Chapter

Heavy Metal Contamination in the Coastal Environment and Trace Level Identification

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Abstract

Heavy metal pollution in the coastal environment is a great concern as its adverse effects on marine health. Heavy metals are a group of persistent organic pollutants and last for years in the environment. Due to their widespread distribution, high hydrophobicity, prolonged persistence, and negative effects on the environment and human health, these chemicals have raised attention. Due to a lack of research and advanced detection techniques, heavy metal pollution in coastal areas of some Asian countries is critical. Scientists have developed several methods for detecting heavy metals in the environment, including atomic absorption spectroscopy, inductively coupled plasma massspectroscopy, and high-performance liquid chromatography coupled with electrochemical or UV-Vis-detectors. However, a newly optimized, sensitive, cost-effective, and precise technology for detecting heavy metals at ultra-trace levels is solid phase micro-extraction and gas chromatography mass-spectrometry. As a result, the book chapter will describe the theoretical, practical approach, and modern technology for detecting and quantifying heavy metal contaminations in the marine ecosystem, including the effects of heavy metals on the marine animals, human and environmental health, and challenges and future perspectives of heavy metal degradation using a green approach, as well, the effects of heavy metals on the marine animal, human, and environmental health.

Keywords: heavy metals, pollutant, marine ecosystem, SPME, trace level

1. Introduction

Chemical production has increased from one million tons in 1930 to over 400 million tons now, with around 100,000 different chemical substances registered on the European Union market, of which 30,000 to 70,000 are used daily [1, 2]. The most of chemicals in water bodies, including heavy metals, derive from wastewater from industrial, agricultural, and domestic sources, as well as municipal sewage treatment plants [3]. Around 10% of the globally available runoff is being used by industries and municipalities, resulting in a stream of effluent that flows into rivers, lakes, groundwater, or coastal water. As a result, each year over 300 million tons of heavy metals from industrial and consumer products, including Cr, Cu, Zn, As, Cd, Pb, and Sn, find their way into natural waters [4]. Cement plants, coal and energy bases, textiles, ship breaking/recycling, and tanneries are only a few examples of key types of businesses that have become important for macro and microeconomic growth as well as heavy metal pollution. Agriculture, which uses 140 million tons of fertilizers and several million tons of pesticides each year, contributes to further pollution [4]. Chemical pollution is mainly a threat to developing countries due to the lack of compliance with environmental and safety regulations. Low labor costs and favorable geographic locations have made the ship-repairing industry highly profitable, releasing considerable quantities of heavy metals into the environment [5]. Even at low levels of exposure, these metals are hazardous to the physical and chemical functions of animals and can damage their several organs such as brain, liver, and reproductive organs. As a result, monitoring and assessment can aid with coastal environmental protection management and planning. When using heavy metals, trace metals analysis can be used to detect and identify small amounts of metals in a sample, which is important for quality control and regulatory compliance.

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1.1 Heavy metals

In comparison to water, heavy metals are metallic elements with a higher density. Assuming that toxicity and heaviness are connected. Heavy metals also include metalloids such as arsenic, tin, lead, etc., which can cause harmful effects at low concentrations [6]. Environmental contamination of these metals is responsible for threatening the environment and global public health. Due to vast development in their use in numerous industrial, agricultural, domestic, and technological applications, human exposure has increased. Heavy metals in the environment could be found in geological, pharmaceutical, industrial, agricultural, atmospheric, and domestic effluent sources (**Table 1**). Smelters, foundries, mining, and other metal-based industrial operations are all major contributors to environmental contamination [7].

Heavy metals are naturally occurring elements found throughout the earth's crust; however, human activities such as mining and smelting, industrial application, and

Heavy metals	Application
Nickel (Ni)	Batteries processing units, Galvanization, metal refining, fertilizers, painting industries
Zinc (Zn)	Painting and dye, wood preservatives, fertilizers, rubber and detergent industries
Arsenic (As)	Wood preservatives, dye and automobile industries
Cadmium (Cd)	Painting, galvanized, pesticide, polyvinyl plastic, refined petroleum products industries
Aluminium (Al)	Aluminium phosphate Pesticide, ceramics, automotive parts industries
Iron (Fe)	Engine parts and metal refining industries
Copper (Cu)	Electroplating, metal refining and plastic industries
Lead (Pb)	Pesticides, mobile batteries, petrol based materials and leaded gasoline industries
Chromium (Cr)	Electroplating, leather, textile, pulp, tanning, and chrome plating industries
Tin (Sn)	Wood preservatives, Leather, Textile dye, antifouling paint, pesticide industries

Table 1.
Industrial uses of the heavy metals.

domestic and agricultural use of metals and metal-containing compounds end up causing the vast majority of environmental contamination and human exposure. Heavy metals are usually found in trace amounts in the earth's crust, ranging from a few parts per trillion (ppt) for noble metals to up to 5% for iron. They could be encountered in their elemental, metallic form. Weathering and erosion led them to leach into the soil, rivers, and groundwater. When the Earth's mantle was still liquid 4–5 billion years ago, heavy metals sank to the center and formed the iron- and nickel-rich core [8].

Due to their trace concentrations (ppt range to less than 10ppm) in a wide range of environmental matrices, heavy metals are classified as trace elements. Physical factors such as phase association, temperature, sequestration, and adsorption affect heavy metal bioavailability. Chemical parameters, such as lipid solubility, complexation kinetics, and octanol/water partition coefficients, have an impact on speciation at thermodynamic equilibrium. Biological factors include species characteristics, biochemical/physiological adaptability, and trophic interactions.

1.2 The significance of heavy metals to animal and plant life

Metals are required for the proper performance of several biochemical and physiological processes in humans, animals, and plants. Microelements are trace elements having minor dietary requirements, such as chromium (Cr), iron (Fe), cobalt (Co), manganese (Mn), copper (Cu), molybdenum (Mo), zinc (Zn), and selenium (Se). They are found in trace levels (ppt, ppb, or ppm) in a range of matrices and their bioavailability varies [9]. Trace elements are commonly added to animal feed as a nutritional supplement to enhance health and productivity. Heavy metals have been shown to impact a variety of cellular organelles and components, including the cell membrane, mitochondria, lysosome, endoplasmic reticulum, nuclei and enzymes involved in metabolism, detoxification, and damage repair. Excessive exposure to these elements at elevated concentrations has been associated with cellular or systemic problems and may be a source of pollution [10].

Chlorophyll production, protein modifications, DNA synthesis, photosynthesis, redox reactions in the chloroplast and mitochondria, nitrogen fixation, and sugar metabolism are all affected by heavy metals. More than 300 enzymes and 200 transcription factors required zinc as a cofactor for membrane integrity maintenance, auxin metabolism, and reproduction [11]. However, the remaining excess of heavy metals in the environment is responsible for harmful consequences.

2. Increasement of heavy metals in the coastal environment

Metal corrosion, air deposition, soil erosion of metal ions and heavy metal leaching, sediment resuspension, and metal evaporation from water resources to soil and groundwater are all potential sources of environmental contamination. Natural occurrences such as volcanic eruptions and weathering are also identified as major contributors to heavy metal contamination. Metal refineries, petroleum combustion, high-tension lines, coal combustion in power plants, nuclear power stations, microelectronics, wood preservation, plastics, textiles, and paper processing industries have all been industrial sources [7]. Tin (Sn), molybdenum (Mo), cobalt (Co), copper (Cu), selenium (Se), zinc (Zn), chromium (Cr), nickel (Ni), magnesium (Mg), manganese (Mn), and iron (Fe) are reported to be essential nutrients needed for a variety of physiological and metabolic activities. Deficiencies in these micronutrients can lead to a range of syndromes and disorders.

Land-based metal polluting industries, such as textiles, coal and energy bases, cement plant, leather, and ship breaking/recycling, have expanded significantly over the past few decades as these types of enterprises have become an important factor for macro and micro perspectives of economic growth. These industries release significant amounts of heavy metals into the environment indicating opportunities and possible risks to a more globalized economy. However, about 40% of the world's seas have been significantly impacted by human activity, with the most severe consequences occurring in coastal regions [12, 13]. Indeed, anthropogenic metal contamination in coastal and marine environments has been a major issue since it may have toxic effects on aquatic living organisms, destroy natural ecosystems, and significant health risks to humans through consumption of contaminated seafood [14].

2.1 Heavy metal contamination in the marine ecosystem

Metal concentrations in the marine environment are estimated to be in the nanogram to microgram per liter (liquid phase) or per gram range as they are found naturally components of the earth's crust (solid phase). Concentrations of important heavy metals (Zn, Pb, Cd, Cu, Sn, and Hg) in the marine environment have increased by five to ten times in the past few decades compared to values recorded fifty to one hundred years ago [15]. The global increase in metal contamination in marine ecosystems has been mainly driven by economic development and accelerated industrialization in recent decades. Metals enter aquatic systems and accumulate in various ways, as shown in **Figure 1**. Changes in physicochemical parameters such as salinity, redox potential, temperature, pH, and organic ligand concentrations could cause metals

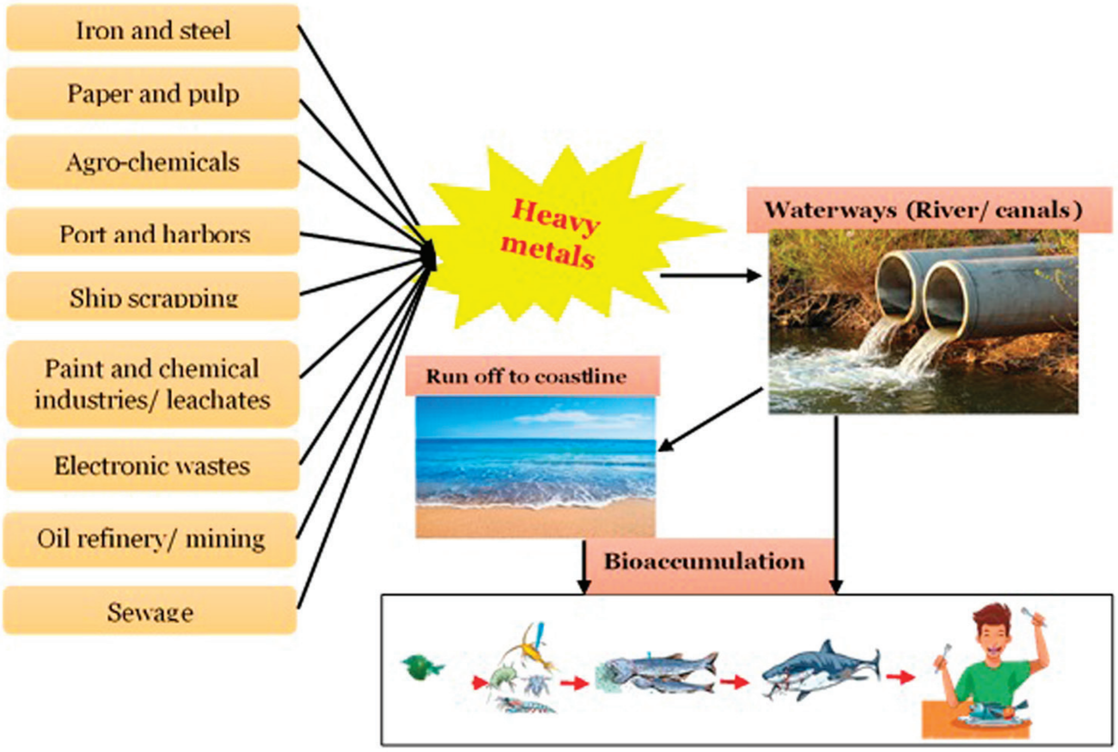

Figure 1.
Major routes for metals contamination and bioaccumulation in the aquatic environment.

to disintegrate from a solid phase once adsorbed into marine sediments. As a consequence, the toxicity, mobility, and bioavailability of metals are largely determined by the environment [15, 16]. Important terrestrial and aquatic ecosystems, including mangrove forests, intermittently and permanently flooded wetlands, and tidal flats, are found in the coastal environment, which is highly dynamic and ecologically complex. These enriched ecosystems are at risk due to environmental consequences and human encroachment. The wastes from scrapped ships, including oils and persistent organic pollutants (POPs), enter the coastal bay, which is home to a variety of marine life, including many endangered and vulnerable species; pollution has been identified as one of three major transboundary issues affecting the marine ecosystem. Heavy metals can accumulate in aquatic habitats to toxic levels because they are not biodegradable, although some metals are essential to the ecosystem's function. Metals are eventually integrated into the sediment at the bottom, where organisms (benthic organisms) can gather them. Heavy metals affect aquatic life at greater levels. Cadmium and copper concentrations in the water surrounding shipbreaking zones were high enough to affect fish spawning and death. In coastal areas, a higher concentration of mercury and tin has delayed the development of mollusks, and lead has reduced the nesting capacity of marine birds [17].

Low levels of dissolved metals in seawater may or may not present a hazard to marine biota but some species have shown a tendency to accumulate the metals from the water. Li et al. [18] studied the effects of chelating agents on the uptake and accumulation of cadmium by *Mytilus edulis*. Complexation of cadmium with either EDTA, humic and alginic acids, or pectin doubles both rate of accumulation and the final tissue concentration. Yap et al. [19] determined trace metal (Hg, Cd, Cu, Ag, Zn, and Pb) concentrations in mussels from the estuaries were compared with those of coastal and offshore regions in the southeastern North Sea. Bandara et al. [20] reported that tributyltin contamination in marine gastropod; *Thais clavigera* and mussels, *Perana perana*, *Perna viridis*, *Crassostrea madrasensis,* and *Crassostrea cuculata*. Levels of selected heavy metals in sediments collected from subtidal areas off the Iranian coastline of the Arabian Gulf were measured by Pourang et al. [21]. This study concluded that the concentrations of Cd, Pb, and Ni in the sediments (2.9, 90.5, and 64.9 μg/ g dry weight, respectively) were notably higher than global baseline values. Assessment of contaminants in Dubai coastal region, United Arab Emirates, was conducted by Al-Darwish et al. [22]. This study found that the highest concentrations of the selected metals were found in chronically polluted areas and reported elevated levels of Cu, Ni, and Zn in comparison with background levels of unpolluted sediments in the Arabian Gulf, which is heavily occupied by a variety of industries.

3. Toxicity of heavy metals

Heavy metals: Fe, Co, Cu, Mn, Mo, Se, Zn, Cr, and Cd, as well as Hg, Pb, and As, have a high density compared to water and are present in trace amounts in different matrices. Heavy metals could cause toxicity at low concentrations, hence their heaviness and toxicity are associated [23]. Heavy metals have a negative impact on the soil, water, air, plants, animals, and humans. High heavy metal concentrations in soil can impact soil quality, particularly pH, color, porosity, and natural composition, as well as crop yield and the extinction of many species of normal flora and animals. Their buildup in the water creates significant issues for humans and ecosystems due to a decrease in drinking water quality and cleanliness, as well as a decrease in water supplies for all life forms. Increased acid rain, corrosion, eutrophication and haze, decreased agricultural yields, and a shortage of oxygen can be caused by heavy metal contamination in the air. They can damage plants' roots and leaves, disrupt important biochemical processes such as photosynthesis, impair mineral absorption, damage chlorophyll, and inhibit root growth and development, leading to a reduction in total plant growth [24].

Heavy metal toxicity in animals shows itself with reduced body weight, renal damage, liver damage, shorter life span, increased oxidative stress, changes in cell composition, and DNA damage. In humans, they can cause renal illness, liver disease, lung complications, and some cancers [25]. Heavy metals accumulate in organs and soft tissues when they are not metabolized by the body, causing them toxic. Ingestion of contaminated food or water, inhalation, or skin absorption have all been routes they enter the human body. One of the most common ways for heavy metals to enter the bodies of animals is via ingestion. These metals can have inhibitory, stimulatory, or toxic effects on specific biochemical processes, resulting in a variety of health problems in the nervous system (Alzheimer's, Parkinson's, depression, and dementia), the bone system (bone mineralization), and the reproductive system. reactive oxygen species (ROS) can also cause DNA and RNA damage and malignancies of the lungs, skin, and bladder, as a consequence of its production. The amount of exposure, the length of exposure, the pollutant concentration, and the organisms exposed to it, as well as the metal's type and oxidation state, determine its toxicity [26].

3.1 Heavy metal toxicity amplification in plants and animals

Heavy metals persist in nature, posing a threat to human health in addition to their detrimental impacts on plants and wildlife. For example, lead (Pb) is one of the most toxic heavy metals, with a soil retention time of 150–5000 years and a reported concentration retention period of up to 150 years [27]. Plants that grow in heavy metal-contaminated areas tend to collect higher concentrations of heavy metals in the food chain. The main route for heavy metals into animal and human tissues would be through contaminated food, making them vulnerable to a variety of diseases.

Several heavy metals such as Cr, Cd, Pb, Hg, and Al are highly toxic even in trace concentrations, even though they are nonessential and have no physiological role [28]. Both essential and nonessential heavy metals damage plants in comparable ways, caused by low biomass accumulation, chlorosis, growth and photosynthetic inhibition, altered water balance and nutrient assimilation, and senescence, which leads to plant death.

3.2 Potential Human Exposure to heavy metals

Each year, over 300,000 employees are exposed to heavy metals and metal-containing compounds in the workplace. One of the biggest sources of health concern is industrial worker exposure to the high risk of Cr-induced diseases. Cr is anticipated to be released into the environment at a rate of 33 tons per year, which poses a significant carcinogenic risk. The Occupational Safety and Health Administration (OSHA) in the United States recently established a "safe" level of $5 g/m^3$ for an eight-hour time-weighted average. The overall human population's atmospheric levels range from 1 to $100 ng/cm^3$, while levels near Cr-related industries can exceed this range [10].

Nonoccupational exposure occurs when heavy metal-containing meals and water are consumed. Whenever it comes to chromium contamination, recorded levels range from 1 to 3000 mg/kg in soil, 5 to 800 g/L in seawater, and 26 g/L to 5.2 mg/L in rivers and lakes. The amount of chromium in food varies wildly depending on how it is processed and cooked. Fresh foods contain chromium levels ranging from 10 to 1,300 g/kg [29]. Employees in chromium-related industries can be exposed to two orders of magnitude higher levels of chromium than the general population.

Human exposure to heavy metals seems to be mostly by inhalation, with the lung being the primary target organ. However, significant human exposure to heavy metals has also been recorded through the skin [30]. For example, exposure to chromium found in cement is implicated in the worldwide incidence of dermatitis among construction workers. Exposure to Cr(VI)-containing chemicals in the workplace and the environment has been linked to multi-organ toxicity in humans, including kidney impairment, allergy and asthma, and lung cancer.

Enormous concentrations of heavy metals in the air would irritate the nose lining and lead to ulcers. The numerous health problems documented in animals after swallowing heavy metals at detectable levels include stomach irritation and ulcers, sperm loss, anemia, and endocrine abnormalities [8]. Some people who are extremely sensitive to heavy metals have experienced allergic reactions such as edema and severe redness of the skin. In both humans and animals, toxic substances in drinking water have been related to an increased risk of stomach cancer. Ingestion of extremely high concentrations of these compounds by humans, whether it be by accident or on purpose, has resulted in severe respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological consequences, in people who died or survived as a result of medical care. Strong evidence of heavy metal carcinogenicity in humans and terrestrial mammals has also been reported by Mahurpawar [25] and Tchounwou et al. [10].

3.3 Heavy metal toxicity and carcinogenicity

Heavy metal toxicity is mostly determined by their oxidation state and lipophilicity. Even though the processes of biological interaction are unknown, the chemicals can penetrate through cell membranes, and their intracellular reduction to reactive intermediates may be connected to toxicity variation. It can be absorbed to some extent through the lungs, gastrointestinal tract, and even intact skin. It is considered a detoxification process when harmful substances are reduced at a distance from the target site for toxic or genotoxic action; nevertheless, when the compound is reduced in or near the cell nucleus of target organs, it may help activate their toxicity [31].

Under physiological conditions, heavy metals can be reduced by hydrogen peroxide (H_2O_2), ascorbic acid, and glutathione reductase to form reactive intermediates such as thiol radicals and hydroxyl radicals. Any of these heavy metal species could disrupt cellular integrity and function by attacking DNA, proteins, or membrane lipids [32].

With animal research, many harmful effects of heavy metals on mammals have been reported [25, 33]. After subcutaneous treatment of Cr, rats developed severe urea nitrogen, creatinine elevations, proteinuria, an increase in blood alanine aminotransferase activity, and hepatic lipid peroxide production. In similar studies, Sahu et al. [34] found that chromium induced kidney impairment in rats when administered as a single subcutaneous injection. Giving Cr to rats in water caused hepatic

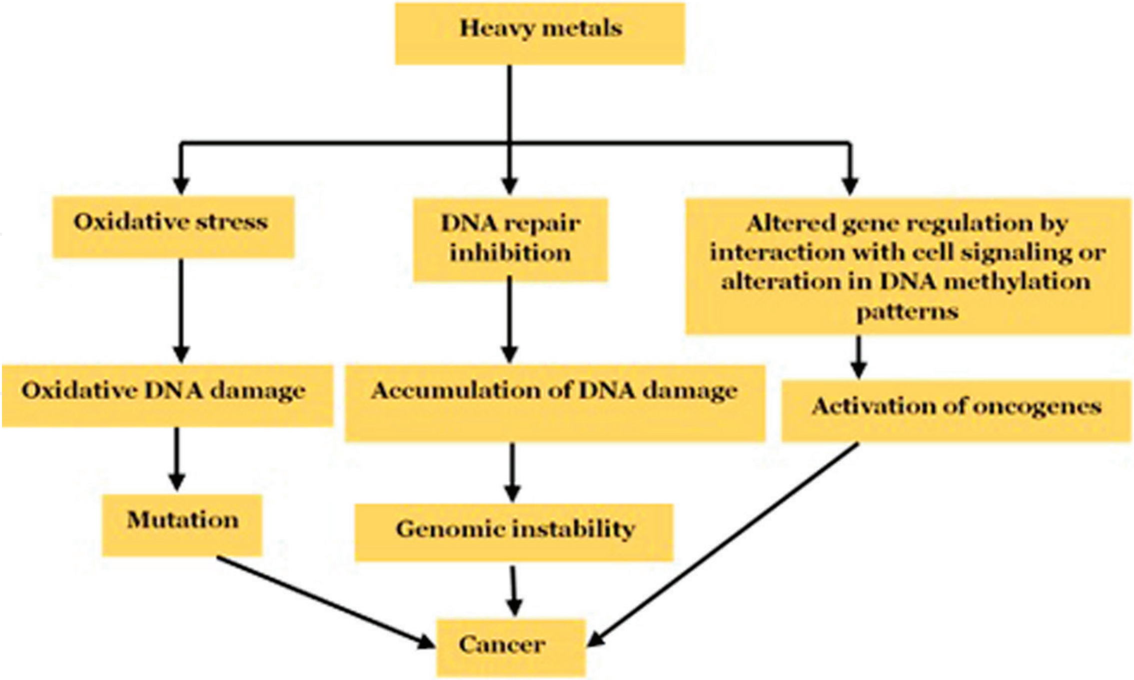

Figure 2.
Mechanism of heavy metal induced carcinogenicity (Source: Hartwig [37]).

mitochondrial and microsomal lipid peroxidation, as well as increased urine lipid metabolite excretion, including malondialdehyde.

In humans, heavy metals have been linked to harmful health consequences. Respiratory malignancies have been recorded among workers exposed to Cr, Sn, Pb, and As-containing substances in the workplace following the epidemiological research [35]. DNA strand breakage in peripheral lymphocytes and lipid peroxidation products in urine in exposed employees reinforce the proof of heavy metal-induced human toxicity. Oxidative damage is assumed to be the cause of genotoxic impacts, such as chromosomal abnormalities and DNA strand breaks. According to the current study by Singh et al. [36], non-oxidative processes appear to have a role in carcinogenesis. Carcinogenicity appears to be linked to inhalation of less soluble chemicals such as Sn and Cr. Surface charge, phagocytization capacity, crystal modification, and size are all features of chromium that may be significant in predicting cancer risk, according to epidemiological studies (**Figure 2**).

4. Heavy metals in the environment

Environmental research on heavy metals requires a basis in environmental chemistry, ecotoxicology, and ecology. The study of xenobiotics in food chains is a significant field of research with important environmental, ecological, and economic implications. According to Ali et al. [38], marine chemistry has public health implications: “Aquatic chemistry is a key component of public health”.

Understanding heavy metal pollution in coastal areas of certain countries, such as Asian and Oceania countries, is vital due to a lack of research and advanced xenobiotic monitoring methods. In recent years, several methods for detecting heavy metals in environmental matrices have been developed. Supercritical fluid extractions [39], acid extraction, alkaline extraction digestion with sodium hydroxide, and subsequent extraction with tetra ethyl ammonium hydroxide are examples of these methods [40]. When heavy metals are present in matrices at very low levels (ppb and ppt), however, extracting these chemicals is time-consuming, costly, and a source of inaccuracy and cross-contamination [41]. As a result, in many regions around the world, detecting heavy metals in aquatic settings has become difficult and inaccessible. solid phase extraction (SPE) and liquid-liquid extraction (LLE) are the most prevalent methods for separating metal compounds from matrices [42]. SPE cartridges, on the other hand, are costly and nonreusable, while LLE extraction procedures require a substantial volume of organic solvents. Bandara et al. [20] have optimized an automated solid phase micro extraction (SPME) method to detect tributyltin at ultra-trace concentrations (ppt levels) because it reduces sample preparation, solvent usage, and analytical costs.

For the quantitative determination of metals, atomic absorption spectrometry (AAS), inductively coupled plasma-mass spectrometry (ICP-MS), and gas chromatography-mass spectrometry (GC-MS) are widely employed.

4.1 Heavy metal quantification

For the assessment and implementation of heavy metal pollution management methods, environmental monitoring and quantification are required. The concentrations of potentially toxic metals and metalloids in diverse environmental media, such as water, sediments, and biota, should be monitored regularly. This environmental analysis will provide important information on the distribution, major sources, destination, and bioaccumulation of these elements in the environment, as well as on their bioaccumulation.

4.2 Assessment of heavy metal pollution using biomarkers and bioindicators

Łuczynska et al. [43] explain the use of bioindicators for heavy metal pollution monitoring and evaluation as follows: "Measuring metal concentrations in selected species of the resident biota could provide a more meaningful assessment of the impact of metal pollution." To assess heavy metal contamination and environmental pollution, a variety of plant and animal species have been used as bioindicators. Bandara et al. [20] studied the impact of tributyltin contamination in the Sri Lankan coastal stretch employing mollusks *Perna perna*, *Thias clavigera*, and *Perna viridis* at commercial and fishery harbors as the first record of tributyltin contamination.

4.3 Atomic absorption spectrometry (AAS)

By its simplicity and the fact that it can quantify a large number of metals (cobalt, chromium, cadmium, copper, iron, manganese, nickel, lead, and zinc) with a minimum detection limit of 1 ppb, flame atomic absorption spectrometry (FAAS) is extensively used for metal determination from the soil, water, and biological samples. A graphite furnace and greater atomization temperatures are required for electrothermal atomic absorption spectrometry (ETAAS). This method has the advantage of requiring a minimal sample volume (20–50 uL) and having excellent minimum detection limits at parts per billion level.

The use of chemical modifiers in ETAAS analysis of volatile elements (arsenic, antimony) is required to stabilize the analysis, which would otherwise evaporate at temperatures above 400°C. One of the most successful methods for determining trace elements in various matrices is chemical vapor production in combination with atomic absorption spectroscopy. HGAAS (hydride generation atomic absorption spectroscopy) and cold vapor atomic absorption spectroscopy are two examples of this technology (CVAAS). HGAAS is used for the analysis of hydride-forming metals (selenium, arsenic, tin, and lead) while CVAAS is used for mercury analysis from various samples.

4.4 Mass spectrometry with inductively coupled plasma (ICP-MS)

ICP-MS (inductively coupled plasma-mass spectrometry) is a method for analyzing multi elements at trace levels in a range of liquid samples. It has a high level of precision and accuracy. As a result, solid materials must be digested before the examination, and digestion methods require the use of HNO_3 or HNO_3 and H_2O_2. In argon plasma, the material is atomized and ionized, and the resulting ions are sorted by a mass analyzer according to their mass-charge ratio (m/z) before being detected at the detector. The detection limits of this method are 0.2 ppt in solution and 0.1 ppb in tissues.

4.5 Solid phase micro extraction (SPME) and GCMS method

SPME is a solvent-free method that was developed by Pawliszyn in 1989 and combines sample extraction and concentration in a single process [44]. It consists of an organic phase-coated fiber that uses absorptive/adsorptive processes to selectively extract and concentrate the analytes present. SPME- GCMS procedure has mainly four steps that include extraction, derivatization, separation, and final detection. Ion exchange and gas chromatographic (GC) systems have been used to detect metal compounds directly from aquatic samples. The advantages of heavy metal determination include the availability of compound-sensitive, simple, cost-effective, and selective detectors (MS) with high-resolution power methods [45]. The recovery rate

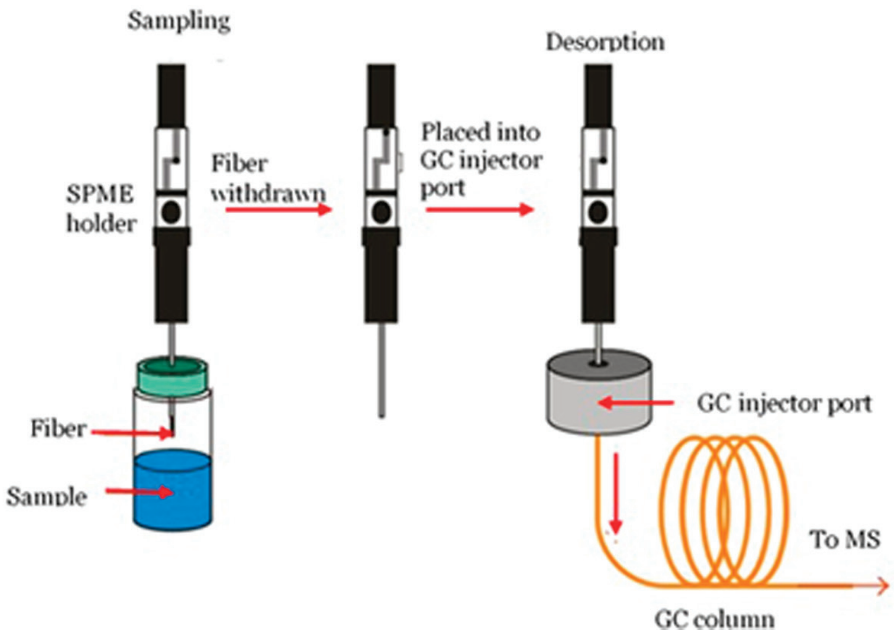

Figure 3.
SPME-GCMS analysis protocol of TBT. Source: Schmidt and Podmore, [46].

of this method to detect the quantity of organotin (Sn) in marine water was found to be 88% by Bandara et al. [20].

Heavy metal usage and contamination of the environment could come from active maritime heavy boating and shipping activities in coastal areas, as well as other industrial activities. As a result, SPME is a cost-effective, precise, and sensitive standardized method to detect and quantify heavy metals at the parts per trillion level anywhere in the world (**Figure 3**).

5. Conclusions

In both aquatic and terrestrial environments, heavy metals and metalloids are common pollutants. The hazard of an environmental chemical is determined by its persistence in the environment, as well as its toxicity and bioaccumulative potential. Toxic environmental pollutants that are persistent and bioaccumulative are more hazardous. persistence, bioaccumulation, and toxicity (PBT) are the three characteristics of heavy metals that make them hazardous. Some of the most environmentally hazardous heavy metals and metalloids are Cr, Ni, Cu, Zn, Cd, Pb, Hg, and As. These components' trophic transmission in aquatic and terrestrial food chains/webs has significant implications for animal and human health. The concentrations of potentially hazardous heavy metals and metalloids in various environmental segments as well as in the resident biota must be measured and monitored. Environmental chemistry and ecotoxicology of hazardous heavy metals and metalloids reveal that measures should be done to decrease their impact on human health and the environment. Some suggestions are as follows:

I. Heavy metal and metalloid background concentrations should be documented in various environmental media around the world for future reference.

II. Assess and record the levels of potentially toxic heavy metals and metalloids in water, sediments, and resident biota regularly.

III. Regular studies should be conducted to quantify the daily consumption of freshwater fish and other consumables, such as rice, by the world's resident population. This data will aid in a more reliable and accurate evaluation of human and environmental risk.

IV. Heavy metal contamination in aquatic and terrestrial ecosystems should be kept to a minimum to protect the biota and the health of its consumers.

V. The adverse impacts of toxic heavy metals on human health and the environment should be made widely understood.

VI. Before being released into natural waterways, industrial wastewaters must be properly treated.

VII. A priority for protecting human health and the environment should be encouraging and promoting scientific research on the environmental assessment of harmful substances, particularly heavy metals and metalloids.

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