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Arsenic in Water (Ground, Surface), Accumulation in the Food Chain and their Impact on Human: A Review 2020 - 2024

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Abstract: ***Arsenic a non - essential natural toxic metalloid, the 20th most abundant element in the earth's crust enters the environment due to geothermal activities, hydrological factors and anthropogenic activities. Arsenic due to its high water solubility and easy bioaccumulation in ecological matrices became toxic even at a deficient concentration. In the environmental matrices the inorganic forms As (III) and As (V) exists in water bodies i. e. ocean, rivers, lakes, ponds, and groundwater while in aquatic organisms it also exists in the organic form monomethyl arsenic acid (MMA); dimethyl arsenic acid (DMA), the inorganic arsenic is more toxic than organic one. Globally the ground water which due to geogenic sources contains higher concentrations of arsenic (ug to mg/L) impacts the health of approximately 220 million people mainly in the South Asian countries (India, Bangladesh, Pakistan, Nepal, and Afghanistan) and Vietnam, Mexico, Indonesia, Philippines, and Cambodia. In the food chain accumulation of arsenic is due to irrigation by arsenic - contaminated water, use of arsenic - containing fertilizers and manures. Aquatic animals including fish and seafood accumulate arsenic via contaminated water and their food. Arsenic accumulation retards the photosynthesis process in the plants, retards the root size and plant growth. Accumulation of arsenic in aquatic animals, and fish alters their growth, behaviour, development and fertility by affecting gill, liver, kidney, gastrointestinal tract and enzymatic activities. The accumulation of arsenic in humans is via the food chain (cereals, vegetables, fruits, fish, seafood and drinking water). Worldwide rice is the crop which accumulates the maximum arsenic in all the cereals followed by wheat. The root part of plants accumulates more arsenic than shoots or leaves. Human exposure/accumulation/to arsenic not only causes skin, bladder, lung, kidney and gastric cancer but also negatively impacts the endocrine system. In this review concentrations of arsenic in water and food reported from 2020 - 2024 globally are compiled. The negative impact of arsenic accumulation/exposure to plants, aquatic animals, seafood and humans is also documented in this review. This study will help policymakers and stakeholders to draft such policies which can reduce the incidence of arsenic poisoning.***

Keywords: Arsenic, Water, Human, Plants, Fish

1. Introduction

Arsenic (As) which is called a king of pollutants is the 20th most abundant element in Earth's crust (the concentration of arsenic in Earth's crust is 1.8ppm). Arsenic is a ubiquitous metalloid (which shows both metallic and non - metallic properties), detected in more than 240 different minerals of the environment, in the form of sulfides, sulfosalts, arsenates, and arsenites. Arsenic in organic and inorganic forms is found naturally in the lithosphere, hydrosphere, atmosphere, and biosphere [1]. The inorganic forms of arsenic in the environment are arsenite (AsIII) and arsenate (As V) while organic forms are monomethyl arsenic acid (MMA); dimethyl arsenic acid (DMA), arsenobetaine, arsenocholine etc., the inorganic forms are more toxic than organic form. Due to high industrial applications an arsenic - free environment is not feasible, the metalloid is used in semiconductors, cosmetics, alloys, batteries, glass industry, fertilizers, pesticides, fireworks and medicines [2]. As per the report in 2023, 60, 000 metric tons of arsenic were produced globally and Peru alone contributed about 50%. The literature survey denotes that due to high industrial application and the presence of arsenic - containing rocks, the metalloid arsenic is present in all the compartments of the environment i. e. groundwater, river water, pond water, canal water, seawater, air, aquatic animals including fish. Due to global industrial development and population growth, the demand for uncontaminated drinking water is increasing. In the older days when the surface water was not contaminated citizenry consumed surface water. So, to provide safe drinking water to 7.8 billion people groundwater has been extensively utilized, but the quality of the groundwater has deteriorated due to contamination by human - made substances and geochemical reactions by aquifer recharge. Groundwater of the Asia, Africa, North and South America, Europe and Oceania continents, contains arsenic beyond their permissible limit. The groundwater of the countries USA, China, India, Bangladesh, Taiwan, Mexico, Mongolia, Vietnam, Indonesia, Afghanistan, Nepal, Pakistan, Philippines, Cambodia, and Chile contains arsenic from ug to mg/L [3 - 5]. As per estimation, approximately 220 million people globally are exposed to higher levels of arsenic and major sufferers are from Asia [6]. Ahmed et al. [7] has reported that out of the total 64 districts in Bangladesh, 62 districts' groundwater contains arsenic beyond permissible limits. Arsenic is considered a first class carcinogen to humans epidemiological and toxicological studies have confirmed that arsenic is directly related to skin, bladder, lung, kidney and gastric cancer [8] in humans. Acute exposure to arsenic in humans also causes skin damage, cardiovascular problems, multiple organ failure, reproductive toxicity, neurotoxicity and immunotoxicity.

In the present study, the accumulation of arsenic in surface water, groundwater, and river water, and their transfer to vegetables, crop plants, seafood, and milk is documented. The present study also outlines adverse health effects on humans.

2. Sources of Arsenic in the Environment

Arsenic in the environment (aquatic, air, soil) enters due to both natural and anthropogenic activities [9]. Arsenic from both sources due to weathering reactions, atmospheric changes and biological activity congregate in the environment.

2.1 Natural sources:

Rock weathering, forest fires, volcanic eruptions, Biogenic sources and wind - born soil particles are the natural sources of arsenic within the environment. The concentration of arsenic in groundwater depends on:

2.1.1 Geogenic Sources:
All three types of rocks i. e. igneous, metamorphic and sedimentary contain arsenic. Metamorphic and igneous rocks contain arsenic less than 5 mg/kg while sedimentary rocks contain 5 - 10mg/kg. Literature reveals that some coal samples contain 35000mg/kg of arsenic.

2.1.2 Geothermal activity: Geothermal fluid contains arsenic that is leached to groundwater from volcanic rock or molten lava. Hot springs of volcanogenic sources also contain high concentrations of arsenic (>4.8 mg/L of water).

2.1.3 Hydrogeological factors: Hydrological factors which influence arsenic concentration in the groundwater are the type of aquifers and the presence of other minerals.

2.1.4 Biogenic Sources: Biogenic sources involve the presence of living organisms i. e. (bacteria and other natural biological processes. Some bacteria convert arsenic from less toxic forms to more toxic forms and organic matter in the sediments is decayed by microbes which release arsenic in the groundwater.

2.2 Anthropogenic Sources

Anthropogenic sources denote human activities and industrial processes. Anthropogenic sources are:

2.2.1 Mining and smelting: Globally mining, smelting and ore processing are the major sources of arsenic contamination in water and air. Due to improper disposal of mining waste and tailings, the arsenic is accumulated in the surrounding environments (water, air).

2.2.2. Industrial effluents: The wastewater produced during the production of chemicals, metals, and semiconductors contains arsenic; due to a lack of proper treatment facilities the arsenic - containing wastewater is discharged into water bodies causing accumulation of arsenic in aquatic ecosystems.

2.2.3 Coal combustion: The burning of coal to produce energy is another source of **c**ontamination of water, soil, and environmental resources by arsenic. Improper disposal of coal ash (a rich source of arsenic) is another source of contamination of soil and water by arsenic. Terrestrial and aquatic environments are also contaminated by arsenic due to atmospheric deposition of arsenic - containing air produced during coal burning.

2.2.4 Agricultural practices: Arsenic - based pesticides (Zinc methyl arsenate, MMA, DMA) and poultry litter (as fertilizer) are applied in the agricultural fields from where the arsenic is leached and runoff in groundwater and nearby water bodies causing accumulation of arsenic in soil and water. Accumulation of arsenic residues in cultivated soil impacts the crop quality/yield and bioaccumulation in food.

2.2.5. Food additives: Arsenic - containing compounds such as 4 - aminobenzenearsenic acid and 3 - nitro - 4 - hydroxyphenylarsenic acid are used as animal food additives and wood preservatives. As arsenic in food preservatives is water soluble it reaches the environment via poultry litter.

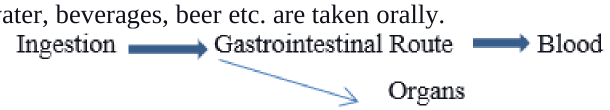
3. Sources of Exposure to Humans

The major source of accumulation of arsenic in humans is drinking water as studies have shown that inorganic arsenic beyond its permissible limit is present in the groundwater/ drinking water of Asia, Africa, North and South America, Europe and Oceania continents. Another source of arsenic accumulation is the uptake of crops irrigated by arsenic - contaminated water and food prepared by such water. Dairy products and seafood including fish, shellfish, cereals, and poultry products are the source of arsenic accumulation in the human body. Accumulation of arsenic in humans who smoke or chew tobacco is higher than in non - smokers as tobacco contains inorganic arsenic.

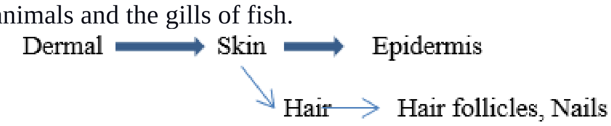
3.1 Routes of uptake of arsenic by Humans:

Humans and animals including aquatic animals' uptake arsenic via:

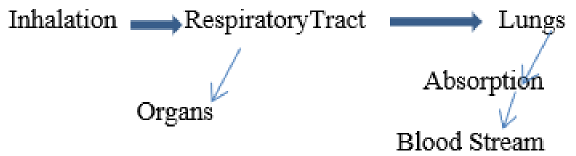
(i) Ingestion: Ingestion means via the gastrointestinal route i. e. mouth. Arsenic accumulates in the bloodstream and organs like the pancreas, liver etc of humans and animals (aquatic animals including, fish or farmed fish) via absorption when arsenic - contaminated food, rice, vegetables, fruits, egg, milk, seafood including fish are consumed and contaminated water, beverages, beer etc. are taken orally.



(ii) Dermal: When metalloid is absorbed via the skin it is termed dermal uptake and arsenic is bioaccumulated in the epidermis, hair, hair follicles, and nails of humans and other animals and the gills of fish.



(iii) Inhalation: Inhalation means uptake of the arsenic - containing air, vapours or aerosols. The arsenic accumulation in the air is due to the burning of arsenic - containing fossil fuels, cotton gins and tobacco smoke. From the respiratory tract, inhaled arsenic accumulates in the bloodstream and lungs.



Most accumulation of arsenic in humans and other animals is via ingestion and inhalation.

4. Arsenic in Environment

Arsenic beyond its permissible limit is found in all the environmental components i. e. water, air, soil and food chain.

4.1 Arsenic in freshwater

A survey of the literature reveals that globally freshwater particularly groundwater of 107 countries contains arsenic beyond WHO permissible limit, Asian countries in contamination are at the top with 32 countries followed by Europe (31 countries) followed by Africa (20), North America (11), South America (9) and Australia (4). Groundwater of the regions of the sedimentary basin close to deltaic areas (circum - Himalayan region) and modern mountain belts (Alpine - Himalayan - Tibet belt and Cordilleran - Andean belt) is more contaminated by arsenic. Two natural sources/processes of groundwater contamination by arsenic are biogeochemical processes and geogenic sources. Water table fluctuation, pH, organic matter in sediments, age of groundwater, groundwater flow direction, and marine transgression are some of the factors which affect arsenic contamination. The release of arsenic in water is due to the dissolution of arsenic - bearing minerals in the presence of organic matter; oxidative dissolution of iron and arsenic - bearing rock minerals; and exchange of arsenic by nitrate, phosphate and bicarbonate.

Arsenic concentration in the river and lake water ranges from 10 - 360ug/L. Human activities and discharge of mining waste in rivers and canals are the main causes of higher concentrations of arsenic in river water and lake water. In the natural water bodies, arsenic mainly exists in the inorganic form As (III) and As (V). Redox reactions, pH, microbial activity, and phosphorous concentration are the main factors which affect the form of arsenic, in water bodies with high microbial activities stable organic forms MMA and DMA also exist.

The concentration of arsenic in groundwater, river water, surface water and drinking water is given in Table 1.

4.2. Arsenic Occurrence in Seawater

The arsenic concentration in the unpolluted seawater ranges from 1 - 3ug/L. Due to human activities, the arsenic concentration in coastal waters and estuaries became 7.2 ug/L. Hydrothermal fluid increases the concentration of arsenic in seawater, in the east Pacific rise the concentration became 80.5 ug/L, close to shorelines the 1386 - 5850ug/L arsenic was found. The chemical form of arsenic depends on pH at pH 2.5 - 7 As exists as As (V) in the form $H_2AsO_4^{-1}$, at pH 7 - 12 $HAsO_4^{-2}$, as As (III) in the form of As $[OH]_3$ at pH < 9.3. In the seawater organic form of arsenic MMA (III, V) and DMA (III, V), dimethylarsinoyl acetate, and dimethylarsinoyl ethanol are also found.

4.3. Arsenic in Food Chain

Arsenic in aquatic environments and soil systems contaminates the food chain and affects the soil productivity, crop quality and health of the terrestrial ecosystem.

4.3.1 Arsenic in cereal Grains: Food crops (cereals and vegetables) major sources of human accumulation of arsenic are contaminated by soil. In the cultivated soil the arsenic accumulates due to the application of fertilizers, pesticides, and irrigation by the arsenic - contaminated water. Due to anaerobic conditions, rice has the highest efficiency of arsenic accumulation among all the cereal crops. The degree of accumulation of arsenic depends on rice variety, rice grain processing, irrigation method etc. Studies have shown that the accumulation of arsenic in brown rice is higher by 70 - 80% than in polished white rice. More accumulation of arsenic in rice is due to the phosphate transporter mechanism. In the rice inorganic arsenic dominates and varies from 27 - 93%. In the rice consumed by the European population, the average arsenic concentration is 130ug/kg, while in other cereals is 92ug/kg. Besides rice wheat grain also accumulates arsenic, in the mid–Gangetic Plain of India the wheat grain contains 27ug/kg of arsenic. The degree of accumulation in wheat grains depends on wheat variety, irrigation water, sludge amendment, and use of agrochemicals. The concentration of arsenic in cereals is given in Table 1.

4.3.2 Arsenic in fruits/vegetables; Fruits and vegetables are the essential components of the human diet. The fruits and vegetables are contaminated by arsenic the amount of accumulation depends on the type of vegetable, soil type, and irrigation water and geogenic contamination. Accumulation of arsenic is most common in root vegetables. The concentration of arsenic in vegetables grown in the Indo - Gangetic Plain ranges from 37 - 3947 ug/kg [10]. The translocation of arsenic in the above - ground parts of vegetables is very low, resulting in more accumulation of arsenic in root tubers and leafy

Table 1: Arsenic in water, food material and human

Source	Country	Arsenic level ug/L	Reference
Groundwater	Canada	1.5 - 738.8	Verma & Chaurasia, [11]
Groundwater	Finland	17 - 980	
Groundwater	India	10 - 3200	
Groundwater	USA	0 - 2600	
Groundwater	Thailand	1 - 5000	
Groundwater	Pakistan	0 - 906	

Groundwater	Taiwan	10 - 1820	
Groundwater	Nepal	0 - 2620	
Groundwater	Japan	1 - 293	
Groundwater	Greece	0 - 10000	
Groundwater	Cambodia	0 - 900	
Groundwater	Vietnam	0.7 - 3050	
Tube well water	Bangladesh	100 - 720ug/L	Hossain et al. [12]
Drinking water	USA	0 - 35 ug/L	Nigra et al. [13]
Drinking water	Mexico	0 - 39 ug/L	Ortiz Letechipia et al. [14]; Alarcón – Herrera et al. [15]
Drinking water	Guatemala	0.88 - 17.9 ug/L	Marcillo et al, [16]
Groundwater		0 - 49	
Surface water		6 - 107	
Drinking water	El Salvador	13 - 73	Morales - Simfors et al. [17]; Bundschuh et al. [18]
Groundwater		5 - 78	
Surface water		0.23 - 105	
Drinking water	Nicaragua	0 - 1320 ug/L	Delgado Quezada et al. [19]
Groundwater		0.1 - 1320	
Surface water		0.99 - 2650	
Drinking water	Venezuela	<5	Bundschuh et al., [18]
Groundwater		<2 - 9	
Surface water		<2 - 230	
Drinking water	Costa Rica	1 - 186	Bundschuh et al. [18]
Groundwater		<10 - 29100	
Surface water		<5 - 18	
Surface water	Panama	8 - 16.4	Nunez et al. [20]
Drinking water	Peru	01 - 10.1	Bolisetty et al. [21]
Groundwater		0.1 - 1100	
Surface water		1.4 - 42.5	
Drinking water	Brazil	<10	Teixeira et al. [22]
Groundwater		0 - 2980	
Surface water		0 - 3300	
Drinking water	Australia	0.001 - 73	Medunic et al. [23]
Groundwater		0.001 - 220000	
Surface water		0.001 - 5000	
Drinking water	Turkey	30 - 105	Baba et al. [24]
Groundwater		10 - 6300	
Drinking water	China	<10	Luo et al. [25]
Groundwater		21 - 2611	
Surface water		0.46 - 19.5	
Groundwater	Taiwan	10 - 1800	Shaji et al. [4],
Drinking water	India	0.01 - 9.4	Dhillon [26]
Groundwater		<10 - 390	
Rivers water	USA	0.05 - 60	Wang et al. [27]
Lakes water	Canada	0.2 - 972	
Lake water	Japan	0.6 - 1.7	
Lake water	USA	10, 000 - 20, 000	
River water	Chile	1400 - 21, 000	
Lake water	Ghana	2 - 7900	
Lake water	Ethiopia	2.39 - 566	
River water	Korea	1.3 - 1.7	
River water	Bolivia	10 - 11140	
River water	China	13.9 - 58.9	
Ground water	Uruguay	1.72 - 120.5	Machdo et al. [28]
Ground water	African Continent	1760	Irunde et al. [29]
Surface water		10, 000	
Ground water	South Africa	0.1 - 172.5	Mudzielwana et al. [30]
Ground water	China	0.1 - 158.2	Xiao et al. [31]
Surface water		0.3 - 59.3	
River water	Indonesia	0.8 - 136.8	Irnnawati et al. [32]
Hot Springs		166.7	
Estuary water		60.7	
Ground water		9.5 - 146.7	
Ground water	Bangladesh	13 - 501	Chakraborty et al. [33]
Ground water	Nadia, India	3 - 206	Das et al. [34]
Ground water	Bihar, India	0 - 500	Thakur et al. [35]
Ground water	Punjab, India	0 - 255.6	Kumar & Singh [36]

Drinking water	Congo	0.5 - 23.7	Muimba - Kankolongo et al. [37]
Drinking water	Ethiopia	0.6 - 73.4	Bianchini et al. [38]
Groundwater		4 - 1109	
Surface water		0.2 - 566	
Drinking water	Ghana	0.01 - 122	Irunde et al [29]
Groundwater		0.003 - 28, 950	
Surface water		0.003 - 10, 400	
Drinking water	Mali	0.01 - 5	Bokar et al. [39]
Groundwater		0.8 - 139	
Surface water		1.2 - 5	
Drinking water	Morocco	0 - 1.9	Lotfi et al. [40]
Groundwater	Kenya	0 - 22.9	Kiplangat et al. [41]
Surface water		0 - 46	
Drinking water	Nigeria	0 - 2390	Orosun. [42]
Groundwater		0.4 - 1100	
Groundwater	South Africa	0.8 - 1553	Irunde et al [29]
Surface water		0.6 - 119	
Drinking water	Tanzania	5 - 70	
Groundwater		0.5 - 123	
Surface water		1 - 82	
Drinking water	India	0.01 - 732	Mondal et al. [43],
Cooking water		0.01 - 1542	
River water	Vietnam	47.7 - 696.9	Seah et al [44]
Marine water	Kuwait	0 - 43	Ali et al. [45]
Indian Ocean		0.8 - 1.1	Wang et al. [9]
Atlantic Ocean		0.6 - 1.6	
Pacific Ocean		1.0	
Southern ocean		1.7 - 1.8	
Tasman Sea		1.4	
Estuary	France	1.3 - 3.7	
Estuary	Belgium	1.8 - 4.9	
Drinking water	India	0.01 - 732	Mondal et al. [43]
Cooking water		0.01 - 1542	
Ground water	Karnataka	0.19 - 10.55	Ravindran et al. [46]
Ground water	Bangladesh	210	Rokonuzzaman et al. [47]
Rice		410ug/kg	
Vegetables/fruits		1880ug/kg	
Ground water	Vietnam	480	Ngoc et al. [48]
Vegetables/fruits		870ug/kg	
Potato	India	5.6 - 176 ug/kg	Mondal et al. [43],
Cooked Rice		16 - 1128ug/kg	
Wheat grain		0.96 - 234 ug/kg	
Wheat flour		3.6 - 448 ug/kg	
Cereals	Bangladesh	310ug/kg	Rahaman et al. [3]
Pulses		110 ug/kg	
Vegetables		290 ug/kg	
Fruits		210 ug/kg	
Meat		330ug/kg	
Eggs		320ug/kg	
Rice	Thailand	84 - 490ug/kg	Pradit et al. [49]
Rice	China	50ug/kg	Luo et al. [25]
Rice	Republic of Korea	30 - 770ug/kg	Hoang et al. [50]
Rice	Japan	100 - 160ug/kg	Abedi & Mojiri [51]
Rice	USA	30 - 660ug/kg	Guaman et al. [52]
Rice	Peru	160 - 610 ug/kg	
Rice	Mexico	60 - 300ug/kg	García - Rico et al. [53]
Rice	Uruguay	140 - 280ug/kg	
Rice	Colombia	38 - 272ug/kg	Urango - Cárdenas et al. [54]
Rice	Argentina	40 - 1310ug/kg	Oteiza et al [55]
Rice	Brazil	10 - 1390ug/kg	Fão, et al. [56]
Rice	India	291 - 1411ug/kg	Sanyal et al. [57]
Rice	Bangladesh	21 - 660ug/kg	Moxness Reksten et al [58]
Rice	Brazil	233ug/kg	
Rice	Bangladesh	160 - 1440ug/kg	Hossain et al. [12]
Paddy	Malaysia	84.7 ug/kg	Zulkafflee et al. [59]
Rice	Cote d Ivoire	100 - 5800 ug/kg	Kinimo et al. [60]
Rice	Bangladesh	30 - 1840 ug/kg	Adeloju et al. [61]

Vegetables		5 - 540 ug/kg	
Vegetables	India	312 - 1464ug/kg	Sanyal et al [.57]
Vegetables	Bangladesh	170ug/kg	Moxness Reksten et al. [58]
Vegetables Fresh	Kuwait	1930 - 5730ug/kg	Gebeyehu & Bayissa [62]
Canned vegetables		2500 - 5100ug/kg	
Mushroom		510ug/kg	
Rice	China	603 - 729 ug/kg	Zheng et al. [63]
Spinach		95.7 ug/kg	
Broccoli		112 ug/kg	
Tomato		107 ug/kg	
Tine peas		115 ug/kg	
Maize	Pakistan	1470 - 3540ug/kg	Natasha et al. [64]
Wheat		2310 ug/kg	
Spinach		400 ug/kg	
Mustard		390 ug/kg	
Carrot		240 ug/kg	
Cabbage		200 ug/kg	
Fenugreek		190 ug/kg	
Cereals	Mali	1 - 37ug/kg	Bokar et al. [39]
Leaves and Fruits		100 - 45900ug/kg	
Vegetables	Zimbabwe	190 - 5800ug/kg	Meck et al. [65]
Brinjal	Bangladesh	350 ug/kg	Haque et al. [66]
Potato		280ug/kg	
Bottle gourd		430 ug/kg	
Pumpkin		320 ug/kg	
Green Amaranth		360 ug/kg	
Tomato	Zimbabwe	600 ug/kg	Meck et al. [65]
Okra		1000ug/kg	
Onion		1300ug/kg	
Pumpkin		5200 ug/kg	
Spinach		4030ug/kg	
Vegetables	Congo	800 - 2600ug/kg	Muimba - Kankolongo et al., [37]
Lettuce	China	1990ug/kg	Qin et al. [67]
Mustard		3260ug/kg	
Garlic		3160ug/kg	
Radish	Bangladesh	210 - 1760ug/kg	Hossain et al. [12]
Tomato		80 - 910ug/kg	
Potato		150 - 1400 ug/kg	
Bitter gourd	Bangladesh	2030ug/kg	Proshad et al. [68]
Okra		2550ug/kg	
Bean		1640 ug/kg	
Chilli		2910 ug/kg	
Bottle gourd		2850 ug/kg	
Cucumber		1640 ug/kg	
Sponge gourd		3890 ug/kg	
Cow Milk	Bangladesh	440ug/L	Rahman et al. [3]
Cow Milk	India	6.37ug/L	Das et al. [69]
Goat milk		3 ug/L	
Fish	Oman sea	740 - 3300ug/kg	Okati et al. [70]
Fish	China	110ug/kg	Luo et al. [27]
Shellfish		3600ug/kg	
Shark Fins	Hongkong	70 ug/kg	Garcia - Barcia et al. [71]
Fish & Shellfish	Japan	200 - 8300ug/kg	Abedi et al. [51]
Fish	Bangladesh	97 - 1318ug/kg	Adeloju et al. [61]
Fish	Thailand	0 - 2730ug/kg	Pradit et al. [49]
Shrimp		970 - 7280ug/kg	
Fish	Philippines	58 - 330ug/kg	Jalova et al. [72]
Fish	Bangladesh	560ug/kg	Rahman et al. [3]
Pagellus erythrinus	Italy	3620ug/kg	Di Bella et al. [73]
Pagellus acarne		4720 ug/kg	
Mullus barbatus		9940 ug/kg	
Sepia offcinalis		2268 ug/kg	
Ctenopharyngodon idella	China	41 ug/kg	Yang et al. [74]
Carassius carassius		89 ug/kg	
Hypothalmichthys nobilis		118 ug/kg	
Scomberomorus niphonius		995 ug/kg	
Trichiurus lepturus		1130 ug/kg	

Larimichthys polyactis		1400 ug/kg	
Lacteolabrax japonicus		852 ug/kg	
Sardina pilchardus		2260 ug/kg	
Clarias gariepinus	South Africa	0.06 - 0.096mg/kg	Misra et al. [75]
Micropteurs salmoides		0.138 - 0.214	
Leptodactylus natalensis		0.107 - 0.222	
Oreochromis mossambicus		0.063 - 0.169	
Coptodon rendalli		0.093 - 0.107	
Fish	Greece	1700 - 5390ug/kg	Golfinopoulos et al. [76]
Coastal fish		11800 - 62600ug/kg	
Fish	Mexico	0 - 2000ug/kg	García - Rico et al., [53]
Fish	Colombia	10 - 170ug/kg	Urango - Cárdenas, et al., [54]
Fish	Brazil	0.4 - 18000ug/kg	Fão, et al. [56] 1
Fish	Argentina	30 - 13250ug/kg	Oteiza et al. [14]
Fish	Australia	290 - 29500ug/kg	Rahman et al. [77]
Fish	Angola	560 - 2260ug/kg	Moxness Reksten et al. [58]
Fish	Congo	10 - 1200ug/kg	Muimba - Kankolongo et al., [37]
Fish (lake)	Canada	400 - 6000ug/kg	Tanamal et al., [78]
Fish	Cote d Ivoire	4 - 427 ug/kg	Kinimo et al. [60]
Fish	India	10 - 630 ug/kg	Sanyal et al. [57]
Fish	Brazil	233 ug/kg	Moxness Reksten et al. [79]
Fish	Bangladesh	1800ug/kg	
Crayfish	USA	2.6 - 13.9ug/g	Hull et al. [80]
Sunfish		0.07 - 0.61ug/g	
Fish	Zimbabwe	50 - 420ug/kg	Meck et al. [65]
Catfish	Bangladesh	30 - 750 ug/kg	Hossain et al. [12]
Spotted head fish		40 - 420ug/kg	
Lata fish		40 - 510 ug/kg	
Koi fish		10 - 560 ug/kg	
Tyangra fish		90 - 640 ug/kg	
Fish Gill Tissue	India	70 - 1290ug/kg	Kumar et al. [81]
Fish Kidney Tissue		70 - 170ug/kg	
Fish Liver Tissue		120 - 200ug/kg	
Fish Brain Tissue		60 - 150ug/kg	
Human Liver	China	147ug/g	Chen and Costa, [82]
Human Kidneys		26.6ug/g	
Human Heart		11.7ug/g	
Human Skin		2.9ug/g	
Human Brain		8.3ug/g	
Human Lung		11.1ug/g	
Human Spleen		11.7ug/g	
Human Muscle	China	12.2ug/g	Chen and Costa, [82]
Human Pancreas		11.2ug/kg	
Human Cerebellum		10.9ug/g	
Haemolysed Blood		0.422ug/g	
Air dust	China	6.81 - 10.7ng/m$^{3;}$ 8.67 - 20.5 ng/m^3	Mao et al. [83]; Wang et al. [84]
Road Dust	India	165 - 329 mg/kg	Patel et al. [85]

vegetables than in fruity or fleshy vegetables above the ground [65**]**. The concentration of arsenic in fruits and vegetables is given in Table 1.

4.3.3 Arsenic in aquatic animals, seafood including Fish

The literature has revealed that globally animal tissues i. e. milk; egg, fish, Shrimp, meat, egg, and seafood contain arsenic ranging from ug to mg /mg dry weight of the sample. Das et al**.** [86] have reported that in Bangladesh broiler bird skin contains 212ug/kg of arsenic; the liver contains 943ug/kg arsenic while accumulation of arsenic in lung, kidney and thigh muscles was 96, 88 and 68 ug/kg respectively. In poultry farms arsenic - contaminated groundwater is used and food additives also contain arsenic the arsenic is accumulated in eggs and animals. In Bangladesh as per Das et al**. [**86**]**, the accumulation of arsenic in Chicken whole egg was 227ug/kg; in albumin 65ug/kg and yolk it was 107 ug/kg., while in duck egg it was 155, 95 and 46 ug/kg in whole, albumin and yolk respectively. As per studies by the US Food and Drug Administration 70% of arsenic uptake by citizenry globally is due to the consumption of seafood (seawood, shellfish, finfish, bivalves, and fish). In seafood arsenic mainly exists in organic forms. The bioaccumulations of arsenic in aquatic organisms depend on organism type, body size, age, and geogenic source [87]. Hull et al**. [**80] found that bioaccumulation of arsenic in benthic organisms of shallow lakes is more than in deeper lakes globally. Fish in Estuary and marine bioaccumulate more arsenic than freshwater. Uptake of arsenic by fish is transcutaneous (via skin), respiratory (via gills) and gastrointestinal tract. Acute bioaccumulation of arsenic in fish causes erratic motion, lateral swimming and excessive mucus secretion. The concentration of arsenic in fish and other seafood is given in Table 1.

4.3.4 Impact of arsenic accumulation on Aquatic animals including fish

The literature survey denotes that accumulation of arsenic in aquatic animals especially in fish significantly alters the behaviour, growth, development, fertility and histopathology. In the presence of arsenic fish shows erratic movement, and lateral swimming. Accumulation of arsenic impacts the respiratory, cardiovascular, gastrointestinal, neurological and hematological systems. Piyushbhai et al**. [**88] during their research work found that the presence of inorganic arsenic in water causes behavioural abnormalities in zebrafish embryos. They also reported altered enzyme activities with expression of proinflammatory cytokines. Accumulation of arsenic in fish/ high concentration of arsenic in water adversely affects the liver, gill, brain, kidney, skin, blood glucose, and enzyme activities in the fish. Moneeb et al. [89] reported that arsenic in fish *Clarias gariepinus* causes necrosis, hypertrophy and hyperplasia, lymphocytic aggregation, congestion of blood vessels, retardation of glucose content, and accumulation of melanomacrophase. Accumulation of arsenic in freshwater Catfish, *Clarias batrachus* adversely impacts kidney inflammation and tubular atrophy in renal tubules, disruption of tubular linings, dense chronic inflammation, hemorrhage and vacuolation in Bowman's capsule were the findings of Pichhode et al**. [**90] In the kidney, due to arsenic exposure, vacuolization is also reported in the number of species [91]. . Muthukumaravel, et al**. [**92] during their research studies on *Chanos chanos,* found that on exposure to arsenic in fish there is degeneration of gill epithelium, gill filament hypertrophy, necrosis in the gills with hyperplasia of epithelial surface**.** High concentration of arsenic in water bodies causes degeneration of club cells, damage to epithelial cells with alteration in epidermal histomorphology, hypertrophy and hyperplasia in *Clarias batrachus* with the decrease of glycogen level [93**]**, while in *Heteropneustis fossils* there was hypo and hyperpigmentation. Accumulation of arsenic in water bodies causes stress in breathing due to degeneration in the gill's cartilaginous bars, basal lamellar region, increase in mucous secretion with destruction of secondary epithelial cells of gill lamella; impaired osmoregulatory system in *Channa punctatus* was the findings of Kumar et al. [94]. Retardation in glycogen, protein and triglycerides due to exposure to arsenic is also observed in a few aquatic animals. Shakeri et al**. [**95**]** reported that the accumulation of arsenic in fish muscle was more than in liver tissue.

4.3.5 Impact of arsenic accumulation on plants

Though arsenic is not an essential constituent of plant growth it can accumulate in plants to toxic levels, the accumulation depends on arsenic concentration in soil, fertilizers and pesticides used and in the irrigation water [96**]**. Accumulation of arsenic in plants negatively impacts cellular metabolism with damage to DNA, proteins and lipids via the generation of reactive oxygen species [97]. Arsenic accumulation reduces the root size and proliferation with an impact on root cells and alteration of transporter gene expression. Arsenic shortens the vessel's size and tracheids in stems with the decrease in water transport leading to retardation of growth, callose deposition and retardation in xylem conductance **[**98] Accumulation of arsenic retards the rate of photosynthesis with chloroplast membrane disintegration causing a reduction in the number of leaves, and stomatal conductance.

4.3.6 Impact of arsenic accumulation on Humans:

Exposure of humans to arsenic via water, food chain and air significantly adversely affects human health. Prolonged exposure to arsenic increases the risk of lung, liver, bladder, and pancreatic cancer. Skin disorders i. e. lesions, discolouration, and the development of corns; nausea, vomiting, diarrhoea, abdominal pain, muscle pain and cramps**,** hearing loss, hallucinations, and gastrointestinal lesions in humans by arsenic exposure are reported by several researchers [99, 100]. Arsenic exposure also causes cardiovascular diseases, hypertension, renal, and neurological disorders, respiratory diseases, reproductive diseases, and Alzheimer's and Parkinson's diseases [3, 100]. It is reported that prolonged exposure to arsenic even in small amounts enhances the chances of diabetes, and hyperthyroidism in humans which may be due to inhibition of enzymes α - ketoglutarate dehydrogenases and pyruvate. Arsenic exposure/accumulation also causes reproductive dysfunctions, low sperm count, premature delivery and abortion. Anaemia, leukaemia, pancytopenia, hepatic fibrosis, cirrhosis, and hepatic necrosis occur in humans when they are exposed to arsenic for a long period. If the amount of arsenic in the blood of children of 2 - 3 years is high it reduces the intellectual functioning**.** The adverse impact of arsenic accumulation/exposure is greater in malnourished persons than in well - nourished individuals. Dey et al. [101] during their work found that arsenic accumulation leads to an uncontrolled generation of reactive oxygen species (ROS) with decreased activity of the enzymes catalase, glutathione peroxidase and superoxide dismutase, damages DNA mitochondria, alters lipid profile with increased cytokine levels [102]. Arsenic exposure also adversely impacts the immune system causing immunotoxicity [103].

5. Conclusions

- Arsenic in its inorganic forms (As III & V) beyond its permissible limits is found in most of the water bodies mainly in groundwater globally especially in the south Asian countries (Ganga - Meghna - Brahmaputra region of India, Bangladesh) due to geogenic and anthropogenic activities.
- Due to the presence of arsenic in water bodies and soil the food chain i. e. cereals particularly rice, vegetables, fruits, fish, seafood, milk, and meat are contaminated by arsenic.
- Approximately 220 million people all over the world are impacted due to drinking arsenic - contaminated water and arsenic - contaminated food.
- Arsenic in plants retards its growth by negatively impacting the photosynthesis process. In the root part of the plant, arsenic is more accumulated.
- Bioaccumulation of arsenic in fish and seafood negatively impacts the behaviour, growth, development, fertility and histopathology.
- For humans, arsenic is a well - documented carcinogenic element and increases the probability of lung, liver, bladder, and pancreatic cancer. Skin disorders, endocrine disruption, reproductive dysfunctions, Anemia, leukemia, pancytopenia, and hepatic fibrosis are also reported due to exposure/ accumulation of arsenic in humans.

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References

[1] M. Balali - Mood, K. Naseri, Z. Tahergorabi Z, et al. "Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic", Frontiers in Pharmacol, 12, 643972, 2021. DOI: 10.3389/fphar.2021.6439 72

[2] J. Briffa, E. Sinagra, Blundell, "Heavy metal pollution in the environment and their toxicological effects on humans (Review) ", Heliyon, 6 (9), e04691, 2020. DOI: 10.1016/j. heliyon.2020. e04691

[3] M. S. Rahaman, N. Mise, S. Ichihara, " Arsenic contamination in food chain in Bangladesh: A review on health hazards, socioeconomic impacts and implication", Hygiene and Environ Health Adv, 2, 100004, 2022. DOI: 10.1016/j. heha.2022.100004

[4] E. Shaji, M. Santosh, K. V. Sarath KV, et al. " Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula", Geosci Front, 12, 1079, 2021.

[5] R. Tiwari, P. Satwik Khare, S. Rai, "Arsenic contamination in India: Causes, effects and treatment methods", Int J of Engg Sci and Techno, 13 (1), pp146 - 152, 2021. DOI: 10.4314/ijest. v13i1.22S

[6] J. Podgorski, M. Berg, "Global threat of arsenic in groundwater". Science, 368 (6493), pp845 - 850, 2020. . DOI: 10.1126/science. aba1510. PMID: 32439786

[7] F. T. Ahmed, A. H. A. N. Khan, R. Khan et al. "Characterization of arsenic contaminated groundwater from central Bangladesh: Irrigation feasibility and preliminary health risks assessment", Environ Nanotechno Monitor & Management, 15, 100433, 2021. DOI: 10.1016/ j. enmm.2021.100433

[8] I. Palma - Lara, M. Martínez - Castillo, J. C. Quintana - Pérez, et al. "Arsenic exposure: A public health problem leading to several cancers", Regul Toxicol Pharmacol, 110, 104539, 2020. DOI: 10.1016/j. yrtph.2019.104539

[9] N. Wang, Z. Ye, L. Huang, " Arsenic Occurrence and Cycling in the Aquatic Environment: A Comparison between Freshwater and Seawater",. Water, 15 (1), 147, 2023. DOI: 10.3390/w15010147

[10] S. Singh, R. Yadav, S. Sharma, "Arsenic contamination in the food chain: A threat to food security and human health", J of App Bio & Biotechno, 11 (4), pp 24 - 33, 2023. . DOI: 10.7324/ JABB.2023.69922

[11] S. K. Verma, S. R. Chaurasia, "Implicating the effects of consuming water with a high level of arsenic content: highlighting the cause and consequences of arsenic contamination in drinking water", Water Practice and Technol, 19 (4), pp1071 - 1083, 2024. . DOI: 10.2166/ wpt.2024.072

[12] M. S. Hossain, S. M. A. Rahman, M. M. Rahman, et al. "Arsenic Contamination in Soil, Vegetable, Groundwater, and Riverine Fish Species in Joypurhat, Bangladesh", Indon Jl of Social and Environ Issues (IJSEI), 3 (1), pp 29 - 36, 2022. DOI: 10.47540/ijsei. v3i1.427

[13] A. E. Nigra, A. Cazacu - De Luca,, A. Navas - Acien, "Socioeconomic vulnerability and public water arsenic concentrations across the US", Environ Pollu, 313, 120113, 2022. DOI: 10.1016/j. envpol.2022.120113

[14] J. Ortiz Letechipia, J. González - Trinidad, H. E. Júnez - Ferreira, et al. "Aqueous Arsenic Speciation with Hydrogeochemical Modeling and Correlation with Fluorine in Groundwater in a Semiarid Region of Mexico", Water, 14, 519, 2022.

[15] M. T. Alarcón - Herrera, D. A. Martin - Alarcon, M. Gutiérrez, et al. "Co - occurrence, possible origin, and health - risk assessment of arsenic and fluoride in drinking water sources in Mexico: Geographical data visualization", Sci Total Environ, 698, 134168, 2020.

[16] C. E. Marcillo, G. G. Prado, N. Copeland, et al. "Drinking water quality and consumer perceptions at the point - of - use in san rafael las flores, Guatemala", Water Pract Technol, 15, pp 374–385, 2020. .

[17] N. Morales - Simfors, J. Bundschuh, I. Herath, et al. "Arsenic in Latin America: A critical overview on the geochemistry of arsenic originating from geothermal features and volcanic emissions for solving its environmental consequences", Sci Total Environ, 716, 135564, 2020.

[18] J. Bundschuh, M. A. . Armienta, N. Morales - Simfors,, et al. "Arsenic in Latin America: New findings on source, mobilization and mobility in human environments in 20 countries based on decadal research 2010–2020", Crit Rev Environ Sci Technol, 51, pp 1727–1865, 2020.

[19] V. Delgado Quezada, M. Altamirano Espinoza, J. Bundschuh, "Arsenic in geoenvironments of Nicaragua: Exposure, health effects, mitigation and future needs", SciTotal Environ, 716, 136527, 2020.

[20] J. V. Núñez, A. S. Pineda, J. V. Pérez, et al. "Heavy Metals in Water, Soils and Sediments of La Villa River Basin - Panama", Int J Plant Soil Sci, 33, pp 1–12, 2021.

[21] S. Bolisetty, A. Rahimi, R. Mezzenga, "Arsenic removal from Peruvian drinking water using milk protein nanofibril - carbon filters: A field study", Environ Sci Water Res Techno, 7, pp 2223–2230, 2021.

[22] M. C. Teixeira, A. C. Santos, C. S. Fernandes, et al. "Arsenic contamination assessment in Brazil—Past, present and future concerns: A historical and critical review", Sci Total Environ, 730, 138217, 2020.

[23] G. Medunić, Ž. Fiket, M. Ivanić, "Arsenic Contamination Status in Europe, Australia, and Other Parts of the World". In: Srivastava, S. (eds) Arsenic in Drinking Water and Food. Springer, Singapore, 2020. DOI: 10.1007/978 - 981 - 13 - 8587 - 2_6

[24] A. Baba, T. Uzelli, H. Sozbilir, "Distribution of geothermal arsenic in relation to geothermal play types: A global review and case study from the Anatolian plate (Turkey) ", J. Hazard Mater, 414, 125510, 2021.

[25] C. Luo, J. Routh, D. Luo, et al. "Arsenic in the Pearl River Delta and its related water body, South China:

Occurrence and sources, a review", Geosci. Lett, 8, 12, 2021.

[26] A. K. Dhillon, " Arsenic Contamination of India's Groundwater: A Review and Critical Analysis. In Arsenic Water Resources Contamination. Advances in Water Security", 1st ed.; Fares, A., Singh, S., Eds.; Springer: Cham, Switzerland, Volume 8, pp.177–205, 2020.

[27] N. Wang, Z. Ye, L. Huang, "Arsenic Occurrence and Cycling in the Aquatic Environment: A Comparison between Freshwater and Seawater", Water, 15 (1), 147, 2022. . DOI: 10.3390/w15010147

[28] I. Machado I, Buhl V, Mañay N.2023. Arsenic levels in groundwater and its correlation with relevant inorganic parameters in Uruguay from the Medical Geology perspective, in Arsenic in the Environment: Bridging Science to Practice for Sustainable Development (Eds) van der Wal, Ahmad, Petrusevski, Weijma, Savic, van der Wens, Beerendonk, Bhattacharya, Bundschuh & Naidu. DOI: 10.1201/9781003317395 - 49

[29] R. Irunde, J. Ijumulana, F. Ligate, et al. "Arsenic in Africa: Potential sources, spatial variability, and the state of the art for arsenic removal using locally available materials", Groundwater for Sust Dev, 18, 100746, 2022.

[30] R. Mudzielwana, M. W. Gitari, S. A. Akinyemi, et al. "Hydrogeochemical characteristics of arsenic rich groundwater in Greater Giyani Municipality, Limpopo Province, South Africa", Groundwater for Sust Dev, 10, 10036, 2020. DOI: DOI: 10.1016/j. gsd.2020.100336

[31] T. Xiao, A. M. Muhammad, X. Pan, et al. "Spatial distribution and risk identification of arsenic contamination in water and soil through GIS - based interpolation techniques in Jianghan Plain, Central China", Front in Environl Sci, 10, 1001862, 2022. . DOI: 10.3389/fenvs.2022.1001 862

[32] I. Irnawati, R. Idroes, U. Zulfiani, et al. "Assessment of Arsenic Levels in Water, Sediment, and Human Hair around Ie Seu'um Geothermal Manifestation Area, Aceh, Indonesia", Water, 13 (17), 2343, 2020. DOI: 10.3390/ w13172343

[33] T. P. Chakraborty, G. C. Ghosh, P, Ghosh, et al. "Arsenic, iron, and manganese in groundwater and its associated human health risk assessment in the rural area of Jashore", Bangladesh. J of Water and Health, 20 (6), pp 888 - 902, 2022. DOI: 10.2166/wh.2022.284

[34] A. Das, S. S. Das, N. R. Chowdhury, et al. "Quality and Health Risk Evaluation for Groundwater in Nadia District, West Bengal: An Approach on Its Suitability for Drinking and Domestic Purpose", Groundwater Sustain Dev, 10, 100351, 2020.

[35] B. K. Thakur, V. Gupta, P. Bhattacharya, et al. "Impact of Socioeconomic Factors on Households' Willingness to Pay for Arsenic - Free Safe Drinking Water - A Case Study of Bihar, India", Groundwater Sustain. Dev, 19, 100837, 2022.

[36] A. Kumar, C. K. Singh, "Arsenic Enrichment in Groundwater and Associated Health Risk in Bari Doab Region of Indus Basin, Punjab, India", Environ Pollut, 256, 113324, 2020.

[37] A. Muimba - Kankolongo, C. Banza Lubaba Nkulu, J. Mwitwa, et al. "Contamination of water and food crops by trace elements in the African Copperbelt: A collaborative cross - border study in Zambia and the Democratic Republic of Congo", Environ Adv, 6, 100103, 2021.

[38] G. Bianchini, V. Brombin, C. Marchina, et al. "Origin of fluoride and arsenic in the main ethiopian rift waters", Minerals, 10, 453, 2020.

[39] H. Bokar, A. Traoré, A. Mariko, A, et al. "Geogenic influence and impact of mining activities on water soil and plants in surrounding areas of Morila Mine, Mali", J of Geochem Explor, 209, 106429, 2020. DOI: 10.1016/ j. gexplo.2019.106429

[40] S. Lotfi, M. Chakit, D. Belghyti, "Groundwater quality and pollution index for heavy metals in Sais plain, Morocco", J Health Pollut, 10, 200603, 2020.

[41] A. S. Kiplangat, H. Mwangi, S. Swaleh, et al. "Arsenic Contamination in Water from Selected Boreholes in Nairobi City County, Kenya", Eur J Adv Chem Res, 2, pp 1–6, 2021.

[42] M. M. Orosun, "Assessment of arsenic and its associated health risks due to mining activities in parts of North - central Nigeria: Probabilistic approach using Monte Carlo", J Hazard Mater, 412, 125262, 2021.

[43] D. Mondal, M. M. Rahman, S. Suman, et al. "Arsenic exposure from food exceeds that from drinking water in endemic area of Bihar, India", Sci Total Environ, 754, 142082, 2021. . DOI: 10.1016/j. scitotenv.2020.142082

[44] K. Y. Seah, T. Souliyavong, B. Lorbriayao, et al. "A case study on regional arsenic sources and its distribution in Mekong River groundwater", APN Science Bulletin, 13 (1), pp296–309, 2023. DOI: 10.30852/sb.2023.2372

[45] A. Ali, S. Chidambaram, "Assessment of trace inorganic contaminates in water and sediment to address its impact on common fish varieties along Kuwait Bay",. Environ Geochem Health, 43, pp**:** 855–883, 2021. DOI: 10.1007 /s10653 - 020 - 00559 - 6

[46] G. Ravindiran, S. Rajamanickam,, S. Sivarethinamohan, et al. " A Review of the Status, Effects, Prevention, and Remediation of Groundwater Contamination for Sustainable Environment", Water, 15 (20), 3662, 2022. DOI: 10.3390/w15203662

[47] M. Rokonuzzaman, W. Li, C. Wu, et al. "Human health impact due to arsenic contaminated rice and vegetables consumption in naturally arsenic endemic regions", Environ Pollu, 308, 119712, 2022. DOI; 10.1016/j. envpol.2022.119712

[48] N. T. M. Ngoc, N. V. Chuyen, N. T. T. Thao, et al. "Chromium, Cadmium, Lead, and Arsenic Concentrations in Water, Vegetables, and Seafood Consumed in a Coastal Area in Northern Vietnam", Environ Health Insights, 14, 1178630220921410, 2020. DOI; 10.1177/11786302209 21410

[49] S. Pradit, P. Noppradit, P. Jitkaew, et al. "Heavy Metal Contamination and Ecological Risk Assessment in the Sediment Cores of the Wetlands in Southern Thailand", J of Marine Sci and Engg, 10 (12), 1921, 2022. DOI: 10.3390/ jmse10121921.

[50] A. T. P. Hoang, N. Prinpreecha, K. W. Kim, " Influence of mining activities on arsenic concentration in rice in Asia: A review", Minerals, 11, 472, 2021.
[51] T. Abedi, A. Mojiri, "Arsenic uptake and accumulation mechanisms in rice species', Plants, 9, 129, 2020.
[52] S. T. Z. Guaman, W. C. Ccahua, N. C. Rafael, et al. "Estimation of arsenic contents in rice purchased on Peruvian markets and estimation of dietary intake by Peruvians through rice consumption", Sci Agropecu, 12, pp 185–191, 2021.
[53] L. García - Rico, M. P. Valenzuela - Rodríguez, M. M. Meza - Montenegro, et al. "Arsenic in rice and rice products in Northwestern Mexico and health risk assessment", Food Addit Contam Surveill, 13, pp 25–33, 2020.
[54] I. D. Urango - Cárdenas, S. Burgos - Núñez, L. A. Ospina Herrera, et al. "Determination of arsenic chemical species in rice grains using high - performance liquid chromatography coupled to hydride generator with atomic fluorescence detector (HPLC - HG - AFS) ", Methods X 8, 101281, 2021.
[55] J. M. Oteiza, P. A. Barril, C. E. Quintero, et al. "Arsenic in Argentinean polished rice: Situation overview and regulatory framework", Food Control, 109, 106909, 2020.
[56] N. Fão, S. Nascimento, A. H. de La Cruz, et al. "Estimation of total arsenic contamination and exposure in Brazilian rice and infant cereals", Drug Chem Toxicol, 44, pp 400–408, 2021.
[57] T. Sanyal, P. Bhattacharjee, S. Paul, et al. "Recent Advances in Arsenic Research: Significance of Differential Susceptibility and Sustainable Strategies for Mitigation", Front Public Health, 8, 464, 2020. DOI: 10.3389/ fpubh.2020.00464
[58] A. Moxness Reksten, A. M. Joao Correia Victor, E. Baptista Nascimento Neves, et al. "Nutrient and Chemical Contaminant Levels in Five Marine Fish Species from Angola - The EAF - Nansen Programme", Foods, 9 (5), 629, 2020. DOI: 10.3390/foods9050629
[59] N. S. Zulkafflee, N. A. Redzuan, J. Selamat, et al. "Evaluation of Heavy Metal Contamination in Paddy Plants at the Northern Region of Malaysia Using ICPMS and Its Risk Assessment", Plants, 10 (1), 3, 2020. DOI: 10.3390/ plants 10010003
[60] K. C. Kinimo, K. M. Yao, S. Marcotte, et al. "Trace metal (loid) s contamination in paddy rice (Oryza sativa L.) from wetlands near two gold mines in Côte d'Ivoire and health risk assessment", Environ Sci Pollut Res, 28, pp 22779–22788, 2021. .
[61] S. B. Adeloju, S. Khan, A. F. Patti, "Arsenic contamination of groundwater and its implications for drinking water quality and human health in under - developed countries and remote communities—A review ", Appl Sci, 11, 1926, 2021.
[62] H. R. Gebeyehu, L. D. Bayissa, "Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia", PLOS ONE, 15 (1), e0227883, 2020. DOI: 10.1371/journal. pone.0227883
[63] C. Zheng, Z. B. Yang, X. X. Xu, et al. "Assessing the risk of human exposure to bioaccessible arsenic from total diet through market food consumption in Chengdu, China", Environ Geochem Health, 45, pp 2065–2076, 2023. DOI: 10.1007/s10653 - 022 - 01325 - 6
[64] Natasha, I. Bibi, M. Shahid, et al. "Hydrogeochemical and health risk evaluation of arsenic in shallow and deep aquifers along the different floodplains of Punjab, Pakistan", J of Hazard Materials, 402; 124074, 2021. DOI: 10.1016/j. jhazmat.2020.124074
[65] M. L. Meck, D. Mudimbu, T. C. Davies, " Accumulation of potentially harmful elements in edible parts of vegetables grown on two different geological substrates in Zimbabwe", J Geochem Explor, 208, 106392, 2020.
[66] M. M. Haque, N. M. Niloy, M. K. Khirul, et al. "Appraisal of probabilistic human health risks of heavy metals in vegetables from industrial, non - industrial and arsenic contaminated areas of Bangladesh", Heliyon, 7, e06309, 2021. DOI: 10.1016/j. heliyon.2021. e06309
[67] J. Qin, A. Niu, Y. Liu, et al. " Arsenic in leafy vegetable plants grown on mine water - contaminated soils: Uptake, human health risk and remedial effects of biochar", J of Hazard Mat, 402, 123488, 2021. DOI: 10.1016/j. jhazmat.2020.123488
[68] R. Proshad, T. Kormoker, M. S. Islam, et al. "Potential health risk of heavy metals via consumption of rice and vegetables grown in the industrial areas of Bangladesh", Human and Ecolol Risk assess, 26 (4), pp 921 - 943, 2020. DOI: 10.1080/10807039.2018.1546114
[69] A. Das, M. Joardar, N. R. Chowdhury, et al. "Arsenic toxicity in livestock growing in arsenic endemic and control sites of West Bengal: risk for human and environment. Environ Geochem Health, 43 (8), pp 3005 - 3025, 2021. DOI: 10.1007/s10653 - 021 - 00808 - 2
[70] N. Okati, M. Shahriari Moghadam, F. Einollahipeer,. "Mercury, arsenic and selenium concentrations in marine fish species from the Oman Sea, Iran, and health risk assessment", Toxicol. Environ. Health Sci, 13, pp 25–36, 2021. . DOI: 10.1007/s13530 - 020 - 00062 - 6
[71] L. Garcia Barcia, J. Argiro, E. A. Babcock, et al. . "Mercury and arsenic in processed fins from nine of the most traded shark species in the Hong Kong and China dried seafood markets: The potential health risks of shark fin soup", Mar Pollut Bull, 157, 111281, 2020.
[72] M. C. Jalova, A. D. Lomantong, L. G. Calibo, et al. "Assessment of heavy metals found in commonly consumed fishes from lake Lanao, Philippines", Isr J Aquac Bamidgeh, 75, 1426167, 2021.
[73] C. Di Bella, A. Traina, C. Giosuè, et al. "Heavy metals and PAHs in meat, milk, and seafood from augusta area (Southern Italy): Contamination levels, dietary intake, and human exposure assessment", Front Public Health, 8, 273, 2020.
[74] L. Yang, M. Guo, C. Xin, et al. "Comparison of trace element concentrations in freshwater fish and marine fish consumed in Shandong Province, China, and their potential risks to human health", Mar Pollut Bull, 165, 112114, 2021.
[75] D. Mishra, R. Chakrabortty, K. Sen, et al. "Groundwater vulnerability assessment of elevated arsenic in Gangetic plain of West Bengal, India; Using

primary information, lithological transport, state - of - the - art approaches", J of Contami Hydrol, 256, 104195, 2023. DOI: 10.1016/j. jconhyd.2023.104195

[76] S. K. Golfinopoulos, S. P. Varnavas, D. E. Alexakis, "The status of arsenic pollution in the Greek and Cyprus environment: An overview", Water, 13, 224, 2021.

[77] M. M. Rahman, M. T. Shehzad, A. K. Nayak, AK, et al. "Health risks from trace elements in muscles of some commonly available fish in Australia and India". Environ Sci Pollut Res, 27, pp 21000–21012, 2020.

[78] C. Tanamal, J. M. Blais E. Yumvihoze, et al. "Health risk assessment of inorganic arsenic exposure through fish consumption in Yellowknife, Northwest Territories, Canada", Hum Ecol Risk Assess, 27, pp 1072–1093, 2021.

[79] A. Moxness Reksten, Z. Rahman, M. Kjellevold, et al. "Metal Contents in Fish from the Bay of Bengal and Potential Consumer Exposure - The EAF - Nansen Programme", Foods, 10 (5): 1147, 2021. DOI: 10.3390/foods 10051147

[80] E. A. Hull, M. Barajas, K. A. Burkart, et al. "Human health risk from consumption of aquatic species in arsenic - contaminated shallow urban lakes", Sci of the Total Environ, 2021, 770, 2021. DOI: 10.1016/ j. scitotenv.2021.145318

[81] N. Kumar, N. K. Chandan, S. Bhushan, et al. "Health risk assessment and metal contamination in fish, water and soil sediments in the East Kolkata Wetlands, India, Ramsar site", Scientific Reports, 13 (1), pp 1 - 18. DOI: 10.1038/ s41598 - 023 - 28801 - y

[82] Q. Y. Chen, M. Costa, "Arsenic: A Global Environmental Challenge", Annu Rev Pharmacol Toxicol, 61, pp 47 - 63, 2021. DOI: 10.1146/annurev - pharmtox - 030220 - 013418.

[83] X. Mao, X. Hu, Y. Wang, et al. "Temporal trend of arsenic in outdoor air $PM_{2.5}$ in Wuhan, China, in 2015–2017 and the personal inhalation of PM - bound arsenic: implications for human exposure", Environ Sci Pollut Res, 27, pp21654–21665, 2020. DOI: 10.1007/s11356 - 020 - 08626 - 2

[84] J. Wang, Y. Wan, L. Cheng, et al. "Arsenic in outdoor air particulate matter in China: Tiered study and implications for human exposure potential", Atmospheric Pollu Res, 11 (4), pp 785 - 792, 2020. DOI: 10.1016/j. apr.2020.01.006

[85] K. S. Patel, A. Yadav, Y. K., Sahu, et al. "Tree Bark as a Bioindicator for Arsenic and Heavy Metal Air Pollution in Rajnandgaon District, Chhattisgarh, India", J of Hazar Toxic and Radioactive Waste, 24, 0000475, 2020. DOI: 10.1061/ (ASCE) HZ.2153 - 5515.0000475

[86] S. Das Sarkar, P. R. Swain, S. K. Manna, et al. "Arsenic contamination in food chain - a menace to food safety, human nutrition and health", J Environ Biol, 43, pp 339 - 349, 2022. DOI: 10.22438/jeb/43/3/MRN - 1973

[87] W. Zhang, A. Miao, N. Wang N, et al. "Arsenic bioaccumulation and biotransformation in aquatic organisms", Environ Intern, 163, 107221, 2022. DOI: 10.1016/ j. envint.2022.107221

[88] M. P. Piyushbha, A. Binesh, S. A Shanmugam, et al. "Exposure to low - dose arsenic caused teratogenicity and upregulation of proinflammatory cytokines in zebrafish embryos", Bio Trace Elem Res, 201 (7), pp 3487–3496, 2022. DOI: /10.1007/s12011 - 022 - 03418 - w

[89] R. H. Moneeb, I. A. Mekkawy, U. M. Mahmoud, et al. "Histopathological and ultrastructure studies on hepatotoxicity of arsenic in Clarias gariepinus (Burchell, 1822): Hepatoprotective effect of *Amphora coffeaeformis*", Scientific African, 8, e00448, 2020. DOI: 10.1016/ j. sciaf.2020. e00448

[90] M. Pichhode, S. Karpgye, S. Gaherwal, "Impact of sodium arsenate on histological changes in liver and kidney of fresh water catfish, Clarias batrachus", Agricultural Sci Digest–a Research Journal 42 (4), pp 506–510, 2022. . DOI: 10.18805/ag. d - 5349

[91] T. Das, M. Goswami, "Acute toxicity impact of sodium arsenite on behavioural changes and histopathology of kidney and intestine of the freshwater fish, Channa punctatus and its revival with aqueous garlic extract", Biosci Biotechno Resh Communic, 13 (2), pp 913–922, 2020. DOI: 10.21786/bbrc/13.2/79

[92] K. Muthukumaravel, K. P. Pradhoshini, N. Vasanthi, et al. "Sublethal effects of arsenic on oxygen consumption, hematological and gill histopathological indices in *Chanos chanos*", Int J of Environ Res and Public Hlth, 18 (24); 12967, 2021. DOI: 10.3390/ijerph 18241 2967

[93] K. Dwivedi, S. Singh, "Toxicological effect of arsenic on organs of fishes: A review", J of Entomo and Zoology Studies, 9 (5), pp 465 - 473, 2021.

[94] V. Kumar, S. Raman, R. K. Talukder, et al. "Arsenic bioaccumulation and identification of low - arsenic - accumulating food fishes for aquaculture in arsenic - contaminated ponds and associated aquatic ecosystems", Biol Trace Element Res, 200 (6), pp 2923–2936, 2021. DOI: 10.1007/s12011 - 021 - 02858 - 0

[95] A. Shakeri, M. R. Fard, B. Mehrabi, et al. "Occurrence, origin and health risk of arsenic and potentially toxic elements (PTEs) in sediments and fish tissues from the geothermal area of the Khiav River, Ardebil Province (NW Iran) ", J of Geochem Exploration, 208, 106347, 2020. DOI: 10.1016/ j. gexplo.2019.106347

[96] O. T. Kayode, A. P. Aizebeokhai, A. M. Odukoya, "Arsenic in agricultural soils and implications for sustainable agriculture", Earth and Environ Sci, 655, 012081, 2021. . DOI: 10.1088/1755 - 1315 /655/ 1/012081

[97] D. Sinha, S. Datta, R. Mishra, et al. "Negative Impacts of Arsenic on Plants and Mitigation Strategies", Plants, 12, 1815, 2023. DOI: 10.3390/ plants12091815

[98] S. Sandil, M. Óvári, P. Dobosy P, et al. " Effect of arsenic - contaminated irrigation water on growth and elemental composition of tomato and cabbage cultivated in three different soils, and related health risk assessment", Environal Res, 197, 111098, 2021. DOI: 10.1016/ j. envres.2021.111098

[99] G. Bjørklund, T. Tippairote, M. S. Rahaman, et al.2020. Developmental toxicity of arsenic: a drift from the classical dose–response relationship", Arch Toxicol, 94, pp 67–75, 2020. DOI: 10.1007/s00204 - 019 - 02628 - x

[100] A. P. Ferragut Cardoso, K. T. Udoh, J. C. States, "Arsenic - induced changes in miRNA expression in cancer and other diseases", Toxicol Appl Pharmacol, 409, 115306, 2020. DOI: 10.1016/j. taap.2020.115306

[101] T. Dey, A. Ghosh, S. Mishra, et al. "Attenuation of arsenic induced high fat diet exacerbated oxidative stress mediated hepatic and cardiac injuries in male Wistar rats by piperine involved antioxidative mechanisms", Food and Chemical Toxico, 142, 111477, 2020. DOI: 10.1016/j. fct.2020.1114 77

[102] M. Thakur, M. Rachamalla, S. Niyogi, et al. "Molecular Mechanism of Arsenic - Induced Neurotoxicity including Neuronal Dysfunctions", Int J of Mol Sci, 22 (18), 10077, 2020. DOI: 10.3390/ijms 22181 0077

[103] S. Muzaffar, J. Khan, R. Srivastava, et al. "Mechanistic understanding of the toxic effects of arsenic and warfare arsenicals on human health and environment", Cell Biol Toxicol, 39, pp 85–110, 2023. DOI: 10.1007/s10565 - 022 - 09710 - 8