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Evaluating Heavy Metal Contamination and Ecological Risks in Rivers Surrounding Banyuroto Landfill in Indonesia

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ABSTRACT

This study, carried out between May and June 2023, aimed to assess the influence of landfill leachate on environmental conditions, specifically regarding the pollution of river water near the Banyuroto landfill. The parameter of the difference heavy metals in this study are Mercury (Hg), Cadmium (Cd), Lead (Pb), Chromium (Cr), Manganese (Mn), Copper (Cu), and Iron (Fe). The potential ecological risk index is investigated due to the harm to the nearby river ecology. The sampling was conducted at eight discrete locations in close proximity to the dump. The levels of heavy metals were quantified using Atomic Absorption Spectroscopy (AAS). Furthermore, the Potential Ecological Risk (PER) technique was utilized to assess the potential environmental dangers that these metals may pose. The findings unveiled disparate concentrations of heavy metals across the various locations where point 5 of the sampling become most polluted area due to increased anthropogenic activities. The Mercury (Hg) concentrations ranged from 0.014 to 0.032 mg/kg, whereas the Cadmium (Cd) and Chromium (Cr) levels exhibited minimal variation in the below Limit of Detection (LOD). Lead (Pb) exhibited LOD readings, suggesting their minimum presence. The concentrations of Manganese (Mn) and Copper (Cu) were relatively low, whereas Iron (Fe) exhibited the greatest levels, ranging from 0.2405 to 1.2209 mg/l. The maximum potential ecological risk values were calculated and ranked from highest to lowest as follows: Hg (262.19) > Fe (20.35) > Cr (0.374) > Cd (0.245) > Cu (0.297) > Mn (0.100). Remarkably, the possible environmental hazards associated with all heavy metal characteristics constantly remained below the threshold of 40 except the maximum concentration of the total of Heavy Metals. This indicates that their concentrations present a substantial ecological danger in some situations.

1. Introduction

The exponential expansion and progress of human populations, driven by natural processes such as reproduction and urban migration, have resulted in a rise in diverse human activities. One of the direct or indirect consequences of these operations is the production of waste, which is usually gathered and treated at final disposal sites. Studies have demonstrated that landfills situated in locations with a history of environmental damage can lead to a decline in the quality of water, specifically in terms of Chemical Oxygen Demand (COD) and Ammonium Nitrogen (NH4-N) levels (Stefania et al., 2018). In addition, landfills have an effect on the quality of groundwater along hydraulic gradients. Both solid waste and leachate samples have been shown to include heavy metals such as iron and zinc (Singh et al., 2008). The effects mentioned are not limited to a particular area, since research conducted in different regions such as Saudi Arabia and Brazil has shown comparable results (Al-Arifi et al., 2013; Engelmann et al., 2017).

Furthermore, leachate, the aqueous solution generated from refuse in landfills, has the potential to infiltrate rivers or the soil if not effectively controlled. The untreated or inadequately handled leachate has serious environmental consequences. Molenda and Chmura (2012) conducted a study on the impact of industrial waste dumps on the quality of river water. They emphasized that landfill leachate can greatly change the levels of harmful compounds in river waters. In a case study by Javanmardi et al. (2022), the researchers examined the influence of municipal solid waste landfill on water resources in Khalkhal. The study revealed that landfill leachate can cause water pollution, however the extent of its effects on drinking and agricultural uses can vary. In addition, Chounlamany et al. (2018) evaluated the pollution levels in a specific section of a river that was impacted by landfill leachate and domestic waste. They highlighted the substantial impact of leachate on many water quality indicators, particularly dissolved oxygen and chemical oxygen demand levels.

Inclement weather intensifies the risk of leachate pollution by amplifying both the quantity and movement of the pollutants (Ruhl et al., 2010). Insufficient leachate storage and processing systems at landfills increase the potential for pollution (Tomašević et al., 2013). Leachate can cause chemical contamination due to the existence of heavy metals, halogenated organic chemicals, and volatile organic compounds (Apritama et al., 2019). If contaminated groundwater is consumed, the presence of harmful bacteria such as Escherichia coli and Salmonella in leachate also presents a danger of infection to humans and animals. Additionally, leachate has the ability to modify the physical characteristics of water, leading to changes in its color, odor, and flavor, ultimately resulting in a decline in water quality.

Specifically, the Serang River Watershed and the Banyuroto landfill are one of crucial areas of concern in this context. The Banyuroto landfill benefits from its geographical condition, characterized by a gradient of 15-25%, which facilitates waste treatment by effectively regulating the movement of leachate and gas. Nevertheless, the existence of clay soil requires specific focus on the stability of landfills, particularly in the rainy season. The close proximity of the landfill to residential areas highlights the importance of implementing efficient waste management practices in order to mitigate water, air, noise, and odor pollution and safeguard the well-being of the local population. Regular surveillance and community engagement are crucial proactive measures in this context.

To summarize, the proper handling of landfill leachate is essential for preventing harm to the environment and safeguarding public health. This paper is important to predict the risk of landfill leachate in tropical condition and developing country which different with developed country. This highlights the significance of implementing efficient waste management procedures at locations such as the Banyuroto landfill. The purpose of this study is the evaluation of river water around the Banyuroto landfill to assess risks to the ecology and human around the landfill.

2. Methods

The research technique for this study involved multiple stages to thoroughly evaluate the influence of landfill leachate on water quality. In the first stage, sample locations were carefully picked around the Banyuroto landfill to strategically capture the emergence of leachate and its potential contamination of surrounding water bodies. Water samples were taken on May 16, 2023, from multiple locations to ensure a comprehensive analysis of the overall water quality in the area. In order to retain the quality of the samples, they were placed in sterile containers, treated with appropriate preservatives based on the parameters being examined, and stored in a cooler box to ensure their preservation until laboratory testing.

The laboratory testing commenced on May 22, 2023, and finished on June 22, 2023. The methods used were customized for each parameter, with a particular emphasis on employing Atomic Absorption Spectrophotometry (AAS) for the analysis of heavy metals. The data acquired from these tests were subsequently scrutinized to ascertain the magnitude of water contamination in the vicinity of the Banyuroto landfill.

The study employed a range of instruments to analyze water quality measures, such as BOD, COD, and heavy metals. The BOD analysis involved the use of Winkler bottles, measuring pipettes, burettes, beakers, and measuring cups. The COD analysis utilized reflux sets, thermoreactors, and UV-Vis Spectrophotometers, whereas the heavy metal analysis involved the use of electric stoves, AAS (Atomic Absorption Spectroscopy), and measuring flasks.

The materials utilized in the research were essential components in every test method. The following chemicals were used for BOD: $MnSO_4$ solution, concentrated H_2SO_4, KOH-KI solution, Aquades, and Na_2SO_3 solution. The COD analysis employed concentrated sulfuric acid, digestion solutions, and Aquades. The heavy metal analysis required the utilization of water samples, Aquades, and concentrated HNO_3.

Banyuroto landfill is located in Dlingo Hamlet, Banyuroto, Nanggulan Subdistrict, Kulon Progo Regency, Yogyakarta Special Region Province with the landfill coordinates are: 7°48'9.723"S, 110°11'6.818"E. The study utilized a purposive sample technique, specifically selecting eight sampling places, as depicted in Figure 1. The grab sampling method, in accordance with the SNI 6989.57:2008 criteria, was employed for surface water sampling. The specimens were gathered in 250 mL High-Density Polyethylene (HDPE) containers, with the pH level lowered to below 2 using nitric acid (HNO_3), and subsequently placed in an insulated container for transit to the laboratory.

The laboratory conducted measurements of heavy metal concentration according to SNI standards for many metals, utilizing Flame Atomic Absorption Spectrophotometry (SSA) and fume hoods during the testing procedure. Furthermore, Inductively Coupled Plasma (ICP) Mass Spectrometry was employed to identify minute amounts of Hg metal in environmental samples.

The data analysis entailed a comparison between the surface water quality in the vicinity of the Banyuroto Landfill and the environmental protection criteria specified in Indonesian Government Regulation No. 22 of 2021 and Local Regulation of Yogyakarta quality standards No. 20 of 2008 class II. The ecological risk assessment was performed utilizing the methodology introduced by Hakanson (1980). The Potential Ecological Risk (PER) index is a quantitative method used to assess the potential risk that contaminants, particularly heavy metals, pose to the environment. It was originally proposed by Swedish scientist Hakanson in 1980. The PER index considers the toxicity of various substances and their concentration in the environment to estimate the potential harm they could cause to ecosystems. This method is widely applied in environmental studies, especially for evaluating soil and water pollution. The formula for counting PER is as follows:

$$c_f^i = \frac{c^i}{c_n^i}$$

$$c_r^i = T_r^i \ x \ c_f^i$$

$$\mathrm{RI} = \sum E_r^i$$

Notes:

c^i= heavy metal concentration for each sampling point
c_n^i= heavy metal quality standards
c_f^i= pollutant coefficient
T_r^i= toxic response factor
E_r^i= Ecological risk index for each heavy metal element
RI = Total Ecological Potential Index

T is a toxic response factor for each heavy metal (Table 1).

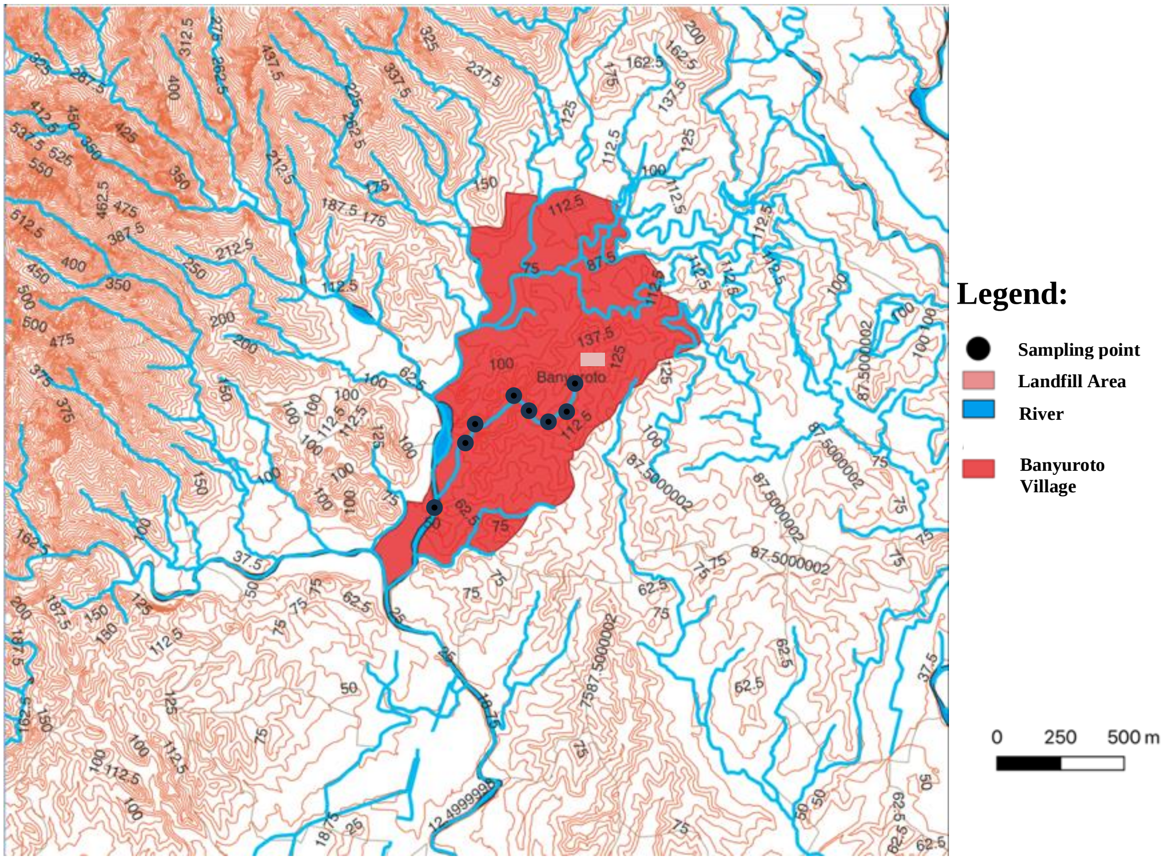

Figure 1. Map of research location

Table 1. Toxic response factor for each heavy metal

Heavy Metal type	Toxic response factor (T)
Cu	5
Pb	5
Zn	1
Mn	1
Cr	2

Cd	30
As	10
Ni	6

Table 2. Index and Level of Potential Ecological Risk (PER)

	Pollution Level	**RI**	**Risk Class**	**Risk Level**
E_r^i **< 30**	Slight	RI < 40	A	Slight
30 < E_r^i **< 60**	Medium	40 < RI < 80	B	Medium
60 < E_r^i < 120	Strong	80 < RI < 160	C	Strong
120 < E_r^i **< 240**	Very Strong	160 < RI < 320	D	Very Strong
E_r^i **> 240**	Extremely Strong	RI > 320	-	-

Source: Jiang, 2014

In the context of ecological risk assessments, like the one conducted by Jiang et al. (2014), the terms "slight," "medium," and "strong" risk are used to categorize the severity of the ecological threat posed by contaminants, such as heavy metals in soil (Table 2). These categories help in understanding the extent of potential damage and in guiding appropriate response measures:

- Slight Risk: This category indicates a low level of ecological risk. The presence of contaminants is relatively minor and not expected to cause significant harm to the environment or ecological balance. In this scenario, regular monitoring may be sufficient without immediate need for remedial action.
- Medium Risk: This level suggests a moderate degree of ecological risk. Contaminants are present in quantities that could potentially cause harm to the environment, but not at an extremely alarming level. This might necessitate more vigilant monitoring and potentially some measures to mitigate the risk.
- Strong Risk: Represents a high level of ecological risk. Contaminants are present in concentrations that are likely to cause significant environmental damage, potentially affecting biodiversity, ecosystem health, and even human health. This category typically requires immediate and substantial remedial action to manage and mitigate the risks.
- Very Strong Risk: Represents the highest level of ecological threat. This category is used to indicate extremely hazardous situations where the concentration and toxicity of pollutants, such as heavy metals in soil or water, are at levels that pose severe and immediate risks to the environment and ecosystem health.

The classification into these risk levels is typically based on quantitative assessments that consider factors like the concentration of pollutants, their toxicity, the susceptibility of the local environment and ecosystems to damage, and the potential for bioaccumulation and biomagnification.

3. Results and dicussion

3.1 River Water Test Results

The provided data appears to be a set of measurements for various heavy metals in water samples taken from different sites (S1 to S8). The parameters measured include Mercury (Hg), Cadmium (Cd), Lead (Pb), Chromium (Cr), and Manganese (Mn), with their concentrations given in milligrams per liter (mg/l). The data also includes the Indonesian standard limits for these metals as per "PP RI No. 22 tahun 2021 lamp.VI 2021. The additional data beyond heavy metals in the dataset includes measurements for

Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Electrical Conductivity, pH, and Temperature across the eight sampling sites (S1 to S8).

Table 3. Recapitulation value of river water samples around Banyuroto Landfill

NO	Parameters	S1	S2	S3	S4	S5	S6	S7	S8	Unit	Indonesian Standard
1	Hg	0.0215	0.0195	0.0197	0.0149	0.0177	0.0164	0.0268	0.0328	mg/l	0.002
2	Cd	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.0002	<LOD	mg/l	0.002
3	Pb	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	mg/l	0.03
4	Cr	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.187	<LOD	mg/l	0.05
5	Mn	0.0185	0.0674	0.0682	0.0621	0.0780	0.0560	0.0303	0.0959	mg/l	-
6	Cu	0.0098	0.0098	0.0014	0.0014	0.0024	0.0119	<LOD	<LOD	mg/l	0.02
7	Fe	0.4594	0.6468	0.7889	0.6547	1.2209	0.2405	0.2641	0.3509	mg/l	-
8	river flow speed	0.283	0.558	0.267	0.573	0.585	0.222	0.668	0.978	m/s	-
9	COD	82.978	90.193	98.721	92.161	94.785	86.264	97.409	73.144	mg/l	25
10	BOD	14.000	8.274	9.912	10.644	12.282	14.758	11.324	22.947	mg/l	3
11	Electrical conductivity	0.201	0.139	0.083	0.277	0.137	0.265	0.273	0.168	uc/cm	-
12	pH	8.22	8.12	8.37	8.63	8.23	8.48	8.49	8.48	mg/l	6-9
13	Temperature	28.87	28.08	27.72	27.72	28.1	28.13	28.31	28.19	$°C$	Dev 3

The Hg concentrations vary across the sampling sites, with the highest level observed in sample S8 (0.0328 mg/l) and the lowest in S4 (0.0149 mg/l). All values exceed the Indonesian standard of 0.002 mg/l, indicating potential contamination. For Cd, most samples indicate "<LOD" (Limit of Detection), suggesting that Cd levels are below the detectable limit, except for sample S7, which shows a minimal concentration (0.000245 mg/l). This is below the standard limit of 0.002 mg/l. Lead (Pb) All samples for these metals are marked "<LOD," implying concentrations below detectable levels. The standard limit for Pb is 0.03 mg/l.

The Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) values in the data significantly exceed the Indonesian standard limits, indicating substantial organic pollution. High COD and BOD levels are known to pose serious threats to aquatic environments. They can lead to reduced dissolved oxygen (DO) levels, which endanger aquatic life, especially in industrial areas (Hasan et al., 2021; Kaur et al., 2010). Such pollution levels can also degrade receiving water bodies and have toxic effects on fish populations (Jamieson et al., 2017; Mamta & Singh, 2017). The variability in electrical conductivity points to differences in ionic content across the sites, though there's no standard limit provided for comparison. The pH levels, ranging from slightly to more alkaline (8.12 to 8.63), are within the acceptable standard range (6-9). This is generally suitable for most aquatic organisms, although specific effects depend on the local ecosystem and species. Meanwhile, the recorded temperatures vary slightly across the sites. Temperature influences various physical and chemical processes in water bodies and can affect aquatic life, especially when there are significant deviations from the norm (Isaak et al., 2012).

The levels of Mercury (Hg) in all samples exceed the Indonesian standard limit (0.002 mg/l), indicating potential severe contamination. Mercury pollution is a major environmental concern, as it can cause serious damage to ecosystems and human health. Studies have shown that Mercury release from industrial activities can lead to dissolved mercury concentrations exceeding national limits in various environments (Song et al., 2018; Lin et al., 2011). Moreover, exposure to Mercury can pose significant health risks, including impacts on the brain, kidneys, and developing fetus, and can affect fetal growth, neurocognitive function, and the cardiovascular system (Li et al., 2021). The presence of Mercury in water at such high levels is indicative of severe pollution, potentially resulting from industrial discharge or natural mineral deposits. This contamination can impact aquatic life, leading to bioaccumulation in the food chain and posing risks to human health, especially for communities relying on these water sources for drinking or fishing (Ullrich et al., 2007; Chen & Driscoll, 2018). The findings underscore the urgency of remedial action to address Mercury contamination in these water bodies.

3.2 Spatial distribution of heavy metals in rivers

The map provided appears to be a thematic spatial distribution map highlighting areas of heavy metal contamination within the Serang River, located near the Banyuroto Landfill. The map uses color-coding to denote varying levels of heavy metal concentration in relation to the river and its surroundings (Figure 2).

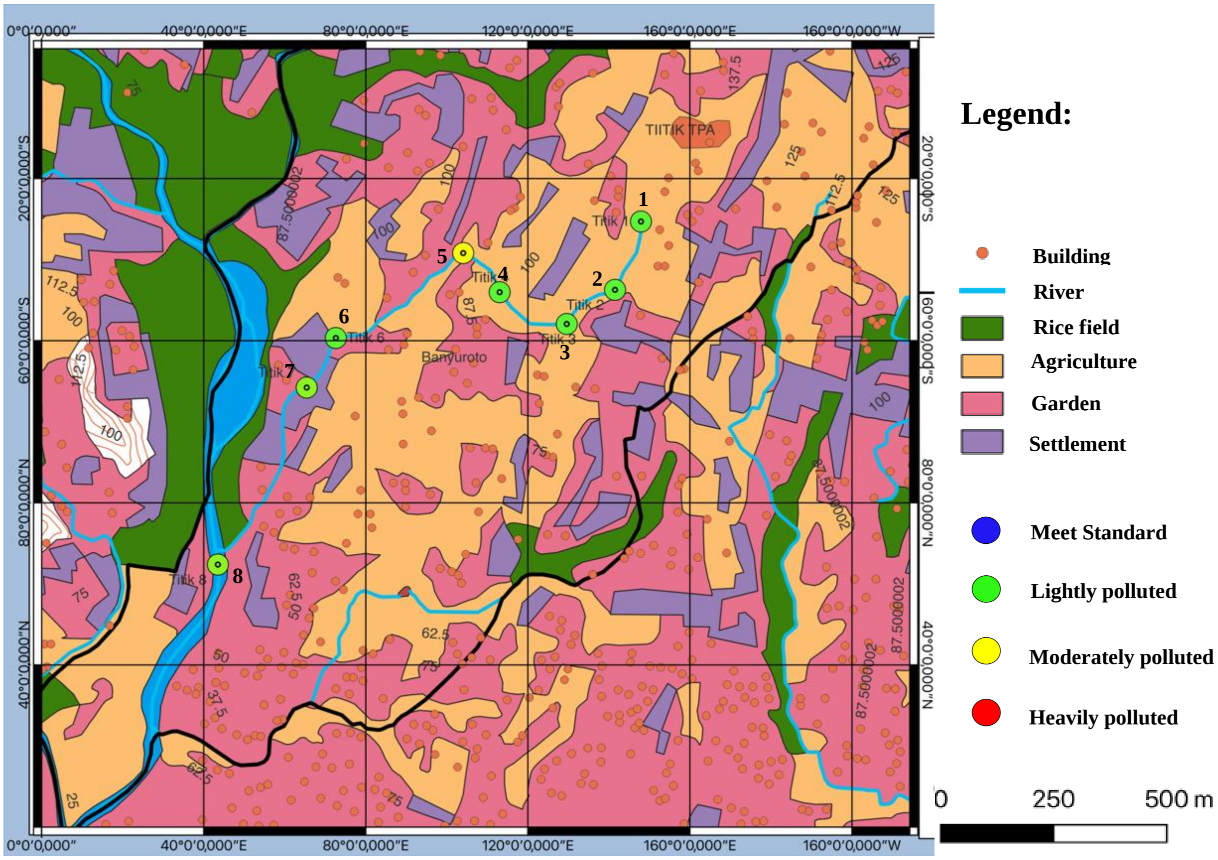

Figure 2. Spatial map of heavy metals in rivers around Banyuroto Landfill

Spatial analysis is an essential method in environmental studies as it incorporates geographic and locational aspects of data, which is particularly relevant in examining water quality and heavy metal distribution in areas like the Banyuroto Landfill. Key factors in spatial analysis include the distance from potential pollutant sources like leachate, which can be a primary contaminant for rivers, with closer proximity indicating higher contamination risk (Gao et al., 2018). River hydrodynamics, such as flow rate and type, influence the sediment interaction and thus the accumulation and sedimentation of heavy metals, with laminar flows favoring deposition and turbulent flows potentially resuspending particles (Li et al., 2019). Assessing heavy metal concentration in riverbed sediments offers insights into the cumulative effects of these metals on the river ecosystem's health (Liu et al., 2003). The area's topography and geography, including aspects like discharge, slope, soil type, and vegetation cover, play a role in the dynamics of water flow and heavy metal deposition (Smith & Wieder, 2019).

The map visualizes these spatial relationships and indicates the pollution levels across different sections of the river, with blue representing safe conditions, green for light pollution, yellow for moderately contaminated, and red for heavily polluted areas. Notably, sampling points 1, 2, 3, 4, 6, 7, and 8 fall within the light pollution category, while point 5 is considered medium polluted. The proximity of point 5 to residential areas and agricultural lands may account for its higher pollution levels due to increased anthropogenic activities (Johnson et al., 2018).

The spatial distribution and pollution levels depicted in the map are critical for understanding the impacts of human activity on river water quality. The areas immediately downstream from waste discharge points, such as points 1 and 2, are crucial, as they receive the most direct impact from the landfill. Although points 3 to 8 may be less impacted due to distance and potential dilution or natural attenuation processes, they may still be vulnerable to cumulative pollution from industrial, agricultural, or residential sources. A more detailed analysis based on actual measurements from each sampling point is essential to accurately assess the river's health and the broader implications for environmental and human well-being (Fernandez et al., 2020).

3.3 Potential Ecological Risk Assessment

Table 4 assesses the potential environmental risk of heavy metals in the river around the Banyuroto landfill. The Risk Index (RI) suggests that the average concentrations of heavy metals pose a "slight" risk (RI < 40), with an average value of 25.57 classified under risk class A. However, the maximum concentration of heavy metals reaches 40.51, categorized as "medium" risk under risk class B. Jiang (2014) suggests that such values are within natural environmental concentrations and are not inherently harmful. The ranking of metals based on their index values from highest to lowest risk is Mercury (Hg) > Iron (Fe) > Chromium (Cr) > Copper (Cu) > Cadmium (Cd) > Manganese (Mn).

The implication is that while the landfill influences the heavy metal concentrations, the levels remain within natural limits and are not considered hazardous to the environment. This aligns with research by Xu et al. (2016), who found similar light pollution RI values in soil surrounding oil waste disposal areas, indicating slight pollution. It's important to consider that the RI values could vary based on seasonal and operational changes at the landfill, as heavy metal mobilization and speciation can be influenced by environmental conditions (Wang et al., 2018; Islam et al., 2017).

Moreover, the categorization into slight and medium risks echoes findings from other studies where specific metals have been identified to contribute differently to ecological risk assessments. For example, Li et al. (2019) observed high ecological risk index values in soils adjacent to power generators, indicating severe contamination by all studied metals. In contrast, areas with lower human impact tend to have lower RI values, highlighting the influence of anthropogenic activities on heavy metal dispersion and accumulation (Wang et al., 2014).

Finally, the RI values provide a framework for evaluating the ecological impact of heavy metals, and the findings from the Banyuroto landfill area suggest manageable risk levels. However, continuous monitoring and assessment are essential for early detection of any potential changes that could affect the river ecosystem's health and human welfare.

Table 4. Pontential Risk

Heavy Metals	Average Concentration (mg/L)	Minimum Concentration (mg/L)	Maximum Concentration (mg/L)	E_r^i Average	E_r^i Minimum	E_r^i Maximum
Cu	0.005	0.0014	0.0098	0.1142	0.0339	0.2968
Cd	-	-	0.0002	0	0	0.25
Pb	-	-	-	0	0	0
Cr	-	-	0.1872	0	0	0.3744
Fe	0.578	0.2405	1.2209	9.64	4.01	20.35
Mn	0.060	0.0185	0.0959	0.060	0.02	0.10
Hg	0.021	0.0149	0.0328	169.21	119.12	262.19
		RI		25.57	17.60	40.51
		Risk Level		*Slight*	*Slight*	*Medium*

Table 5. Potential risks from several developing countries

No	**River name**	E_r^i	**Risk Level**	**Reference**
1	Laguna, Philipina	41.02	Medium	Pradit *et al.* (2010)
2	Veeranam, India	125.19	Medium	Suresh *et al* .(2012)
3	Manchar, Pakistan	87.10	Medium	Arain *et al.* (2014)
4	Code, Indonesia	13.05	Slight	Hasti *et.al.* (2020)

The comparison of the results from your study with those from previous studies across different geographic locations provides valuable insights into the varying levels of ecological risk posed by heavy metals in riverine environments. When comparing these values to the findings from the Banyuroto Landfill area, where the average concentration of heavy metals falls within the RI < 40 limit, it suggests that the Banyuroto Landfill area has a lower potential ecological risk compared to Laguna and significantly lower than Veeranam and Manchar. The Banyuroto area's risk is more akin to Code, Indonesia, where the ecological risk is also slight.

4. Conclusions

The Ecological Risk Assessment (ERA) indicates that the quantities of heavy metals, including Cadmium (Cd), Lead (Pb), Chromium (Cr), Manganese (Mn), Copper (Cu), and Iron (Fe), in the vicinity of the Banyuroto dump are below acceptable limits, except for Mercury (Hg). Currently, these metals present a negligible ecological concern. Nevertheless, ongoing surveillance is crucial to alleviate potential forthcoming threats to the ecology encompassing the landfill. Implementing this proactive strategy will enable the early identification of any negative environmental patterns and expedite the execution of measures to protect the ecological integrity of the vicinity surrounding the Banyuroto dump.

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6. Authors Note

The authors declare that there are no conflicts of interest concerning the research, authorship, and/or publication of this article. The authors also affirm that the paper is free from any form of plagiarism and adheres to the highest ethical standards for responsible research and scientific writing.

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