & Sharma, A. K. (2018). Study on distribution pattern of benthic diversity in relation to water quality of river Ganga and its tributaries. *Journal of Emerging Technologies and Innovative Research*, *5*(5), 88-103.

Kumari, B., Kumar, V., Sinha, A. K., Ahsan, J., Ghosh, A. K., Wang, H., & DeBoeck, G. (2016). Toxicology of arsenic in fish and aquatic systems. *Environmental Chemistry Letters*, *15*(1), 43–64. https://doi.org/10.1007/s10311-016-0588-9

Kumpiene, J., Nordmark, D., Hamberg, R., Carabante, I., Simanavičienė, R., & Aksamitauskas, V. Č. (2016). Leaching of arsenic, copper and chromium from thermally treated soil. *Journal of Environmental Management*, *183*, 460–466. https://doi.org/10.1016/j.jenvman.2016.08.080

Magellan, K., Barral-Fraga, L., Rovira, M., Srean, P., Urrea, G., García-Berthou, E., & Guasch, H. (2014). Behavioural and physical effects of arsenic exposure in fish are aggravated by aquatic algae. *Aquatic Toxicology*, *156*, 116–124. https://doi.org/10.1016/j.aquatox.2014.08.006

Malik, A., Khalid, F., Hidait, N., Anjum, K. M., Mahad, S., Razaq, A., Azmat, H., & Majeed, M. B. B. (2023). Arsenic toxicity in fish: Sources and impacts. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.1001468

Masuda, H. (2018). Arsenic cycling in the Earth's crust and hydrosphere: interaction between naturally occurring arsenic and human activities. *Progress in Earth and Planetary Science*, *5*(1). https://doi.org/10.1186/s40645-018-0224-3

Mekkawy, I. A., Mahmoud, U. M., Moneeb, R. H., & Sayed, A. E. H. (2020). Significance Assessment of Amphora coffeaeformis in Arsenic-Induced Hemato- Biochemical Alterations of African Catfish (*Clarias gariepinus*). *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00191

Nasser, N. A., Patterson, R. T., Roe, H. M., Galloway, J. M., Falck, H., & Sanei, H. (2020). Use of Arcellinida (*Testate lobose amoebae*) arsenic tolerance limits as a novel tool for biomonitoring arsenic contamination in lakes. *Ecological Indicators*, *113*, 106177. https://doi.org/10.1016/j.ecolind.2020.106177

Neff, J. M. (1997). Ecotoxicology of arsenic in the marine environment. *Environmental Toxicology and Chemistry*, *16*(5), 917–927. https://doi.org/10.1002/etc.5620160511

Orloff, K., Mistry, K., & Metcalf, S. (2009). Biomonitoring for environmental exposures to arsenic. *Journal of Toxicology and Environmental Health Part B*, *12*(7), 509–524. https://doi.org/10.1080/10937400903358934

Pedlar, R., Ptashynski, M., Wautier, K., Evans, R., Baron, C., & Klaverkamp, J. (2002). The accumulation, distribution, and toxicological effects of dietary arsenic exposure in lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*). *Comparative Biochemistry and Physiology Part C Toxicology & Pharmacology*, *131*(1), 73–91. https://doi.org/10.1016/s1532-0456(01)00281-2

Pongratz, R. (1998). Arsenic speciation in environmental samples of contaminated soil. *The Science of the Total Environment*, *224*(1–3), 133–141. https://doi.org/10.1016/s0048-9697(98)00321-0

Prakash, A. K. V. S. (2020). Effect of arsenic on enzyme activity of a fresh water cat fish, Mystus vittatus. *Liver*, *10*(20), 30

Rabbane, M. G., Kabir, M. A., Habibullah-Al-Mamun, M., & Mustafa, M. G. (2022). Toxic Effects of Arsenic in Commercially Important Fish Rohu Carp, *Labeo rohita* of Bangladesh. *Fishes*, *7*(5), 217. https://doi.org/10.3390/fishes7050217

Rahman, M. A., Hasegawa, H., & Lim, R. P. (2012). Bioaccumulation, biotransformation and trophic transfer of arsenic in the aquatic food chain. *Environmental Research*, *116*, 118–135. https://doi.org/10.1016/j.envres.2012.03.014

Raza, M. A., Kanwal, Z., Shahid, A., Fatima, S., Sajjad, A., Riaz, S., & Naseem, S. (2021). Toxicity Evaluation of Arsenic Nanoparticles on Growth, Biochemical, Hematological, and Physiological Parameters of *Labeo rohita* Juveniles. *Advances in Materials Science and Engineering*, *2021*(1). https://doi.org/10.1155/2021/5185425

Sahu, G., & Kumar, V. (2021). The Toxic Effect of Fluoride and Arsenic on Behaviour and Morphology of Catfish (*Clarias batrachus*). *Nature Environment and Pollution Technology*, *20*(1), 371–375. https://doi.org/10.46488/nept.2021.v20i01.043

Sakthivel, S., Dhanapal, A. R., Munisamy, V. S., Nasirudeen, M. P., Selvaraj, V., Velu, V., & Gurusamy, A. (2022). Molecular characterization and expression profiling of arsenic mediated stress-responsive genes in Dawkinsia tambraparniei (Silas, 1954). *Journal of Applied Biology & Biotechnology*. https://doi.org/10.7324/jabb.2023.117527

Sarkis-Onofre, R., Catalá-López, F., Aromataris, E., & Lockwood, C. (2021). How to properly use the PRISMA Statement. *Systematic Reviews*, *10*(1). https://doi.org/10.1186/s13643-021-01671-z

Sevcikova, M., Modra, H., Slaninova, A., Svobodova, Z., & Faculty of Veterinary Hygiene and Ecology, University of Veterinary and Pharmaceutical Sciences, Brno, Czech Republic. (2011). Metals as a cause of oxidative stress in fish: a review. In *Veterinarni Medicina* (Vol. 56, pp. 537–546). http://vetmed.agriculturejournals.cz/pdfs/vet/2011/11/02.pdf

Sharma, A. K., Malik, D. S., & Bargali, H. (2018). Present status of fish diversity and population abundance of selected fish species in Bhagirathi River at Uttarakhand. *International journal of creative research thoughts*, *6*(1), 432-438

Shekhar, C., Khosya, R., Sharma, A. K., Thakur, K., Mahajan, D., Kumar, R., Kumar, S., & Sharma, A. K. (2025). A systematic review on health risks of water pollutants: classification, effects and innovative solutions for conservation. *Toxicology Research, 14*(1). https://doi.org/10.1093/toxres/tfaf014

Shekhar, C., Khosya, R., Thakur, K., Mahajan, D., Kumar, R., Kumar, S., & Sharma, A. K. (2024). A systematic review of pesticide exposure, associated risks, and Long-Term human health impacts. *Toxicology Reports, 13*, 101840. https://doi.org/10.1016/j.toxrep.2024.101840

Shen, F., Liu, J., Dong, Y., & Gu, C. (2018). Insights into the effect of chlorine on arsenic release during MSW incineration: An on-line analysis and kinetic study. *Waste Management*, *75*, 327–332. https://doi.org/10.1016/j.wasman.2018.01.030

Singh, A. K., & Banerjee, T. K. (2008). Toxic effects of sodium arsenate (Na2HAsO4x7H2O) on the skin epidermis of air-breathing catfish *Clarias batrachus* (L.). *Veterinarski Arhiv*, *78*(1), 73-88

Slimak, M., & Delos, C. (1983). Environmental pathways of exposure to 129 priority pollutants. *Journal of Toxicology Clinical Toxicology*, *21*(1–2), 39–63. https://doi.org/10.3109/15563658308990410

Smedley, P., & Kinniburgh, D. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry*, *17*(5), 517–568. https://doi.org/10.1016/s0883-2927(02)00018-5

Srivastava, N. K., & Prakash, S. (2019). Effect of Zinc on the Histopathology of Gill, Liver and Kidney of Fresh Water Catfish, *Clarias batrachus* (Linn.). *International Journal of Biological Innovations*, *01*(01), 08–13. https://doi.org/10.46505/ijbi.2019.1102

Thomas, D. J. (2007). Molecular processes in cellular arsenic metabolism. *Toxicology and Applied Pharmacology*, *222*(3), 365–373. https://doi.org/10.1016/j.taap.2007.02.007

Tomar, G., Malik, D. S., Sharma, A. K., Kamboj, V., & Kumar, V. (2022). Assessment of water quality and biodiversity status of Alaknanda River at Garhwal, Uttarakhand: a case study. In *Springer proceedings in earth and environmental sciences* (pp. 121–136). https://doi.org/10.1007/978-3-031-05335-1_8

Wang, C., Liu, H., Zhang, Y., Zou, C., & Anthony, E. J. (2018). Review of arsenic behavior during coal combustion: Volatilization, transformation, emission and removal technologies. *Progress in Energy and Combustion Science*, *68*, 1–28. https://doi.org/10.1016/j.pecs.2018.04.001

Zhang, W., Miao, A. J., Wang, N. X., Li, C., Sha, J., Jia, J., ... & Ok, Y. S. (2022). Arsenic bioaccumulation and biotransformation in aquatic organisms. *Environment International*, *163*, 107221. https://doi.org/10.1016/j.envint.2022.107221