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Heavy Metal Accumulation in Aquatic Environments and Its Implications for Fishery Products and Human Health

Niken Candra Dewi[1]

[1] Universitas Nahdlatul Ulama Surabaya, Surabaya, Indonesia

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Abstract

Heavy metal pollution in aquatic environments is a global issue with significant impacts on ecosystems and human health. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and zinc (Zn) are toxic, persistent, and capable of accumulating in aquatic organisms through the processes of bioaccumulation and biomagnification. This study aims to analyze heavy metal accumulation in aquatic environments and its impact on fishery products and human health using a Systematic Literature Review (SLR) approach. Data were collected from scientific articles published over the past five years relevant to the research topic. The review results indicate that heavy metals are distributed in water, sediments, and aquatic biota, with sediments serving as the primary accumulation medium. Aquatic organisms, particularly fish, have the potential to accumulate heavy metals in their body tissues, which can then be transferred to humans through consumption. Long-term exposure to heavy metals can cause serious health problems, including damage to organs and the nervous system. Therefore, sustainable environmental management and water quality monitoring are necessary to minimize the associated risks.

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1. Introduction

Pollution of the aquatic environment due to heavy metals has become a global issue that has received widespread attention in recent decades. Anthropogenic activities such as industry, mining, agriculture, and domestic waste contribute significantly to the increase in heavy metal concentrations in the aquatic environment. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and zinc (Zn) are known to have toxic, persistent, and ability to accumulate in ecosystems, posing a serious risk to the balance of the environment and human health (Ali et al., 2019; Briffa et al., 2020).

The presence of heavy metals in the waters is not only limited to the water column, but is also distributed in sediments and aquatic organisms. The process of bioaccumulation allows heavy metals to accumulate in the tissues of organisms over time, whereas biomagnification leads to an increase in the concentration of those metals throughout the food chain. As a result, high-trophic level organisms, including fish consumed by humans, tend to contain higher concentrations of heavy metals (Yan et al., 2019; Sheikhzadeh & Hamidian, 2021).

The impact of heavy metals on aquatic organisms is very diverse, ranging from physiological disorders, growth, to reproduction. Long-term exposure to heavy metals can cause oxidative stress, tissue damage, as well as decreased organisms' adaptability to the environment. These conditions not only affect the survival of species, but also have implications for the quality and safety of fishery products as the main food source for humans (Maurya & Malik., 2019).

Furthermore, the consumption of fishery products contaminated with heavy metals is one of the main routes of exposure for humans. Certain heavy metals are known to have serious toxic effects on human health, such as nervous system disorders, kidney damage, and carcinogenic effects. For example, mercury is known as a harmful neurotoxin, while cadmium can cause chronic kidney damage. Therefore, the presence of heavy metals in the aquatic food chain is an important concern from a public health perspective (Amqam et al., 2020; Zaynab et al., 2021).

Although various studies have been conducted on the distribution and impact of heavy metals in the aquatic environment, there is still a need to comprehensively examine the relationship between the accumulation of heavy metals in aquatic ecosystems and their implications for fishery products and human health. In addition, variations in the degree of accumulation in different types of organisms as well as differences in environmental conditions suggest that this phenomenon is complex and requires an integrated analytical approach (Hashempour-Baltork et al., 2023).

Based on this background, this study aims to analyze the accumulation of heavy metals in the aquatic environment and evaluate its impact on fishery products and human health. The results of this study are expected to make a scientific contribution in understanding the risk of heavy metal pollution and become the basis for sustainable management of aquatic resources.

2. Literature Review

Heavy metal pollution in the aquatic environment has been the focus of various studies in recent years, especially related to its toxic properties, persistence, as well as its ability to accumulate in biological systems. Heavy metals such as Pb, Cd, Hg, and Zn are known to have stable chemical characteristics and are difficult to degrade, so they can survive in the environment for a long period of time. Studies show that the presence of heavy metals in waters generally comes from anthropogenic activities, including uncontrolled industrial waste, agriculture, and urbanization (Briffa et al., 2020).

In aquatic ecosystems, heavy metals undergo complex distributions that involve interactions between water, sediment, and living organisms. Sediment often acts as the main reservoir of heavy metals, which can be released back into the water column at any time due to changes in environmental conditions such as pH and temperature. This process increases the availability of heavy metals for aquatic organisms, which then absorb them through the gills, skin, or food chain. The accumulation of heavy metals in the organism occurs gradually and is influenced by biological and environmental factors (Chen et al., 2022).

Furthermore, the concepts of bioaccumulation and biomagnification are key in understanding the increased concentration of heavy metals in the food chain. Low-trophic level organisms such as plankton can absorb heavy metals from the environment, which are then passed on to higher-level organisms through the process of consumption. As a result, apex predators, including fish for human consumption, tend to have higher concentrations of heavy metals compared to the

surrounding environment. This phenomenon confirms that heavy metal pollution not only has a local impact, but also has far-reaching implications for food safety (Yan et al., 2019).

From a human health perspective, exposure to heavy metals through the consumption of fishery products is a major concern. Various studies show that chronic exposure to heavy metals can lead to serious health problems, including organ damage, nervous system disorders, and an increased risk of chronic diseases. The level of risk is highly dependent on the type of metal, the concentration, and the frequency of consumption. Therefore, evaluation of the heavy metal content in fishery products is an important step in efforts to protect public health (Hashempour-Baltork et al., 2023).

3. Methods

This study uses the Systematic Literature Review (SLR) method to comprehensively examine the accumulation of heavy metals in the aquatic environment and its impact on fishery products and human health. This method was chosen because it is able to provide a systematic, transparent, and structured synthesis of various research findings that have been published previously. The research process begins with the determination of the topic and the formulation of research questions that focus on the source, distribution, mechanism of accumulation of heavy metals, and their implications for aquatic organisms and humans.

The next stage is the identification of relevant literature through a search of scientific databases, especially Google Scholar, using keywords such as "heavy metals in aquatic environments", "bioaccumulation", "biomagnification", "fish contamination", and "human health risk". The inclusion criteria in this study include scientific articles published in the last five years, available in full-text form, and have direct relevance to the research topic. Meanwhile, the exclusion criteria include articles that have not gone through a peer-review process, lack methodological clarity, or are not directly related to the focus of the study.

After the identification process, a screening stage is carried out by reviewing the title, abstract, and content of the article to ensure compatibility with the research objectives. Articles that pass this stage are then further analyzed through a data extraction process, which includes information about the type of heavy metals studied, environmental media (water, sediment, or biota), analysis methods used, and key findings related to the level of accumulation and impact. The data that has been collected is then classified and synthesized qualitatively to identify patterns, relationships, and differences in outcomes between studies.

In the analysis stage, a descriptive approach is used to explain the phenomenon of heavy metal accumulation in a comprehensive way, including the processes of bioaccumulation and biomagnification in the aquatic food chain. In addition, an evaluation of potential human health risks is carried out based on findings reported in the literature. The results of the synthesis were then compiled systematically to provide an integrated picture of the conditions of heavy metal pollution in the waters and their implications.

To maintain the quality and validity of the research, only articles from reputable journals are used as primary data sources. In addition, the selection and analysis process is carefully conducted to minimize bias and ensure that the results obtained reflect accurate and accountable scientific conditions.

4. Results and Discussion

The results of the literature review show that heavy metal pollution in the aquatic environment is a complex phenomenon and is influenced by various factors, both natural and anthropogenic. Industrial, mining, agricultural, and domestic waste activities are the main sources of heavy metals such as Pb, Cd, Hg, and Zn into aquatic ecosystems. These metals have persistent properties and are not easily degraded, so they tend to accumulate in the environment over a long period of time (Ali et al., 2019; Briffa et al., 2020). This condition leads to an increase in the concentration of heavy metals not only in water, but also in sediments and aquatic organisms.

The distribution of heavy metals in the waters suggests that sediments play a role as the main accumulation site. Sediments have the ability to bind heavy metals through chemical and physical interactions, so their concentrations are often higher compared to water columns. Nevertheless, changes in environmental conditions such as pH, temperature, and biological activity can cause heavy metals bound in sediments to release back into the water, thereby increasing their availability to aquatic organisms (Li et al., 2022). This shows that sediment not only serves as a store, but also as a secondary source of pollution.

The process of bioaccumulation is one of the main mechanisms that causes an increase in the concentration of heavy metals in the organism's body. Aquatic organisms such as fish, shellfish, and shrimp can absorb heavy metals through a variety of pathways, including gills, body surfaces, as well as through food. Over time, heavy metals will accumulate in the body's tissues due to a higher absorption rate compared to the excretion rate. Studies show that the level of heavy metal accumulation is greatly influenced by factors such as the species of the organism, age, body size, and environmental conditions in which it lives (Sheikhzadeh & Hamidian, 2021).

In addition to bioaccumulation, the phenomenon of biomagnification also plays an important role in increasing the concentration of heavy metals in the food chain. Low-trophic organisms such as plankton absorb heavy metals from the environment, which are then passed on to higher-level organisms through the process of consumption. As a result, apex predators, including fish for human consumption, tend to have higher concentrations of heavy metals than organisms at lower trophic levels (Yan et al., 2019). This phenomenon suggests that the risk of heavy metal contamination is not only limited to specific organisms, but can spread widely through the food chain.

The impact of heavy metals on aquatic organisms is significant, especially at the physiological and biochemical levels. Exposure to heavy metals can cause oxidative stress due to increased production of free radicals in the organism's body. This condition can damage cell structure, interfere with enzyme function, and cause tissue damage. In addition, heavy metals are also known to interfere with the

reproductive system, growth, and development of aquatic organisms, ultimately impacting the sustainability of the population (Maurya & Malik., 2019). These impacts suggest that heavy metal pollution affects not only individuals, but also ecosystems as a whole.

In the context of fishery products, the accumulation of heavy metals is a major concern because it is directly related to food safety. Fish and other marine organisms are an important source of protein for humans, but they also have the potential to be a medium of exposure to heavy metals. Research shows that some fish species have a tendency to accumulate heavy metals in certain tissues such as liver, gills, and muscles. The muscle parts commonly consumed by humans often contain small amounts of heavy metals, although the concentration varies depending on environmental conditions and species type (Moiseenko & Gashkina, 2020).

From a human health perspective, the consumption of fishery products contaminated with heavy metals can pose a variety of health risks. Long-term exposure to heavy metals can cause serious disorders, such as nervous system damage, impaired kidney function, as well as other toxic effects. Mercury, for example, is known as a neurotoxin that can affect the development of the nervous system, especially in children. Meanwhile, cadmium can cause kidney damage and impaired calcium metabolism (Zaynab et al., 2021). This risk is becoming increasingly important considering the high dependence of the community on fishery products as a food source.

Health risk assessment is an important approach in evaluating the impact of heavy metal consumption on humans. Parameters such as Estimated Daily Intake

(EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) are often used to assess the level of risk. The results of various studies show that although most values are still within safe limits, there is a potential risk under certain conditions, especially if consumption is carried out continuously over the long term (Amqam et al., 2020). This emphasizes the importance of monitoring the quality of fishery products.

In addition, the variation in the results of the study shows that the level of heavy metal contamination is greatly influenced by environmental conditions and surrounding human activities. Factors such as proximity to pollution sources, water currents, as well as sedimentary characteristics can affect the distribution of heavy metals. Therefore, a general approach still needs to consider the variability of environmental conditions in the interpretation of results (A El-Amier et al., 2021).

Although much research has been done, there is still a gap in understanding the interactions between the various factors that affect the accumulation of heavy metals. Some studies have shown significant differences between species in the ability to accumulate heavy metals, which suggests the need for a more specific approach in risk analysis. In addition, the limitation of long-term data is also an obstacle in understanding the dynamics of heavy metal pollution as a whole (Hashempour-Baltork et al., 2023).

Based on the overall results, the results of this study show that heavy metal pollution in the waters is a serious environmental problem with far-reaching implications for ecosystems and human health. The persistent nature of heavy metals, the ability to accumulate, and the potential for biomagnification make this

pollution difficult to control. Therefore, integrated management efforts and continuous monitoring are needed to minimize the impacts (Jayamurali et al., 2021).

5. Conclusion

Heavy metal pollution in aquatic environments is a complex problem with far-reaching impacts on ecosystems and human health. Heavy metals such as lead, cadmium, mercury, and zinc are persistent and toxic, allowing them to accumulate in water, sediments, and aquatic organisms over the long term. The processes of bioaccumulation and biomagnification lead to increased concentrations of heavy metals in the food chain, particularly in high-trophic-level organisms that are frequently consumed by humans.

The accumulation of heavy metals in aquatic biota not only affects the physiological condition and survival of organisms but also impacts the quality and safety of fishery products. Consumption of fishery products contaminated with heavy metals poses the potential for serious health risks, such as nervous system disorders, organ damage, and chronic diseases resulting from long-term exposure. This highlights the close link between aquatic environmental conditions and human health. Based on the study's findings, integrated and sustainable management efforts are needed to control heavy metal pollution. Environmental quality monitoring, pollution source control, and raising public awareness are crucial steps in minimizing the associated risks. Thus, the sustainability of aquatic ecosystems and food safety can be maintained.

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