JURNAL KESEHATAN LINGKUNGAN
JURNAL DAN APLIKASI TEKNIK KESEHATAN LINGKUNGAN

ISSN 1829-9407 (Print)
ISSN 2581-0898 (Online)

Volume 23, No. 1, January 2026 ; Page: 111-120; *DOI: https://doi.org/10.31964/jkl.v23i1.1112*

Original Research

ENVIRONMENTAL HEALTH RISK ANALYSIS AROUND THE BANJARBAKULA LANDFILL USING THE HIRADC APPROACH

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Article Info

Article history:

Received January 22, 2026
Revised January 26, 2026
Accepted January 29, 2026

Keywords:

Landfill
Environmental Quality
Health Risk
Heavy Metals
Environmental Risk Management

ABSTRACT

Environmental Health Risk Analysis Around the Banjarbakula Landfill Using the HIRADC Approach. *Landfills are a critical component of urban solid waste management systems; however, when inadequately managed, they may pose substantial risks to environmental quality and public health in surrounding communities. This study aimed to analyze environmental quality and public health risks in the vicinity of the Banjarbakula Landfill. A descriptive–analytic cross-sectional design was employed, integrating measurements of ambient air quality, groundwater quality, and soil quality at selected locations around the landfill with a community health survey. Risk analysis was conducted using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) method. The results indicated that concentrations of landfill gases and airborne particulates exceeded environmental quality standards, while groundwater and soil samples were contaminated with heavy metals, including lead, mercury, and cadmium. The community health survey revealed a high prevalence of respiratory disorders, skin diseases, and gastrointestinal disturbances, particularly among residents living closer to the landfill site. Risk assessment identified chemical and biological hazards as the dominant risks, classified as high risk. These findings demonstrate that the management of the Banjarbakula Landfill still requires significant improvements to reduce environmental degradation and public health risks. This study provides a scientific basis for strengthening policy implementation, enhancing landfill management technologies, and improving public health protection in communities surrounding landfill areas.*

INTRODUCTION

Global population growth and accelerating urbanization have increased the generation of municipal solid waste, particularly in developing countries with limited management capacity[1–5]. This situation renders Landfill Sites (TPA) the most critical yet vulnerable component of waste management systems. Several studies indicate that TPAs have the potential to become sources of environmental pollution through leachate production and landfill gas emissions, which can contaminate ambient air, groundwater, and surrounding soil[6–9]. Long-term exposure to these pollutants has been reported to be associated with an elevated risk of respiratory disorders, skin diseases, digestive system disturbances, and other chronic illnesses among nearby communities[10–13].

Internationally, scientific evidence demonstrates that populations residing near TPAs exhibit higher health vulnerability compared to the general population, primarily due to exposure to landfill gases such as methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S), as well as heavy metal contamination—including lead, cadmium, and mercury—in groundwater and soil[14–18]. These risks are reported to be more pronounced in regions with landfill systems that do not meet sanitary landfill standards and where environmental monitoring is limited, as commonly observed in parts of Asia and Africa[19–21].

In the Indonesian context, TPA management continues to face structural and technical challenges. Although regulations governing landfill management have been established, their implementation in the field remains inconsistent. Some TPAs are still located near residential areas and water bodies, accompanied by limited leachate treatment technologies and insufficient continuous monitoring of gas emissions[22–24]. This situation positions TPAs not merely as a technical waste management issue, but also as a public health and environmental justice concern requiring risk-based scientific evaluation.

Banjarbakula Landfill in Banjarbaru City serves as a regional waste management facility catering to an area with continuously growing population and economic activities. High operational loads have the potential to exacerbate environmental pollution risks if not matched by effective management systems. Preliminary observations around Banjarbakula TPA indicate signs of deteriorating air, groundwater, and soil quality, which may impact the health of surrounding communities. Nevertheless, to date, no comprehensive and integrated health risk mapping has been conducted to serve as a decision-making basis for TPA management in the area.

Most previous studies in Indonesia have focused on a single environmental medium or pollutant type, and therefore have not fully captured the complexity of multipollutant exposure and its implications for public health[25–27]. Furthermore, studies explicitly integrating environmental quality data, public health conditions, and environmental risk management frameworks at a regional landfill scale remain limited. A health risk assessment approach is essential to bridge environmental data with health impacts and to establish actionable management priorities.

Based on this background, the present study aims to analyze the public health risks posed by Banjarbakula TPA activities through an integrated approach. This study combines measurements of air, groundwater, and soil quality with community health surveys and Hazard Identification, Risk Assessment, and Determining Control (HIRADC) analysis to identify dominant hazards and establish risk management priorities. The novelty of this research lies in the application of a comprehensive and contextual environmental risk management framework as a foundation for landfill management recommendations oriented toward public health protection and environmental sustainability.

MATERIALS AND RESEARCH METHODS

This study employed a descriptive-analytical design with a cross-sectional approach to analyze the health risks associated with activities at Banjarbakula Landfill (TPA). This approach enables simultaneous observation of environmental quality conditions and community health within the same time frame, allowing the relationships between potential hazards, exposure, and health outcomes to be evaluated concurrently. This design is widely used in environmental health risk studies around landfills, as it effectively links environmental quality data with health indicators of the exposed population.

The research was conducted in the operational area of Banjarbakula TPA and the surrounding residential communities. Data collection included primary data, consisting of environmental quality measurements (air, groundwater, and soil) and community health surveys, as well as secondary data obtained from landfill management documents, reports from relevant agencies, and pertinent scientific literature.

The study's methodological framework refers to the United States Environmental Protection Agency (USEPA) Environmental Risk Management Model, which encompasses problem formulation, risk analysis, risk characterization, and risk management stages. The conceptual flow of the study is illustrated in Figure 1, depicting the relationship between risk assessment and sustainable risk management decision-making.

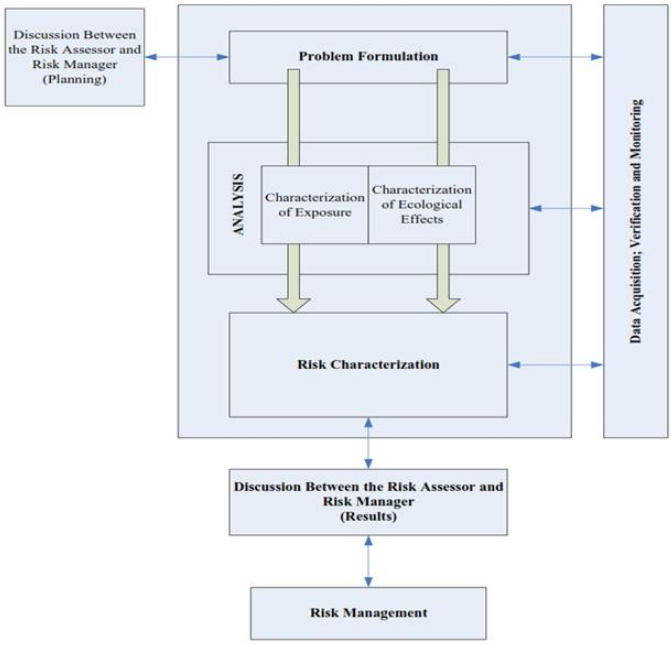

Figure 1. USEPA-Based Environmental Risk Management Framework

The problem formulation stage focused on identifying potential hazards in each waste management process unit at the landfill, including collection, transportation, disposal, as well as leachate and gas emission management. Risk identification was conducted using the Failure Mode and Effect Analysis (FMEA) method to map potential process failures, their causes, and possible consequences. To gain deeper insight into the underlying causes of risk, a Root Cause Analysis (RCA) was performed to identify structural, operational, and managerial factors contributing to risk emergence.

The risk analysis stage was conducted qualitatively through focused discussions and brainstorming sessions with landfill operators and relevant stakeholders. This analysis aimed to assess the level of exposure and the potential impact of risks on human health and the environment, taking into account operational conditions and the local context of landfill management.

Risk assessment was performed by combining two main parameters: likelihood (the probability of risk occurrence) and consequences (the severity of impact). Both likelihood and consequences were classified into five levels, as presented in Table 1 and Table 2.

Table 1. Likelihood Assessment Criteria

Level	Descriptor	Description
A	Almost certain	Very likely to occur frequently
B	Likely	Occurs often
C	Moderate	Occurs occasionally
D	Unlikely	Occurs rarely
E	Rare	Very unlikely to occur

Table 2. Risk Consequences Assessment Criteria

Level	Descriptor	Example : Description / Indicator
1	Insignificant	No injuries; low financial loss
2	Minor	Requires first aid; moderate financial loss
3	Moderate	Requires medical treatment; high financial loss
4	Major	Causes extensive damage, serious injuries, reduced production capacity, significant financial loss
5	Catastrophic	Causes death, severe damage, and very large financial loss

The combination of these two parameters resulted in risk levels visualized in the Environmental Risk Matrix (Table 3), which classifies risks into four categories: low, medium, high, and extreme.

Likelihood \ Consequences	1 *Insignificant*	2 *Minor*	3 *Moderate*	4 *Major*	5 *Catastrophic*
(A) *Almost certain*	H	H	E	E	E
(B) *Likely*	M	H	H	E	E
(C) *Moderate*	L	M	H	E	E
(D) *Unlikely*	L	L	M	H	E
(E) *Rare*	L	L	M	H	H

Legend:

E: Extreme risk – intolerable and requires immediate action

H: High risk – undesirable and acceptable only when risk reduction is not feasible; requires special attention from management

M: Moderate risk – acceptable with approval and requires clearly defined managerial responsibility

L: Low risk – acceptable with management approval and can be addressed through routine procedures

Risks categorized as high and extreme are prioritized for immediate mitigation, whereas moderate and low risks are managed through routine monitoring and control. The final stage of the study is risk management, which focuses on formulating mitigation strategies based on the risk control hierarchy, including engineering controls, administrative controls, and the use of personal protective equipment (PPE). Mitigation recommendations are developed contextually, taking into account the local conditions of Banjarbakula TPA, management capacity, and the potential impact on surrounding communities.

RESEARCH RESULTS AND DISCUSSION

Environmental quality measurements were conducted to assess the level of environmental exposure potentially posing health risks to communities surrounding Banjarbakula Landfill (TPA). The analyzed parameters included ambient air quality, groundwater quality, and soil quality, which were subsequently integrated with community health survey results and risk analysis using the HIRADC method.

Results of ambient air quality measurements indicated that several pollutant parameters exceeded health threshold limits. Methane (CH_4) concentrations were recorded at 5 ppm, surpassing the WHO recommended range of 1–3 ppm, while carbon dioxide (CO_2) levels were measured at 450 ppm, higher than the reference value of 350 ppm.

In addition, particulate matter concentrations were found to be elevated, with PM_{10} at 90 µg/m^3 and $PM_{2.5}$ at 60 µg/m^3, both exceeding ambient air quality standards. The spatial distribution of pollutant concentrations relative to the landfill distance is presented in Figure 2.

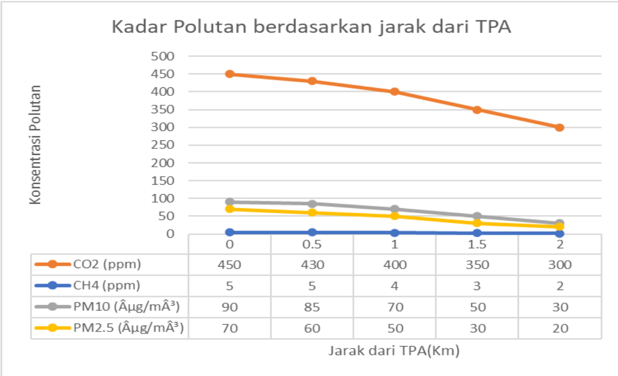

Figure 2: Air Pollutant Concentrations by Distance from the Landfill

Analysis of groundwater quality from wells in communities surrounding Banjarbakula Landfill (TPA) revealed heavy metal contamination. Lead (Pb) concentrations were measured at 0.05 mg/L, exceeding the standard limit of 0.01 mg/L, while mercury (Hg) levels reached 0.001 mg/L, also surpassing the threshold of 0.0005 mg/L. These results indicate that groundwater quality around the landfill does not meet established health standards.

Soil testing around Banjarbakula TPA showed heavy metal accumulation in the surface soil layer. Cadmium (Cd) concentrations were recorded at 2.5 mg/kg, exceeding the threshold value of 1.4 mg/kg. These findings suggest soil contamination in areas surrounding the landfill, particularly near leachate flow paths.

A health survey was conducted among 50 respondents residing within a 1–5 km radius of Banjarbakula TPA. Survey results indicated that 45% of respondents reported respiratory complaints, 25% experienced skin disorders, and 15% reported digestive problems.

Analysis of the relationship between residential distance and respiratory complaints demonstrated a strong positive correlation, with a Pearson coefficient of r = 0.68. This relationship is visualized in Figure 3.

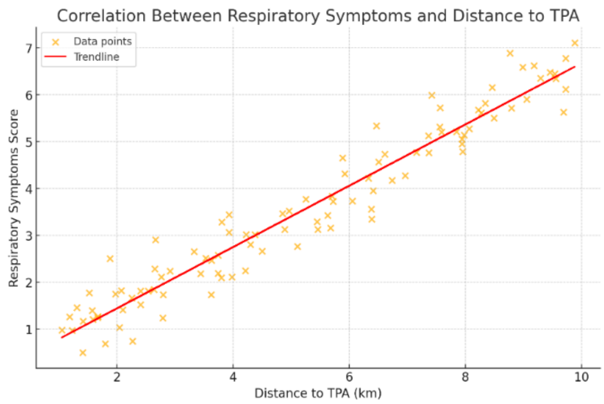

Figure 3: Relationship Between Residential Distance and Respiratory Symptoms

Integration of environmental quality data and community health surveys was conducted through risk analysis using the HIRADC method. The risk assessment results indicated that chemical and biological hazards exhibited the highest risk levels, each with a risk value of 16, categorized as high risk. Physical hazards were classified as moderate risk with a value of 9, while ergonomic hazards fell into the low risk category with a value of 6.

A summary of the risk assessment results is presented in Table 4.

Table 4: Health Risk Assessment Results at Banjarbakula Landfill (TPA)

Hazard Type	Severity (S)	Probability (P)	Risk (R = S × P)	Risk Category
Physical	3	3	9	Moderate
Chemical	4	4	16	High
Biological	4	4	16	High
Ergonomic	2	3	6	Low

Legend:
- High Risk: Value > 12 (Requires immediate control)
- Moderate Risk: Value 6–12 (Control is needed but not urgent)
- Low Risk: Value < 6 (Control can be enhanced but is not a priority)

The results of this study indicate environmental quality degradation around Banjarbakula Landfill (TPA), particularly in ambient air, groundwater, and soil, which directly contributes to an increased risk to community health. Methane (CH_4) and carbon dioxide (CO_2) concentrations exceeding safe thresholds indicate ongoing anaerobic decomposition of waste that is not yet optimally managed. This finding aligns with Rushton, who stated that active landfills are significant sources of hazardous and greenhouse gas emissions, especially when landfill gas capture systems are ineffective(37). Beyond local impacts, high methane emissions also contribute to global climate change due to their considerably higher global warming potential compared to CO_2(38).

Elevated particulate matter (PM_{10} and $PM_{2.5}$) concentrations around Banjarbakula TPA further indicate air pollution with potential adverse health effects. Fine particulates can penetrate the lower respiratory tract and trigger chronic lung disorders. This observation is consistent with Hamidah et al., who reported increased respiratory complaints and decreased lung function among populations exposed to landfill emissions(14), as well as gas dispersion modeling studies demonstrating pollutant spread into residential areas(16).

Groundwater quality around Banjarbakula TPA showed heavy metal contamination with lead (Pb) and mercury (Hg) exceeding health standards, indicating leachate infiltration into the aquifer system. Christensen et al. noted that landfill leachate contains complex mixtures of heavy metals and toxic compounds capable of migrating into groundwater when liner systems and leachate management are inadequate(39). These findings are consistent with studies in several Asian countries reporting elevated health risks from consuming contaminated groundwater near landfills(8).

In addition to groundwater, soil contamination around Banjarbakula TPA was evident from cadmium (Cd) accumulation in the surface soil layer. This heavy metal is persistent and may enter the food chain via crops, posing long-term health risks. Alloway emphasized that soil contamination by heavy metals is often latent yet can have transgenerational impacts(40). Therefore, soil quality degradation around Banjarbakula TPA represents a serious threat to sustainable community health.

The environmental quality decline is reflected in the high prevalence of health disorders among the community, particularly respiratory, dermatological, and digestive illnesses. A strong positive correlation between proximity to the landfill and the severity of respiratory symptoms indicates a clear exposure gradient. These findings are consistent with several studies reporting higher health risks among populations living near active landfills(10,14). Dermatological and digestive disorders reported by respondents also suggest that contaminated groundwater serves as a primary exposure pathway, either through direct contact or consumption.

Social factors further exacerbate health vulnerability around Banjarbakula TPA. Although most residents are aware of potential health risks, limited access to alternative clean water sources and economic constraints hinder the implementation of preventive measures. This observation aligns with Vinti et al., who highlighted that social and economic vulnerability amplifies environmental health impacts near waste management facilities(15). Complaints regarding odors and smoke from waste burning also indicate that landfill impacts extend beyond physical health to affect psychosocial well-being and overall quality of life.

The Hazard Identification, Risk Assessment, and Determining Control (HIRADC) approach applied in this study provided a systematic framework to integrate environmental quality data and community health conditions. Risk assessment results revealed that chemical and biological hazards fall into the highest risk category, requiring prioritized control. These findings are consistent with previous studies emphasizing the importance of managing chemical and biological exposures in landfill operations to protect workers and surrounding communities[35].

Overall, the results are in line with international literature that identifies landfills as major sources of environmental health risks. The consistency of these findings with global studies indicates that the issues observed at Banjarbakula TPA are part of broader waste management challenges, with local characteristics demanding improved management technologies, operational supervision, and integration of health risk analysis into sustainable landfill management policies[37,39,47].

Based on these findings, management of Banjarbakula Landfill requires strengthening landfill gas emission controls and leachate management systems to reduce exposure to key pollutants directly impacting community health. Detected leachate leakage and gas emissions indicate that sanitary landfill practices have not yet been fully implemented, necessitating technological upgrades and stricter operational supervision. Integration of health risk analysis based on environmental quality and community health data, such as through the HIRADC approach, is essential to establish effective and context-specific control priorities. Consequently, Banjarbakula TPA management should not only focus on technical waste control but also prioritize sustainable public health protection as part of regional environmental management policy.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that activities at Banjarbakula Landfill (TPA) have a significant impact on the degradation of ambient air, groundwater, and soil quality in surrounding areas, directly contributing to increased public health risks. Elevated concentrations of landfill gases and airborne particulates, heavy metal contamination in groundwater, and heavy metal accumulation in soil indicate that leachate management and gas emission control systems are not yet functioning optimally. Community health findings revealed a high prevalence of respiratory, dermatological, and digestive disorders, particularly among populations residing closer to the landfill site. HIRADC-based risk analysis confirmed that chemical and biological hazards are the dominant risks requiring prioritized management.

Based on these results, the management of Banjarbakula TPA is recommended to prioritize landfill gas emission control, improvement of leachate management systems, and periodic risk-based environmental quality monitoring. Integration of community health screening with environmental monitoring should be strengthened as part of public health protection. Future studies are recommended to develop quantitative health risk assessments and evaluate the long-term effectiveness of technical interventions and TPA management policies.

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