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HEALTH RISK ANALYSIS OF LEAD (Pb) HEAVY METAL CONTENT IN DRINKING WATER IN FLOOD-PRONE AREAS

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Abstract

Floods are hydrometeorological disasters that have the potential to reduce drinking water quality through the mobilization of environmental pollutants, including heavy metals such as lead (Pb). This study aims to analyze lead content in drinking water and assess the level of public health risks due to exposure through the ingestion pathway. The study uses an environmental health risk analysis approach by calculating non-carcinogenic intake (Ink) and Risk Quotient (RQ) based on the rate of water consumption, duration of exposure, frequency of exposure, and body weight of respondents. The research method uses a descriptive survey with a cross-sectional approach conducted in Peunayan Village, Nisam District, North Aceh Regency. The research sample consisted of 50 respondents with a random sampling technique. The results showed that the lead concentration was 0.0010 mg/L and this value is still below the maximum limit stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010, which is 0.01 mg/L for lead parameters in drinking water. The calculation of non-carcinogenic intake showed a real-time value of 0.000053 mg/kg/day with a Risk Quotient (RQ) of 0.014, indicating that non-carcinogenic health risks are still in the safe category ($RQ \leq 1$). Long-term exposure projections showed an increase in intake and RQ values to 0.67 in the 50-year estimate, but remained below the risk limit. These findings indicate that although lead concentrations still meet safety standards, the potential for long-term exposure accumulation requires attention. Therefore, regular water quality monitoring, public education, and the implementation of simple water treatment technologies are important steps in preventing environmental health risks.

Keywords: Lead (Pb), well water , analysis risk health

INTRODUCTION

Floods are one of the most frequent hydrometeorological disasters in developing countries and have widespread impacts on the environment and public health. In addition to causing infrastructure damage and socioeconomic disruption, floods contribute to the mobilization of various pollutants into water systems. Surface runoff, soil erosion, and the mixing of domestic and industrial waste during floods have the potential to degrade the quality of water used by communities as a drinking water source (Ramadan et al., 2024). One group of contaminants of major concern in environmental health is heavy metals, particularly lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As). These contaminants are commonly found in water systems in areas with high environmental stress and have the potential to enter domestic water sources such as dug and drilled wells. Recent research has shown that flooding can increase the release of heavy metals from sediments into the water column, thereby increasing the potential for surface and groundwater pollution (Wu et al., 2024).

Drinking water quality is a crucial determinant of public health because water is used directly for consumption, food processing, and household needs. Chemical contamination, including heavy metals, is a global issue due to its association with various long-term health problems. Epidemiological studies have shown that chronic exposure to heavy metals through drinking water is associated with neurological disorders, decreased kidney function, and an increased risk of degenerative diseases (Afzal et al., 2024; Ngoc et al., 2024). In flood-prone areas, communities generally rely on local water sources with limited treatment systems. This reliance on water sources increases the potential for exposure to chemical contaminants, particularly when sanitation disruptions occur due to flooding. This situation demonstrates that the impact of flooding on environmental health is not limited to the immediate event but also persists over the long term. Modern environmental health approaches emphasize the importance of health risk analysis to evaluate the impact of contaminant exposure on humans. A risk-based approach allows researchers to quantitatively assess the hazards of exposure and identify potentially vulnerable populations. Recent research has shown that even at relatively low concentrations of heavy metals, long-term exposure can still potentially cause health impacts (Eid et al., 2024). Climate change and urbanization exacerbate the risk of water pollution by increasing the frequency of flooding and putting pressure on water resources. The growth of residential areas is known to be associated with increased heavy metal loads in aquatic environments, necessitating more adaptive, evidence-based water quality management strategies . In addition to environmental factors, community behaviors such as the use of unfiltered water and limited access to treatment technology also increase vulnerability to contamination.

Developments in environmental chemistry research indicate innovative water treatment technologies with the potential to reduce heavy metal content in drinking water. However, the application of these technologies in disaster-prone areas still faces limitations in access and sustainability. In Indonesia, studies on the health risks of heavy metals in drinking water in flood-prone areas are still limited, and most research focuses on water quality analysis without linking it to public health risk assessments. Based on these conditions, this research is urgent because drinking water quality is directly related to public health and achieving sustainable access to clean water. Analysis of heavy metal content in drinking water in flood-prone areas is expected to provide an overview of the level of pollution and potential health risks faced by the community. Therefore, this study aims to analyze heavy metal content in drinking water in flood-prone areas and assess the level of public health risk resulting from exposure using an environmental health risk analysis approach.

LITERATURE REVIEW

Drinking water is a basic human need that plays a vital role in maintaining health and quality of life. Drinking water quality is determined by physical, chemical, and microbiological parameters that must meet health standards. One chemical parameter that receives attention in environmental health is heavy metal content due to its persistent, toxic nature and ability to accumulate in the human body (Huang et al., 2024). The presence of heavy metals in drinking water can originate from natural processes as well as anthropogenic activities such as industry, agriculture, and domestic waste. Heavy metals are elements with high densities that have the potential for toxicity even at low concentrations. Elements such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are known to be commonly found in aquatic environments. The mobility of heavy metals in water is influenced by chemical and physical factors such as pH, redox conditions, organic matter content, and interactions between sediment and water. Changes in environmental conditions, including ponding and sediment disturbance, can increase the solubility of heavy metals, thereby increasing the potential for exposure through drinking water sources (Wu et al., 2024).

Exposure to heavy metals through drinking water is one of the main routes of contaminant entry into the human body. The mechanism of heavy metal toxicity is related to their ability to disrupt enzyme function, trigger oxidative stress, and damage organ tissue. Lead is known to affect the nervous system and cognitive development in children, cadmium is associated with kidney and bone metabolism disorders, and mercury has significant neurotoxic effects (Afzal et al., 2024). The health risks from heavy metal exposure are influenced by concentration, frequency of exposure, duration of consumption, age, and the individual's physiological condition. Vulnerable groups such as children and pregnant women are at higher risk because the body's detoxification system is not yet optimal. Environmental epidemiological research shows that chronic exposure to heavy metals through drinking water is associated with an increased risk of degenerative diseases, metabolic disorders, and developmental disorders (Ngoc et al., 2024). The environmental health approach emphasizes the importance of health risk analysis to evaluate the impact of contaminant exposure. Health risk assessment is generally conducted through calculations of daily intake, Hazard Quotient (HQ), Risk Quotient (RQ), and Cancer Risk (CR). This approach provides a quantitative overview of the level of exposure hazard and helps determine whether an exposure is within safe limits (Ramadan et al., 2024).

Within the framework of environmental health risk analysis, exposure parameters such as consumption rate, frequency of exposure, duration of water source use, and body weight are important components in determining intake levels. The Risk Quotient value is used to interpret the level of non-carcinogenic risk, where a value less than one indicates a low risk, while a value greater than one indicates a potential health impact. In addition to environmental aspects, community behavioral factors also influence levels of heavy metal exposure.

The use of unfiltered water, unhygienic water storage, and limited access to water treatment technology increase community vulnerability to contamination. Therefore, environmental health interventions need to include public education, regular water quality monitoring, and the implementation of simple water treatment technologies. Developments in environmental chemistry research have demonstrated various technological innovations for reducing heavy metal content in drinking water, including adsorption using natural materials, membrane filtration, and nano-based technologies. Community-based technologies are considered potential sustainable solutions in resource-limited areas due to their ease of implementation and relatively low cost (Kayani & Mohammed, 2025). Conceptually, heavy metal contamination in drinking water is understood as an interaction between environmental conditions, water source characteristics, and community behavior. Therefore, health risk analysis is an important framework for understanding the impacts of exposure and formulating effective mitigation strategies to protect public health.

METHOD

This study uses a quantitative approach with a descriptive survey and cross-sectional design. Analytically, the data from the variable measurements were analyzed using the Environmental Health Risk Analysis (ARKL) approach to identify the magnitude of non-carcinogenic health risks arising from the consumption of drinking water contaminated with the heavy metal Lead (Pb) and to formulate risk management efforts. The study location is in Peunayan Village, Nisam District, North Aceh Regency. The study period lasted for approximately six months, from April to September 2025. The subject population in this study was all families who use wells as a source of drinking water in Peunayan Village, Nisam District. Population object is water source in the form of well water used public . The research subject sample consisted of 50 households selected using random sampling techniques , where each household was represented by one respondent according to the established inclusion criteria. object study is well water used as drinking water House ladder .

Data collection consists of from data analysis laboratory For know concentration metal heavy Lead (Pb) uses method Atomic Absorption Spectrophotometry (AAS) and data from results questionnaire covering age respondents , type gender , weight body , speed consumption And duration exposure . Analysis data used is analysis univariate . Variables analyzed including age respondents , type gender , weight body , speed consumption , duration exposure non- carcinogenic intake values , as well as mark Risk Quotient (RQ) with size mark mean , value minimum , and mark maximum use give description data distribution on every variable .

RESULTS AND DISCUSSION

Study This done on region vulnerable flooding in the sub-district Nisam , North Aceh Regency , part of which big its people using well water as source main drinking water . Water quality testing was conducted to determine the concentration of the heavy metal Pb and assess potential public health risks through the Environmental Health Risk Analysis (ARKL) approach. Laboratory test results showed that the Pb concentration in the well water sample was 0.0010 mg/L. This value is still below the maximum limit stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010 , which is 0.01 mg/L for lead parameters in drinking water. However, the persistent and bioaccumulative characteristics of lead indicate that long-term exposure still has the potential to cause health impacts, especially in vulnerable groups. The distribution of respondent characteristics can be seen in Table 1.

Table 1. Distribution of Respondent Characteristics

Characteristics	N	%
Age Respondents (year)		
25 – 34	19	38
35 – 44	16	32
45 – 54	11	22
≥ 55	4	8
Type Sex		
Man	23	46
Woman	27	54
Rate Consumption (L/ day)		
2 – 3	28	56
4 – 5	16	32
≥ 6	6	12

Duration Exposure (years)		
1 – 10	27	54
11 – 20	11	22
21 – 30	8	16
≥31	4	8
Heavy Body (kg)		
41 – 50	14	28
51 – 60	23	46
61 – 70	8	16
≥71	5	10

Respondent characteristics were analyzed to describe exposure factors that influence health risks. The distribution of respondents by age group showed that the majority were in the productive age range of 25–34 years (38%), while the smallest number were in the age group ≥ 55. which is 8% . This condition illustrates that the population exposed to heavy metals through drinking water is dominated by the active age group with relatively high water consumption patterns. Based on gender, female respondents have a larger proportion than men, namely 46% and 54%. This may be related to women's role in household activities that interact more frequently with water sources, including food processing and drinking water supply. The results of the water consumption rate indicate that most consume 2–3 liters of water per day, namely 56%. The rate of water intake is an important component in health risk assessment because it determines the amount of contaminants entering the body through the oral route. The duration of exposure indicates that the majority of respondents have used the same water source for 1–10 years. Long-term exposure increases the potential for accumulation of the heavy metal Pb in the body even though the concentration in the water is relatively low. This is in line with the concept of environmental health risks, which emphasizes that risk is influenced not only by concentration, but also by the frequency and duration of exposure. The results of the respondents' body weight indicate that most are in the range of 51–60 kg. Body weight is an important variable in calculating intake because it determines the relative exposure dose received by an individual. Individuals with lower body weight potentially receive a higher exposure dose per unit body weight. The results of the calculation of non-carcinogenic intake values and Risk Quotients based on the minimum, maximum, mean , and default values in real- time are shown in Table 2.

Table 2. Results calculation Mark Non- Carcinogenic Intake and Risk Quotients based on Minimum, Maximum, Mean , and Default values on Duration real time

Variables	**Min**	**Max**	**Mean**	**Default**
R (L/ day)	1.7	4.6	2.58	2
Dt (year)	1	45	9.84	30
fE (days / years)	340	350	346	350
Wb (kg)	45	83	58.7	70
Tavg (Dt × 365)	365	16,425	3,591	10,950
Ink (mg/kg/ day)	0.000059	0.000069	0.000053	0.000032
RQ	0.015	0.018	0.014	0.009

The results of the non-carcinogenic intake calculations indicate that the exposure value is in the very low range. The minimum intake value is 0.000059 mg/kg/day and the maximum is 0.000069 mg/kg/day, while the average value is 0.000053 mg/kg/day. The default value used in the analysis is 0.000032 mg/kg/day as a standard approach to assessing environmental health risks. The Risk Quotient (RQ) values obtained indicate that all exposure categories are below 1. The minimum RQ value is 0.015 and the maximum is 0.018 with a mean value of 0.014 and a default value of 0.009. These results indicate that the non-carcinogenic health risk due to lead exposure through drinking water is still in the low category. The calculation results show that even though the concentration of heavy metals in water is below the drinking water quality standard, exposure continues to occur continuously. Low intake values indicate that the amount of contaminants entering the body is relatively small, but the accumulative nature of heavy metals requires long-term monitoring. An RQ value below one indicates that non-carcinogenic health risks are not yet significant under the conditions at the time of the study. However, the large variation in exposure duration indicates that some respondents could potentially experience increased risk if water quality changes occur in the future. Environmental factors such as repeated flooding can increase the mobilization of heavy metals, potentially increasing intake values. These findings emphasize that a preventative approach is still necessary even if the calculated risk results are low. Regular water quality monitoring, increasing access to household water treatment technology, and educating the public about drinking water safety are important steps in maintaining environmental health. The results of the calculation of Non-Carcinogenic Intake Values and Risk Quotients based on mean values are shown in Table 3.

Table 3. Calculation Values of Non-Carcinogenic Intake (Ink) and Risk Quotients (RQ) based on Mean Values

Variables	Mark
Real-time ink	0.000053 mg/kg/ day
Ink 10 years to come	0.00050 mg/kg/ day
Ink 30 years to come	0.0015 mg/kg/ day
Ink 50 years to come	0.0026 mg/kg/ day
Real-time RQ	0.014
RQ 10 years to come	0.13
RQ 30 years to come	0.39
RQ 50 years to come	0.67

Results analysis show that mark non- carcinogenic intake (Ink) real time of 0.000053 mg/kg/ day with Risk Quotient (RQ) value of 0.014. Mark This Still far below limit safe (RQ < 1), which indicates that on condition moment This exposure Not yet cause risk significant non- carcinogenic health effects . According to approach Environmental Health Risk Assessment (EHRA), RQ value < 1 indicates that level exposure Still is at in limit safe for population exposed (United States Environmental Protection Agency, 2011). However, the projection results show an increasing trend in Ink and RQ values as exposure duration increases. In the 10-year projection, the RQ value increases to 0.13; in the 30-year projection, it reaches 0.39; and in the 50-year projection, it reaches 0.67. Although still below the risk threshold (RQ < 1), this increase indicates the potential for long-term risks if exposure continues without control intervention. The increase in RQ values over time is consistent with research conducted by Wu et al. (2020), which stated that exposure duration is a major determinant in increasing non-carcinogenic risks in heavy metal exposure through drinking water. The study showed that communities with long-term exposure had significantly increased RQ values compared to short-term exposure. A similar finding was also reported by Ahmed et al. (2021), who found that the accumulation of chronic exposure contributes to an increased risk of kidney and nervous system disorders in the adult population. Physiologically, chronic exposure to environmental contaminants, even at low concentrations, can cause accumulation in body tissues.

According to research by Li et al. (2019), long-term exposure to Pb through drinking water consumption can increase oxidative stress and systemic inflammation. This indicates that although the current RQ is still in the safe category, ongoing monitoring is still necessary as a preventative measure. The RQ value of 0.67 in the 50-year projection is close to the risk threshold (RQ = 1). This condition requires attention in the context of public health. A study by Rahman et al. (2022) shows that areas with an increasing trend of RQ approaching 1 have the potential to experience an increase in cases of chronic health disorders if mitigation efforts are not implemented. Therefore, strategies to control drinking water quality and educate the public about water consumption patterns are important steps in preventing risk escalation. Another factor influencing the Ink and RQ values in this study was the respondents' weight. An average body weight of 58.7 kg tended to yield relatively higher intake values compared to populations with larger body weights, as intake calculations were based on mg/kg/day. This aligns with the findings of Zhang et al. (2021) who stated that individuals with lower body weight had a relatively higher risk in weight-based analyses. Research by Pratama and Nugroho (2022) also showed that body weight and duration of water consumption significantly influenced heavy metal intake values. These findings support the results of this study, which showed that variations in respondents' body weight influence intake values based on mg/kg/day.

Furthermore, the rate of drinking water consumption (mean 2.58 L/day) also contributed to the increase in the Ink value. Consuming large amounts of water without maintaining good water quality can increase daily exposure to contaminants. According to a study by Kumar et al. (2020), variation in daily water consumption is an important factor in environmental health risk prediction models. overall , results study This show that non-carcinogenic risks moment This Still is at on category safe , but there is trend improvement risk in term long . By Because that , is necessary effort preventive in the form of :

1. Monitoring water quality periodically
2. Public education regarding safe water consumption
3. Strengthening regulations on drinking water quality standards

This preventive approach is in line with the environmental risk management principles recommended by the World Health Organization (2022), which emphasizes the importance of controlling risks before they reach a hazard threshold.

CONCLUSION

Based on the research results, it shows that the concentration of heavy metal lead (Pb) is 0.0010 mg/L and this value is still below the maximum limit set in the Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010, namely 0.01 mg/L for lead parameters in drinking water. This indicates that, in general, the water sources used by the community still meet safety requirements for consumption under current conditions. Calculations of non-carcinogenic intake show a real-time value of 0.000053 mg/kg/day with a Risk Quotient (RQ) of 0.014, indicating non-carcinogenic health risks are still in the safe category (RQ≤1). Long-term exposure projections show an increase in intake and RQ values to 0.67 in the 50-year estimate, but remain below the risk limit. These findings indicate that although lead concentrations still meet safety standards, the potential for long-term exposure accumulation requires attention. Therefore, regular water quality monitoring is essential, especially in flood-prone areas that are vulnerable to the mobilization of environmental contaminants. Preventive measures at the household level, such as settling water before consumption, hygienic water storage, and the use of simple filtration systems, can be mitigation measures to reduce potential exposure to heavy metals.

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