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# MOLLUSCS AS BIOMONITORS OF HEAVY METAL POLLUTION: A REVIEW

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**ABSTRACT**
Heavy metal pollution is a worldwide incident with serious consequences. Heavy metals are continuously discharged into the aquatic ecosystem and potentially accumulate in water as well as sediments. This affects the health of the aquatic organisms and the accumulated heavy metals also get transferred to human beings through the food chain. Molluscs are considered as a potential biomonitor for heavy metal contamination in the marine ecosystems due to their wide geographical distribution, sedentary and sessile lifestyle. Being filter-feeders they bioaccumulate several contaminants in their tissues at a much greater rate. Thus, the metal body burden in molluscs might mirror the concentrations of metals in water and sediment giving a sign about the quality of the surrounding environment. This review will provide a general overview of the studies that have used molluscs in aquatic ecosystems influenced by heavy metals as sentinel bioindicators. It will also give some recommendations to control heavy metal pollution and protect the aquatic ecosystem and human beings.

**Keywords:** Heavy metals, Bioaccumulation, Mollusc, Environmental contamination, Biomonitors.

## 1. INTRODUCTION

High population growth, intensive urbanization, increasing industrial activity and exploitation of natural resources has led to a constant increase in the concentration of organic and inorganic discharges entering our aquatic ecosystem [1]. The waste generated by the above-mentioned processes is getting concentrated all over the world, exceeding the critical levels which have been set by different international standards [2]. In several cases, although these metals occur in the natural water bodies at levels which are below their toxic thresholds but since they are non-degradable in nature even low concentrations pose a substantial risk of damage. This is because aquatic organisms like mollusks uptake the heavy metals from water and sediments and being not able to either metabolize or excrete them subsequently bioaccumulate it [3].

A number of scientific research done on heavy metal pollution showed them bioconcentrating and bioaccumulating across the different trophic levels of the food chain [4-6]. When such toxic heavy metals accumulate in an organism's body at high concentration, it leads to an environmental problem. Heavy metals enter the food chain and get accumulated at hazardous levels in different trophic levels. Heavy metal pollution and its toxic effects on aquatic species have received growing attention over the past few decades. Manganese (Mn), Iron (Fe), zinc (Zn), copper (Cu) have important roles in living organisms, hence called essential metals [7]. However, they cause severe damage, if they accumulate in the body at concentrations enough to cause poisoning. Lead, cadmium and mercury play no role in living organisms hence they are toxic even if present in trace amounts [8].

Organisms which provide quantitative information on the environment's quality are generally referred to as biomonitors [9]. They can be plants, animals or fungi giving information about their atmosphere's quality. Generally, biomonitors are characterized by their sedentary lifestyle, wide geographical distribution, easy collection & identification [10]. The study of heavy metal accumulation in aquatic organisms can provide a better picture of metal pollution in the aquatic ecosystem than just the analysis of water or sediment [11]. On account of wide geographical distribution, high tolerance limit to various stresses and round the year availability, molluscs, especially class bivalvia and gastropoda are majorly used as a tool for biomonitoring of aquatic ecosystem. The concentration at which heavy metals accumulate in living organisms is much higher than that present in their surrounding environment [12].

## 2. HEAVY METALS AS MAJOR CONTAMINANT OF AQUATIC ECOSYSTEM AND NEED FOR ITS MONITORING

Heavy metals contamination in aquatic ecosystems has been extensively documented since the mid-1950s when there were Mercury and Cadmium contamination catastrophes in Japan as a result of pollution of the coastal, river and irrigation systems by chemical plants and mining-process effluents [13]. These heavy metals enter the aquatic ecosystem via both anthropogenic & natural sources. The natural sources contributing to metal pollution includes forest fires, erosion of soil and other calamities like volcanic eruptions. Domestic effluents, urban water run-off, mining, petroleum industry, untreated discharges released from industries are some of the sources which contribute to anthropogenic sources [14]. Elevated metal concentrations can result in a decrease or total eradication of those species which are not able to tolerate it and thus has a significant effect on the diversity and trophic structure of the biological community [15].

Metals with a specific density considered to be above 5 $gm/cm^3$ are normally called as heavy metals. These are considered to be toxic with serious health implications. Heavy metals make up 23 of the 35 metals that are a significant source of concern for human beings who are exposed to them via residential and industrial exposure. Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Cadmium (Cd) and Chromium (Cr) are the main toxic metals which pollutethe aquatic ecosystem. Zn, Cu, Ni, and Cr comes under essential trace elements for living organisms but they too become lethal at higher concentrations [16].

As heavy metals possess conservative nature, they get bioaccumulated and biomagnified on passing through-successive levels of the food chain. An organism may acquire these metals in its body either directly from the abiotic environment, like soil, water, sediments or they may enter the organism's body through its food. In the case of molluscs, they acquire it through the sediments and water. When these molluscs are consumed by the next trophic level organisms (like fish, mammals) in the food chain, the heavy metals get accumulated in them and this way gets biomagnified as shown in fig.1.

The risk of human health problems is one of the consequences of such transmission through the food chain. As shown in fig. 2, when humans consume such heavy metal accumulated molluscs they suffer from various toxic effects. Example of these effects in humans include reduced growth and development, organ damage, neuronal impairment, damage to mucus tissues, intestinal tract and reproductive systems at higher levels and in extreme cases they are even lethal [16, 17]. Chronic exposure to an elevated level of heavy metals may lead to degenerative diseases like Alzheimer's, muscular dystrophy and Parkinson's even causing cancer [18].

Metal toxicity in water bodies is a problem of increasing significance from an ecological, evolutionary, nutritional and environmental point of view. Keeping all other sources aside, even if only metals discharged from domestic wastewater and sewage is considered, it proves that this will be a long-term problem for science and humanity [19]. Previously only water and sediments were monitored to check heavy metal contamination however, this was found to be inaccurate as no information was provided about its accumulation in different organisms [20, 21]. Hence currently major research work is done using benthos which provides us information not only about the level of contamination but also about its long-term effects on the environment.

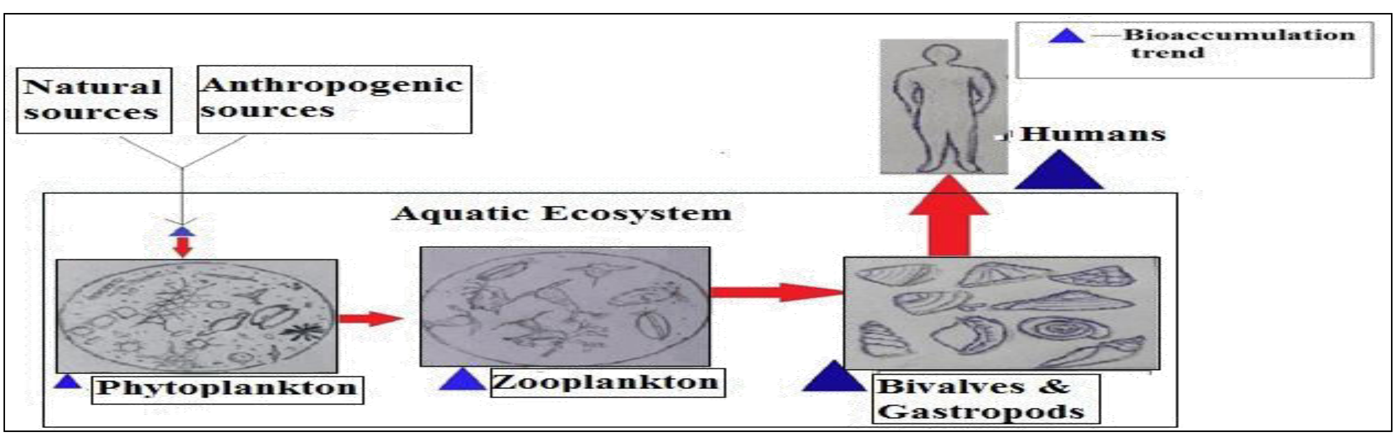


**Fig. 1: Bioaccumulation and biomagnification of heavy metals in the food chain**

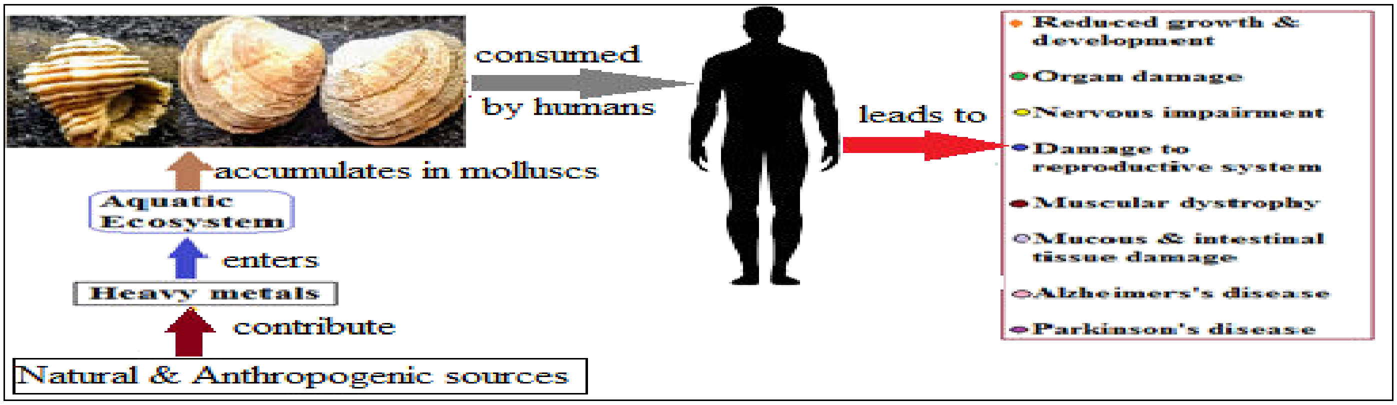


**Fig. 2: Effects of heavy metals in humans on the consumption of heavy metal accumulated mollusks**

## 3. SIGNIFICANCE OF MOLLUSC AS BIOINDICATORS

Molluscans are dominant benthic community biomass, representing a basic food for the next trophic level which is fish [22]. Phylum Mollusca is one of the most diverse phyla in the animal kingdom. It includes seven classes, with class Gastropoda constituting over 80% of the species. Bivalves which constitute around 15% of the total species are the second largest class of the phylum. Molluscs majorly belong to the marine ecosystem but also have few species of the classes bivalves and gastropods living in the freshwater ecosystems [23].

In the year 1976, the "Mussel Watch" program, a breakthrough in its area, was started in the United States of America. It was one of the first large scale geographical environmental surveillance programs that used living organisms. It measured pollutants in four bivalve species on more than a hundred sites at the North American coast [23, 24]. The tissues of mollusc were analyzed for heavy metals, petroleum hydrocarbons radionuclides and halogenated hydrocarbons. Later on, many other countries followed this program providing critical information available even today, on the health of the coastal ecosystem.

Natural biomonitors are used for the assessment of the environment's health, as means for detecting changes in the environment and its effects on human society [10]. The conditions for acceptance of organisms as biomonitors for the assessment of contamination were proposed around fifty years ago in 1970 and are still the same [1, 25]. In summary, qualities like abundance, tolerance for a wide range of metal exposures, having a sedentary mode of life, adequate life span, sturdiness to remain healthy during sampling and further processing in laboratory, easy sampling and identification, having high accumulation rates for the metals makes an organism an optimum bioindicator. Molluscs particularly bivalves, fulfil all these qualities to the maximum. They are not able to inactivate, excrete and metabolize toxic heavy metals when compared to crustaceans, arthropodsand vertebrates like fish [23]. This results in a higher bioaccumulation rate of heavy metals in mollusks [26]. Heavy metal accumulated in molluscs gives a better idea about how much metal load is available for uptake in the natural water bodies as this is not provided completely by the number of metals present in sediments and water. Thus, molluscs, on account of their sedentary mode of life, abundance, economic & ecological importance, play a significant role in biomonitoring of heavy metal pollution worldwide [27, 28].

## 4. AQUATIC BIOMONITORING WITH MOLLUSCS

Molluscs such as clams, oysters, mussels have been used to biomonitor trace metals in the aquatic ecosystem since the late 1960s and early 1970s [29]. As bivalve molluscs are filter-feeders, they uptake heavy elements from water, food and inorganic particulates [30]. Many authors have studied the accumulation pattern in different body parts of molluscs. In one of such studies, assessment of heavy metals in seven different body parts including the shells from *Perna viridis* and *Modiolus metcalfei* was carried out [31], the result being high concentration of Zn and low Cd in different parts of the body. Although soft tissues of molluscs have received greater attention for the measurement of metals among researchers as compared to shells, some authors have preferred to use shells for metal measurements [32]. For example, [33] used the 'Mussel Watch' philosophy, but only in the case of shells for heavy metal accumulation.

Seasonal effects on heavy metal accumulation pattern has attracted many researchers in different parts of the country [34, 35]. A study carried out using soft tissue of *Anadaragranosa* for seasonal heavy metals accumulation from Tanjung Balai, Indonesia showed that heavy metals accumulated were higher in the monsoon season [36]. In contrast to this completely different result was observed in soft tissue and muscle of the pen shell, *Atrina maura,* with higher metal concentrations found during the dry season [37]. Similar results were observed in mollusc species from Indonesia, Jakarta Bay and the coastal area of Bengal, Bangladesh showing a lower rate of accumulation in the rainy season [38-40]. In one of the studies, oyster samples were shown to accumulate a higher concentration of heavy metals during the summer and winter seasons in the Oman Sea and China [41, 42]. The peak of heavy metal accumulation was found to be higher in winter and lower in summer in several mollusk species by some authors [43, 44].

Now in many parts of the world, even gastropods are being considered as additional accumulation monitors thereby transforming the original ‘mussel watch’ into a ‘mollusk watch’ [23, 45]. Gastropods constitute around 80% of the total molluscs species with more than 100,000 extant species [46]. They are ubiquitous and abundant in both aquaticand nearly all terrestrial environments making them a suitable biomonitoras defined by [47]. Two gastropod species, *Bellamya bengalensis* and *Melanoides tuberculata* were proposed as cosmopolitan biomonitors [48]. Freshwater snails too have been proposed as a good model for biomonitoring studies of heavy metal pollution [49-52].

Since it’s not possible to give a complete overview of molluscs being used as bio-monitors in this current article, therefore examples of some work done on the same will be given here in table 1 from different parts of the world showing that both bivalves and gastropods are majorly used as biomonitors.

## 5. METAL LIMITS IN SOFT TISSUES OF FISH MUSCLES FOR FOOD SAFETY

Table 2 summarizes the Maximum Permissible Limit (MPL) of certain heavy metals set by different International standards in soft tissues of fish for food safety. Some of these metals like Cu, Fe, and Zn being essential micronutrients, there is no limit imposed in certain countries for seafood safety.

**Table 1: Literature data of heavy metal concentration in a few species of bivalves and gastropods from different parts of the world**

| Location | Species | (Unit/organ) | Heavy metals | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| ASIA | **Bivalves** | | Cd | Cu | Zn | Ni | Pb | Cr | Hg | |
| Ashtamudi estuary, Kerala, India | *Villorita cyprinoids* | mg/kg d.w. | 0.08 ± 0.39 | 13.73 ± 0.59 | 76d.79 ± 0.67 | 2.42 ± 0.39 | 1.46 ± 0.66 | 3.57 ±0.38 | _ | [53] |
| Kabul River, Pakistan | *Anodonta cygnea* | µg/g w. w | 0.9 ±0.8 | 2.7 ±1.3 | 41.7 ±16.6 | 1.5 ±0.9 | 10.1 ±10.7 | 1.1 ±0.9 | - | [54] |
| Yellow Sea, China | *Chlamys farreri* | mg/kg w.w. | 0.06-0.31 | 0.06-0.48 | 0.56-8.60 | _ | 0.01-0.16 | 0.06-0.22 | _ | [55] |
| | *Atrina pectinata* | mg/kg w.w. | 0.14-0.46 | 0.15-0.53 | 5.77-8.48 | _ | 0.03-0.11 | 0.12-0.18 | _ | |
| Coastal waters of Karnataka, India | *Perna viridis* | mg/kg w.w. | 0.24-3.49 | Bdl-1.84 | Bdl-17.36 | Bdl-2.89 | Bdl-1.95 | Bdl-0.46 | - | [56] |
| Pasir Panjang Malaysia. | *Donax faba* | µg/g d. w. | 3.96 | 7.23 | 51.20 | 3.65 | 12.60 | _ | _ | [57] |
| Port shelter, Hongkong | *Perna. viridis* | µg/g d. w. | 1.2 | 8 | 165 | 28 | 11 | - | - | [58] |
| Reinike Island, Russia | *Crenomytilus grayanus* (Digestive gland) | mg/kg d.w. | 3.8± 2.3 | 12.0 ±1.1 | 108±50.0 | _ | _ | _ | _ | [59] |
| Jinhae Bay, Korea | *Crassostrea gigas* | µg/g w. w | 0.59 ±0.19 | 32.5 ±11.1 | 154 ±46.8 | 0.15±0.06 | 0.15 ±0.06 | 0.22 ±0.10 | 0.01±0.00 | [60] |
| | | | Oceania | | | | | | | |
| Hawkesbury River, Australia | *Crassostrea commercialis* | µg/g d. w | 0.8 -2.1 | 160 - 180 | 1,440-5,440 | - | 0.1- 0.5 | - | 0.12- 0.27 | [61] |
| Maa Bay, New Caledonia | *Comptopallium radula* | µg/g d.w. | 3.57 ±2.69 | 3.91 ±0.38 | 176 ±62 | 13.8 ±4.39 | _ | 3.17 ±1.25 | _ | [62] |
| West Coast & Nelson, New Zealand (Gill) | *Perna canaliculus* | µg/g d.w. | 0.77± 0.14 | 10.6±4.56 | 92.6±280 | 1.93±0.71 | 1.06±0.38 | _ | _ | [64] |
| | | | Europe | | | | | | | |
| East Adriatic Sea, Croatia | *Mytilus galloprovincialis* | mg/kg d.w. | _ | 3.7-11.1 | 59.1-273 | 0.8- 5.0 | 2-7 | 1-2.9 | _ | [64] |
| Balearic Islands, Spain | *Mytilus galloprovincialis* | µg/g d.w. | 2.83 | 4.76 | 234 | _ | 2.48 | 0.53 | 0.2 | [65] |
| Veneto Region, Italy | *Mimachlamys varia* | µg/g w.w. | 0.26 ±0.31 | _ | _ | _ | 0.21±0.15 | _ | 0.02±0.02 | [66] |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Port Neuf, France | *Mimachlamys varia* | μg/g d.w. | 32.1± 3.19 | 66.6± 7.5 | 61.1 ±4.44 | 1.06±0.09 | 0.92 ±0.06 | 0.50 ±0.06 | _ | [67] |
| Ria de Aveiro, Portugal | *Venerupis philippinarum* | μg/g w.w. | 0.045-0.084 | 0.552-1.78 | _ | 0.400-1.16 | 0.160 -0.339 | | 0.013-0.039 | [68] |
| Italy Tyrrhenian coastal areas | *Mytilus galloprovincialis* | mg/kg d.w. | 0.33-0.49 | 5.51-11.5 | 123-180 | _ | 1.67-2.49 | 0.46-1.31 | _ | [69] |
| Alb estuary, Germany | *Corbicula species.* | μg/g d.w. | 0.1 | 38 | 128 | 0.78 | 0.28 | 2 | _ | [70] |
| | | | | | Africa | | | | | |
| Damietta, Egypt | *Donax species* | μg/g w.w. | 0.23 | 30.8 | 65.6 | | 2.48 | | 0.46 | [71] |
| Sidi Moussa lagoon, Morocco | *Venerupis decussatus* | μg/g d.w. | 2.2.1 | 11 | 103.1 | 22.4 | 4.1 | 9.6 | 0.3 | [72] |
| Mediterranean Sea, Libya | *Modiolus galloprovincialis* | μg/g d.w. | 0.63 -2.41 | 3.56 -5.69 | 141 -197 | 1.00 -5.03 | 0.44 -0.71 | 0.37-0.71 | 0.045-0.069 | [73] |
| Lake Timsah, Egypt | *Paratapes undulata* | μg/g d.w. | 1.1 | 11.4 | 73.8 | 5 | 13.9 | 5 | - | [74] |
| | | | | | America | | | | | |
| Venezuela | *Perna viridis* | mg/kg w.w. | 0.02-0.05 | 1.42-3.43 | 8.75-16.38 | 0.22-1.3 | _ | 0.12-0.16 | 0.02-0.08 | [75] |
| Arraial do Cabo, Brazil | *Nodipecten nodosus* | μg/g w.w. | 0.1-0.4 | 1-4 | 8-11 | 0.1 -0.15 | <0.12 | 0.4-1 | _ | [76] |
| Choctawhatchee River, USA | *Corbicula fluminea* | μg/g w.w. | 0.25 | 9.8 | 14 | - | 1.2 | - | _ | [83] |
| Santa Catarina, Brazil | *Crassostrea gigas* | μg/g w.w. | <0.5 | 1.71 | - | 0.05 | <0.5 | - | _ | [78] |
| | ***Gastropods*** | | | | | | | | | |
| ASIA | | | | | | | | | | |
| Upo wetland, Korea | *Cipangopoludina chinensis* | μg/g d.w. | _ | 46.1± 12.2 | 198± 45 | 4.8± 2.2 | 1.67 ± 0.65 | 34.8 ± 96.1 | _ | [79] |
| Uppanar Estuary, India | *Cingulina cingulata* | ppm | 0.026 ±0.01 | 3.00 ± 0.05 | 7.76± 0.05 | - | 0.07 ± 0.01 | - | _ | [80] |
| Intertidal area, Malaysia. | *Nerita lineata* | μg/g d.w. | 1.03 | 25.24 | 92.75 | 5.85 | 92.73 | _ | _ | [81] |
| Sanmen Bay, China | *Thais bronni* | μg/g w.w. | 3.05-9.64 | 8.18-96.81 | 64.54-132.93 | _ | 0.05-0.64 | 0.08-0.31 | 0.008-0.018 | [82] |
| Uran coast, India | *Bursa spinosa* | ppm | 0.216 | 0.599 | 0.345 | _ | _ | _ | _ | [83] |
| Chendering Beach, Malaysia | *Thais aculeata* | μg/g d.w. | 11.3 ± 5.9 | 150.3 ±58.00 | 158.4± 27.90 | _ | _ | 0.6 ± 0.30 | _ | [84] |
| Tarapur, India | *Nerita oryzrum* | ppm | 0.02- 0.05 | 0.43-1.47 | 1.03- 1.42 | 0.06 -0.09 | 0.04-0.11 | 0.03- 0.13 | _ | [85] |
| | | | | | Europe | | | | | |
| Scheldt estuary, Belgium | *Littorina littorea* | μg/g d.w. | 0.92 | 68.22 | 80 | 3.43 | 0.86 | 1.34 | _ | [86] |
| Orwell UK | *Littorina littorea* | μg/g d.w. | 0.57 | 86.5 | 80.1 | 9.06 | 0.88 | _ | 0.34 | [87] |
| France | *Bolinus brandaris* | mg/kg w.w. | 0.85 | _ | _ | _ | 0.08 | _ | 0.07 | [88] |
| | | | | | Africa | | | | | |
| Timsah | *Turritella carinifera* | μg/g d.w. | _ | 13.9 | 75.2 | _ | 42.7 | 18.3 | _ | [89] |
| Red Sea coast, Egypt | *Nerita albicilla* | ppm | _ | 1.35 | 2.5 | 4.9 | 104.3 | _ | _ | [90] |
| Nigeria | *Lanistes lybicus* | mg/kg d.w. | _ | _ | _ | _ | _ | 18.5 | _ | [91] |
| Patagonia, Argentina | *Buccinanops globulosus* (Foot) | μg/g d.w. | 0.29 | 17.26 | 77.29 | _ | 1.02 | _ | _ | [92] |
| | *Trophon geversianus* | μg/g d.w. | 1.23 | 29.77 | 183.09 | _ | _ | _ | _ | |
| Saint-Augustin Lake, Canada | *Cipangopaludina chinensis* | mg/kg d.w. | 0.6 | 10.8 | 56.9 | 1.05 | 1.0 | 0.3 | _ | [93] |

*Bdl- below detection limit; d.w.- dry weight;w.w.- wet weight ppm- parts per million.*

**Table 2: Maximum Permissible Limit set by International Standards of few heavy metals in fish tissue**

| International Standards | Metals (μg/g) | | | | | | | References |
|---|---|---|---|---|---|---|---|---|
| | Cu | Cd | Pb | Zn | Ni | Fe | Cr | |
| Food and Drug Administration of the United States | - | 0.01-0.21 | 0.5 | - | - | - | - | [94] |
| Food and Agriculture Organization | 30 | 0.05 | 0.5 | 40 | - | - | - | [95] |
| (FAO/WHO) Joint | 30 | 1 | 2 | 40 | | | | [96] |
| European community | - | 0.05 | 0.2 | - | - | - | - | [97] |

## 6. CONCLUSION

Heavy metals are universal environmental pollutants in aquatic as well as terrestrial ecosystems. They satisfy all three criteria: Persistence, Bioaccumulation, and Toxicity (PBT), required to be considered as hazardous environmental chemicals. These metals which enter the aquatic system through various sources are readily transported from one system to another in the food chain and thereby get bioaccumulated and biomagnified. Bivalves and gastropods have been successfully used as biomonitors in various monitoring programs. They are ubiquitous, widespread and have a sessile mode of life thereby representing the pollution level of their habitat. Both the soft tissues and shells of molluscs can be used to measure aquatic contaminants like heavy metals where their concentration is several magnitudes higher than those in the ambient environment. They also satisfy other conditions like relatively longer life span, size, sturdiness, suitable dimensions, high tolerance to environmental changes, and easy identification and collection required to be an optimum bioindicator. Thus, mollusks are an important organism for biomonitoring studies with clear advantages over other groups. This review may be used as a base for future research, for knowledge about human exposure tocontaminants as a result of seafood consumption and can further be used to determine consumption recommendations and warnings.

## 7. RECOMMENDATIONS

For the safety of public health and maintaining the quality of seafood, it is very important to give attention to heavy metals accumulation in the aquatic organisms as many times they accumulate toxic metal at levels exceeding the safety limit. Therefore, the following measures are recommended to minimize the toxic effects of heavy metals on human health and conserve our ecosystem.

- Heavy metal contamination in the aquatic ecosystem should be assessed and monitored regularly.
- Effective treatment of wastewaters from industries before discharging them into the natural water bodies.
- Evaluating the current methods for sample collection, its storage, analysis and then select the optimum one for pollution evaluation.
- Taking strict measures for protecting the environment as well as controlling the discharge of toxic heavy metals from various anthropogenic sources.
- Encouraging scientific research on the assessment of toxic heavy metals in the environment through adequate funding for the well-being of humans as well as our ecosystem.
- Increasing public awareness regarding the need for protecting the aquatic environment in order to maintain sustainable development.

***Conflict of interest***

The authors declare no conflict of interest.

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