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Health Risk Analysis of Heavy Metal Contamination in Seafood Consumption

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Abstract

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Heavy metal contamination in the marine environment is a global issue that impacts food safety and human health. Seafood, as a primary source of protein, has the potential to accumulate heavy metals through the processes of bioaccumulation and biomagnification. This study aims to assess the health risks associated with the consumption of seafood contaminated with heavy metals using a Systematic Literature Review (SLR) approach. Data were obtained from scientific articles published in the last five years and analyzed qualitatively. The parameters used in the risk assessment include Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI). The results of the study indicate that most EDI and THQ values are below safe limits; however, there are some conditions where these values exceed the thresholds, particularly in areas with high pollution levels and intensive seafood consumption. Furthermore, HI values indicate that exposure to multiple metals can significantly increase health risks. Environmental factors, organism types, and anthropogenic activities are the primary determinants of contamination levels. Therefore, continuous monitoring and strengthened regulations are necessary to ensure the safety of seafood consumption and protect public health.

1. Introduction

Pollution of the marine environment due to anthropogenic activities is one of the global problems that has continued to increase in recent decades. Various sources of pollutants, such as industrial, agricultural, and domestic waste, contribute to the increase in the concentration of heavy metals in marine waters. Heavy metals have persistent properties, cannot be degraded naturally, and are able to accumulate in the environment and food chains, thus potentially having a serious impact on ecosystems and human health (Ali et al., 2019). This condition makes heavy metal pollution an important issue in environmental studies and food safety.

Seafood is one of the sources of protein that is widely consumed by people in various countries because of its high nutritional content. Nevertheless, marine organisms such as fish, shellfish, and shrimp have the ability to accumulate heavy metals in their body tissues. The process of bioaccumulation and biomagnification causes an increase in the concentration of metals along with trophic levels in the food chain (Okpala et al., 2018). This makes seafood one of the main routes of heavy metal exposure for humans, especially in communities with high levels of consumption.

Heavy metals can be classified into essential and non-essential metals. Essential metals such as iron (Fe), zinc (Zn), and copper (Cu) are needed in certain amounts to support the body's physiological functions, but can become toxic when their concentrations exceed safe limits. In contrast, non-essential metals such as mercury (Hg), lead (Pb), and cadmium (Cd) have no biological function and are toxic even in low concentrations (Briffa et al., 2020). Long-term exposure to heavy metals can lead to a variety of health problems, including nervous system damage, impaired kidney function, as well as an increased risk of chronic diseases.

To understand these potential impacts, a scientific approach is needed that is able to quantitatively measure the level of exposure and health risks. One of the widely used methods is human health risk assessment, which includes the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) parameters. This method is used to evaluate the level of exposure to heavy metals through food consumption as well as the potential non-carcinogenic risks posed (Azizi et al., 2018). With this approach, it can be found out whether the consumption of certain seafood is still within safe limits or has the potential to cause health impacts.

In addition, various international organizations such as FAO/WHO through the Joint Expert Committee on Food Additives (JECFA) and the United States Environmental Protection Agency (US EPA) have set safe limit standards for the consumption of heavy metals in food. This standard is used as a reference in determining the level of food safety and protecting public health from exposure to harmful substances (FAO/WHO, 2018). However, differences in environmental conditions and human activities cause variations in the level of heavy metal contamination in different regions.

A number of studies show that although most seafood is still within safe limits, there is a tendency to increase the concentration of heavy metals in some waters due to increasingly intensive anthropogenic activities (Liu et al., 2019). In addition, factors such as the type of organism, habitat, and consumption patterns of the community also affect the level of exposure to heavy metals. This shows that health risk evaluation needs to be carried out in a sustainable and comprehensive manner.

Based on this description, there are still gaps in the integration of comprehensive risk analysis and data updates related to heavy metal pollution in seafood. Therefore, this study aims to examine the potential human health risks due to the consumption of seafood contaminated with heavy metals using a risk assessment approach that includes EDI, THQ, and HI. The results of this study are expected to contribute to the development of food safety policies and increase public awareness of the risks of seafood consumption.

2. Literature Review

2.1. Heavy Metal Pollution and Bioaccumulation

Heavy metal pollution in the marine environment is the result of the continuous accumulation of anthropogenic activity. The main sources of heavy metals include industrial waste, agriculture, and domestic activities that enter water bodies through river flows and atmospheric deposition. Heavy metals such as cadmium (Cd), mercury (Hg), and lead (Pb) have toxic, persistent, and non-biodegradable properties, so they tend to accumulate in sediments and marine organisms (Milenkovic et al., 2019). The presence of heavy metals in the marine environment is a major concern because of its impact on ecosystem stability and human health.

The process of bioaccumulation occurs when the organism absorbs heavy metals faster than the body's ability to remove them. In addition, biomagnification leads to an increase in the concentration of heavy metals at each trophic level in the food chain. Benthic organisms such as shellfish and mollusks are known to have a high accumulation ability due to their properties as filter feeders that filter particles from the surrounding environment (Chiocchetti et al., 2017). This makes seafood one of the main mediums of heavy metal transfer to humans.

Environmental factors such as pH, temperature, and salinity also affect the level of bioavailability of heavy metals in waters. These variations in conditions cause differences in the rate of metal accumulation in marine organisms. Therefore, understanding the mechanisms of bioaccumulation and biomagnification is essential in assessing potential health risks due to the consumption of contaminated seafood.

2.2. Risk Assessment in Food Safety

Risk assessment is a scientific approach used to evaluate the potential health impacts due to exposure to harmful substances through food consumption. In the context of seafood, commonly used methods include Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI). EDI is used to estimate the amount of heavy metal exposure that enters the human body each day through the consumption of certain foods (Jolly et al., 2019). This value is the basis for determining the initial level of exposure to hazardous substances.

THQ is an indicator used to assess the non-carcinogenic risk of heavy metal exposure. A THQ value greater than one indicates a potential health risk to humans, while a value below one indicates that the risk is still within safe limits (Azizi et al., 2018). This approach is widely used because it provides a simple but effective picture of the level of risk posed by a single type of metal.

In addition, HI is used to evaluate the cumulative risk of exposure to several types of metals simultaneously. The HI value is obtained from the sum of the THQ value of each metal, thus providing a more comprehensive picture of the potential hazards faced (Sanaei et al., 2021). In its interpretation, HI that exceeds one indicates a possible health impact due to exposure to a combination of heavy metals. The use of risk assessment methods that are integrated with international standards such as the Reference Dose (RfD) from the US EPA is very important in ensuring food safety and supporting science-based decision-making in health risk management.

3. Methods

This study uses the Systematic Literature Review (SLR) method to comprehensively examine various scientific findings related to heavy metal pollution in seafood and its implications for human health. This method was chosen because it is able to provide a systematic, structured, and transparent approach in identifying, evaluating, and synthesizing research results that are relevant to the topic being studied. The research process began with the formulation of research focuses and questions that focused on the relationship between the consumption of seafood contaminated with heavy metals and potential human health risks.

The next stage is a literature search conducted through the Google Scholar scientific database using a combination of keywords such as "heavy metals", "seafood contamination", "human health risk assessment", "Estimated Daily

Intake", "Target Hazard Quotient", and "Hazard Index". This search process aims to obtain scientific articles that are relevant to the research topic. After that, a literature selection process was carried out based on the inclusion and exclusion criteria that had been set. Inclusion criteria include articles published in the last 5 years, articles that discuss heavy metal content in seafood, as well as research that uses a health risk analysis approach. Meanwhile, articles that are not topical, do not have access to the full text, or are outside the specified year range are excluded from the analysis process.

After the selection stage, data was extracted from each selected article which included information about the type of metal analyzed, the research method used, and the main results related to the level of contamination and health risks. The data that has been collected is then analyzed qualitatively to identify general patterns, similarities, and differences in results between studies. The final stage of the study is the synthesis of results which aims to draw comprehensive conclusions regarding the level of heavy metal pollution in seafood as well as its implications for human health. This approach is expected to be able to provide a comprehensive and in-depth picture of the issues being researched.

4. Results and Discussion

The results of the literature review show that heavy metal pollution in seafood is a phenomenon that occurs widely and is influenced by various environmental factors and human activities. Various studies indicate that increased industrial activities, urbanization, and poorly managed waste disposal contribute significantly to the high concentration of heavy metals in marine waters. A study conducted by Lin et al. (2021) showed that marine organisms living in waters with high anthropogenic pressure tend to have higher concentrations of heavy metals compared to organisms in relatively clean waters. This confirms that environmental quality plays a very important role in determining the level of seafood contamination.

The heavy metals most commonly found in seafood include cadmium (Cd), mercury (Hg), and lead (Pb), which are known to have high toxic properties. These metals are persistent and are able to accumulate in the tissues of living organisms over a long period of time. According to Ali et al. (2019), chronic exposure to heavy metals can cause nervous system disorders, kidney damage, as well as an increased risk of degenerative diseases. In addition, Briffa et al. (2020) also emphasized that the toxicity of heavy metals depends on the type of metal, the dose of exposure, and the duration of exposure to the human body.

Seafood has a complex role as a source of nutrients as well as a medium of exposure to heavy metals. On the one hand, seafood contains protein, omega-3 fatty acids, as well as various micronutrients that are important for health. But on the other hand, the ability of marine organisms to accumulate heavy metals makes it the main route for contaminants to enter the human body. Okpala et al. (2018) state that the benefits of seafood consumption should be considered in balance with the potential risk of heavy metal contamination, especially in areas with high levels of pollution.

The results of the analysis showed that the level of exposure to heavy metals in humans was generally measured using the Estimated Daily Intake (EDI) parameter. The EDI value describes the amount of metal that enters the body through daily food consumption. Based on several studies, EDI values in most cases are still below the safe limits set by international standards. However, Jolly et al. (2019) found that EDI values can increase significantly in community groups with high levels of seafood consumption, thus potentially increasing health risks.

In addition to EDI, the Target Hazard Quotient (THQ) parameter is used to assess the potential non-carcinogenic risks of heavy metal exposure. A THQ value smaller than one indicates that the health risk is still within safe limits, while a value greater than one indicates a potential negative impact on health. Azizi et al. (2018) reported that in some cases, the THQ value for certain metals such as cadmium and mercury exceeded one, especially in areas with high pollution levels. This suggests that the consumption of seafood from the region can pose health risks if done continuously.

In the context of multi-metal exposure, the Hazard Index (HI) is used to evaluate the cumulative risk of consuming seafood containing more than one type of heavy metal. Sanaei et al. (2021) explain that although the THQ value for each metal is below one, the HI value can exceed one due to the combined effects of several metals. This suggests that an approach that considers only one type of metal is not enough to describe the risk as a whole.

Biological and ecological factors also affect the rate of heavy metal accumulation in marine organisms. Milenkovic et al. (2019) found that benthic organisms such as shellfish and mollusks have higher rates of metal accumulation than pelagic fish. This is due to the feeding habits of benthic organisms that filter particles from sediments, which are often sites of heavy metal accumulation. Thus, the type of seafood consumed is an important factor in determining the level of heavy metal exposure in humans.

In addition, environmental factors such as pH, temperature, and salinity also affect the bioavailability of metals in waters. Chiocchetti et al. (2017) explains that different environmental conditions can cause variations in the rate of metal absorption by marine organisms. Changes in these environmental parameters can increase or decrease the ability of metals to accumulate in the tissues of organisms, thus affecting the level of health risks.

In terms of regulation, various international organizations have set standards for safe limits for the consumption of heavy metals in food. FAO/WHO (2018) through JECFA sets an intake limit value that aims to protect human health from exposure to harmful substances. However, the implementation of these standards in various countries still faces challenges, especially related to environmental quality monitoring and control.

Research conducted by Liu et al. (2019) shows that although most seafood is still within safe limits, there is a tendency to increase heavy metal concentrations in some areas due to human activities. This shows that health risks are not static, but can change along with changing environmental conditions.

Furthermore, Anandkumar et al. (2019) found that industrial activities and urbanization contribute significantly to the increase in heavy metal contamination in marine waters. This emphasizes the importance of good waste management and effective environmental policies in reducing pollution risks.

A comprehensive risk assessment approach is very important in evaluating potential health risks due to seafood consumption. Ahmad et al. (2020) emphasized that the integration of EDI, THQ, and HI parameters provides a more complete picture of the level of exposure and its impact on humans. This approach allows for more accurate identification of risks and can be used as a basis for decision-making.

The results of the study show that heavy metal pollution in seafood is still an issue that needs serious attention. Although most of the research results show that the risk level is still within safe limits, there are certain conditions that can increase health risks, such as high levels of seafood consumption, the types of organisms consumed, and polluted environmental conditions. Therefore, continuous monitoring efforts, increasing public awareness, and strengthening regulations are needed to ensure the safety of seafood consumption and protect human health.

5. Conclusion

Heavy metal pollution in seafood is an environmental problem that has direct implications for human health. Based on the results of the literature review, it can be concluded that heavy metals such as cadmium, mercury, and lead have the ability to accumulate in marine organisms through the process of bioaccumulation and biomagnification. This condition makes seafood one of the main routes for heavy metals to enter the human body, especially in people with high levels of consumption. The risk assessment approach using the Estimated Daily Intake, Target Hazard Quotient, and Hazard Index parameters has proven to be effective in evaluating the level of exposure and potential health risks due to the consumption of contaminated seafood. In general, the results of the analysis show that most of the exposure values are still within safe limits. However, there are certain conditions that can increase health risks, such as high levels of consumption, the types of marine organisms consumed, and environmental conditions that have experienced heavy pollution.

Environmental factors and human activities are the main determinants in the level of heavy metal contamination in marine waters. Therefore, sustainable environmental management and control of polluting sources are indispensable to minimize these risks. In addition, the role of food safety regulations and standards is also very important in ensuring that the seafood consumed is safe for public health. This study emphasizes the importance of an integrated approach in assessing health risks due to seafood consumption, as well as the need for collaborative efforts between governments, researchers, and the community in maintaining environmental quality and food safety.

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