Eduvest – Journal of Universal Studies
Volume 5 Number 11, November, 2025
p- ISSN 2775-3735- e-ISSN 2775-3727

Community adaptation and environmental changes at the Putri Cempo PLTSa, Surakarta

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ABSTRACT

Waste management in urban areas has become a complex challenge in Indonesia, with a significant increase in national waste volume. This research aims to analyze changes in the physical quality of residential environments due to the operation of the Waste-to-Energy Power Plant (PLTSa) at Putri Cempo Landfill, Surakarta, and to identify community adaptation patterns to these environmental transformations. Using a descriptive qualitative approach, data were collected through in-depth interviews and field observations and then analyzed using theories of settlement quality and environmental adaptation. Results show that the PLTSa significantly impacts contextual, spatial, economic, and social aspects of settlements, especially within a radius of ≤500 meters. The absence of buffer zones exacerbates the effects of air pollution and noise. Economically, the reduction in waste-picking activities without adequate livelihood alternatives has become a major problem. The community demonstrates three adaptation patterns: behavioral adjustment, independent waste management, and rarely relocation due to economic limitations. Intervention priorities should be directed toward developing buffer zones and community economic empowerment programs.

KEYWORDS *Community Adaptation; Environmental Quality; Landfill; Waste Management; Waste-To-Energy*

INTRODUCTION

The problem of waste management in urban areas is a complex challenge that is increasingly urgent to overcome, especially in developing countries such as Indonesia (Iqbal, Yudha Irianto, Kamaludin, & Fatmawati, 2024). With a significant increase in the national waste volume from 34.9 million tons in 2022 to 69.9 million tons in 2023, or equivalent to 191,000 tons of daily waste (BPS, 2023), the urgency of implementing a sustainable waste management system is becoming increasingly crucial. Conventional methods such as open dumping that are still being implemented in many landfills in Indonesia have not only failed to solve the problem, but also created new negative impacts on the environment and public health (Hadomuan & Tuti, 2022).

Surakarta City faces multifaceted waste management challenges that extend beyond the operations of Putri Cempo Landfill alone (Suwartha & Pratama, 2020). As one of Central Java's major urban centers with a population exceeding 500,000 inhabitants, Surakarta generates approximately 400 tons of waste daily, placing enormous pressure on existing disposal facilities (Wibowo et al., 2023). The city's waste management infrastructure has struggled to keep pace with rapid urbanization and changing consumption patterns (Sasaki & Arifin, 2019). Several other temporary disposal sites (TPS) across the city also face capacity constraints and operational inefficiencies (Rahmasari et al., 2022). Furthermore, public participation in waste sorting and recycling remains limited, with only approximately 15% of households actively engaging in waste segregation at source (Purnomo et al., 2020). The informal waste sector, comprising hundreds of waste pickers, operates with minimal regulation or support (Damanhuri & Padmi, 2019). These systemic challenges create a cascade effect that ultimately

concentrates pressure on the Putri Cempo Landfill as the city's primary final disposal site (Setiawan et al., 2022).

The Putri Cempo Landfill in Mojosongo Village, Jebres District, Surakarta represents this problem in real terms. Operating since 1986, this landfill has long been a waste collection location with an open dumping method that serves the city of Surakarta and its surroundings. The environmental and health problems caused by open dumping practices at Putri Cempo have manifested in multiple concerning ways. Air quality measurements conducted in surrounding areas have detected elevated levels of methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S) gases emanating from decomposing waste, with concentrations occasionally exceeding national air quality standards. The pungent odor, described by residents as particularly intense during hot weather and when wind blows toward settlements, has become a chronic nuisance affecting daily life quality.

Water pollution presents another critical concern, as leachate from the landfill contains high concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals that pose risks to groundwater sources used by nearby communities. Public health surveillance data indicate elevated incidence rates of respiratory infections, skin diseases, and gastrointestinal disorders among residents living within 500 meters of the landfill compared to the general Surakarta population. Vector-borne disease risks have also increased due to proliferation of flies, mosquitoes, and rats attracted to exposed waste. These environmental and health impacts underscore the inadequacy of conventional open dumping practices and the urgent need for improved waste treatment technologies in Surakarta.

The consequences of this suboptimal waste management have been identified in the form of air pollution, unpleasant odors, noise, and health impacts on the surrounding community. This situation is exacerbated by the location of the landfill adjacent to residential areas, so that exposure to negative externalities becomes more intensive (Ramadhanti, Astuti, & Putri, 2021). To overcome these problems, the Surakarta City Government plans to implement Waste Power Plant (PLTSa) technology at the Putri Cempo Landfill. The gasification technology used in PLTSa offers a solution of dualism by converting waste into renewable energy, while significantly reducing the volume of waste. However, the transition to an energy-based waste management system faces complex challenges, both from operational technical aspects, waste supply management, to the potential for new environmental impacts that may arise around residential areas (Qodriyatun, 2021).

The PLTSa employs advanced gasification technology, a thermochemical process that represents a significant departure from conventional incineration methods. In this process, waste materials are subjected to high temperatures (typically 700-1000°C) in a controlled, oxygen-limited environment. This partial oxidation converts solid waste into synthesis gas (syngas), a combustible mixture primarily composed of carbon monoxide, hydrogen, and methane. The gasification process occurs in multiple stages: first, waste undergoes drying and pyrolysis where volatile compounds are released; second, the remaining char reacts with limited oxygen or steam in the gasification zone; finally, the produced syngas is cleaned and utilized to power internal combustion engines or gas turbines that generate electricity.

This technology offers multiple advantages including significantly higher energy conversion efficiency compared to direct combustion (approximately 25-35% electrical efficiency), substantial volume reduction of waste (up to 90%), lower emissions of harmful

pollutants such as dioxins and furans due to the oxygen-starved environment, and production of inert slag byproduct that can potentially be used in construction materials. The Putri Cempo PLTSa facility is designed with a processing capacity of 550 tons per day and an electrical generation capacity of 5 megawatts (MW), sufficient to power approximately 3,000-4,000 households. By converting waste into renewable energy, this technology addresses the dual challenge of waste management and sustainable energy generation, aligning with Indonesia's commitment to increasing the renewable energy mix in the national grid. The gasification technology used in PLTSa offers a solution of dualism by converting waste into renewable energy, while significantly reducing the volume of waste. However, the transition to an energy-based waste management system faces complex challenges, both from operational technical aspects, waste supply management, to the potential for new environmental impacts that may arise around residential areas (Qodriyatun, 2021).

Changes in waste management mechanisms through the operation of PLTSa have the potential to result in substantial transformations in the physical quality and social dynamics of the surrounding environment. As stated by (Kurniawan, 2020), the quality of the residential environment is influenced not only by the physical dimension, but also by the social dimension which includes interaction patterns and community adaptation capabilities. In this context, the process of community adaptation to physical changes in the environment is a fundamental aspect that needs to be studied in depth. To understand the dynamics of adaptation, this study refers to the adaptation theory developed by Altman et al., 1980 which classifies adaptation in three forms: adaptation by adjustment (self-adjustment without changing the environment), adaptation by reaction (adjustment by modifying the environment), and adaptation by withdrawal (adjustment by avoiding an uncomfortable environment). This theoretical framework allows a comprehensive analysis of the adaptive response of the community around the Putri Cempo Landfill in the face of environmental changes due to the operationalization of PLTSa (Huda, Gunawan, Jamilah, Luthfiyati, & Azizah, 2023).

This study aims to analyze changes in the physical quality of the residential environment caused by waste management through PLTSa and identify community adaptation patterns to these environmental transformations. The research objectives are threefold: first, to systematically assess the impacts of PLTSa operations on the contextual, spatial, economic, and social dimensions of surrounding settlements; second, to document and categorize the adaptation strategies employed by residents in response to environmental changes; and third, to evaluate the effectiveness of current adaptation mechanisms and identify gaps in community support systems.

The significance of this research extends across multiple domains. Theoretically, this study contributes to the growing body of literature on environmental adaptation in the context of waste-to-energy infrastructure by providing empirical evidence from an Indonesian urban setting, where such research remains limited. The findings will enrich understanding of the complex interrelationships between renewable energy-based waste management, environmental change dynamics, and community resilience strategies, particularly in developing country contexts characterized by informal settlements and vulnerable populations. Practically, the results are expected to make a substantial contribution to evidence-based policymaking in sustainable waste management.

The research provides critical insights for local government authorities in Surakarta and similar cities facing analogous challenges, offering guidance on integrating environmental protection and social welfare considerations in infrastructure development. Specifically, the findings can inform the design of effective buffer zone policies, community compensation mechanisms, livelihood transition programs for affected waste pickers, and participatory governance frameworks that ensure community voices are incorporated in environmental decision-making. Furthermore, this research addresses an urgent practical need by identifying intervention priorities that balance the environmental benefits of waste-to-energy technology with the protection of community well-being and environmental justice. The study ultimately seeks to demonstrate that sustainable waste management must harmoniously integrate technological innovation, environmental quality improvement, and social equity considerations to achieve truly sustainable outcomes.

METHOD

This study used a descriptive qualitative method to analyze the impact of PLTSa at the Putri Cempo Landfill on environmental quality and community adaptation. The research design employs a case study approach focusing on the residential areas surrounding the Putri Cempo PLTSa facility in Surakarta City. The selection of this location is purposive, based on its significance as one of Indonesia's pilot waste-to-energy projects and the documented environmental concerns raised by local communities.

Data was collected using multiple techniques—in-depth semi-structured interviews, systematic field observations, and secondary data review—to ensure triangulation and enhance validity. Interviews were conducted with 15 residents from different distance zones from the PLTSa facility, selected purposively based on residency duration, occupation, and age; with PLTSa managers and staff (n=3); and with local community leaders (n=3). Field observations were carried out over three months (July–September 2024) to document environmental conditions and community activities, while secondary data included government reports, environmental impact assessments, and community complaint records.

The data sources thus comprise both primary data (interviews and direct observations) and secondary data (documents and archival records). All interviews were recorded with informed consent, transcribed verbatim, and coded thematically. Data was collected through interviews with the community, PLTSa managers, and RTs, as well as field observations. The analysis was carried out by data reduction, presentation in a descriptive narrative, and drawing conclusions.

This research employs an integrated analytical framework based on Dursun & Saglamer's (2009) settlement quality theory (contextual, spatial, social, economic) and Altman et al.'s (1980) environmental adaptation theory (adjustment, reaction, withdrawal) to systematically examine how the PLTSa operations impact settlement dimensions and how the community adapts. The data analysis was an iterative process involving data familiarization, open, axial, and selective coding to identify themes and build coherent narratives, which were then triangulated for credibility and supplemented with GIS mapping to visualize the spatial distribution of impacts, ultimately aiming to provide a comprehensive insight into the environmental and social effects of the solar power plant.

RESULT AND DISCUSSION

Location Overview

The Putri Cempo Final Disposal Site (TPA) is located in Jatirejo Village, Mojosongo Village, Jebres District, Surakarta City. This landfill has an area of 17 hectares with a capacity of up to 100,000,000 kg of waste (Ardiansyah, Marom, & Nurcahyanto, 2024). Located in a hilly area, the Putri Cempo Landfill experiences an increase in the volume of waste generation every year, which is directly proportional to the increase in the population of Surakarta City. This condition results in an increase in the volume of waste that must be managed and causes various impacts on the quality of surrounding settlements, including contextual aspects (natural characteristics), spatial, social, and economic (Hariyanti & Haryanto, 2021).

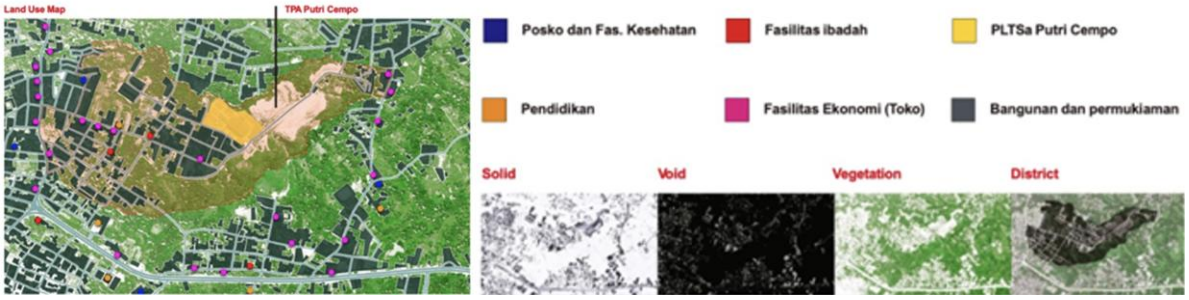

Figure 1. Land Use Putri Cempo Landfill Area, Surakarta
Source: Author, 2024

As an effort to reduce the negative impact of waste generation, the government initiated the construction of a Waste Power Plant (PLTSa) at the Putri Cempo Landfill. This project is based on Presidential Regulation Number 18 of 2016 concerning the acceleration of the construction of waste-based power plants in several cities in Indonesia, including Surakarta (Raharja, Hadiyanto, & Maryono, 2024). The construction of the Putri Cempo PLTSa with a capacity of 5 MW began through the signing of a financing agreement between PT Solo Citra Metro Plasma Power (SCMPP) and PT China Construction Bank (CCB) Indonesia Tbk. The main goal of the PLTSa is to process thousands of tons of waste into fuel, with heat energy from burning waste used to drive electricity-generating generators (Wibowo et al., 2022).

The Impact of PLTSa on the Physical Quality of Settlements

The Putri Cempo Landfill PLTSa area has a relatively flat topography with land conditions dominated by former garbage disposal areas. A factor that greatly affects the quality of the environment is the absence of buffer vegetation that functions as a natural filter. This condition exacerbates the impact of air pollution and noise from solar PV operations, as seen in Figure 2, making the surrounding settlements more vulnerable to the spread of unpleasant odors and air pollution (Rahayona et al., 2024).

Figure 2. Condition of the Drainage Network of the Putri Cempo Landfill
Source: Author, 2024

The distance between the location of the settlement and the PLTSa is a crucial factor that affects the level of impact. Spatial analysis shows that RT 3 which is in Zone 1 (radius ≤500 m) experiences the most significant impact of waste treatment activities, especially in terms of air quality and noise (Figure 3). Based on the standard (Indonesian Ministry of Public Works and Public Housing, 2013), the ideal distance between PLTSa and settlements is at least 1 km, but in this case, many settlements are within a radius of less than 500 meters, thus increasing health risks and reducing quality of life (Widowati et al., 2021).

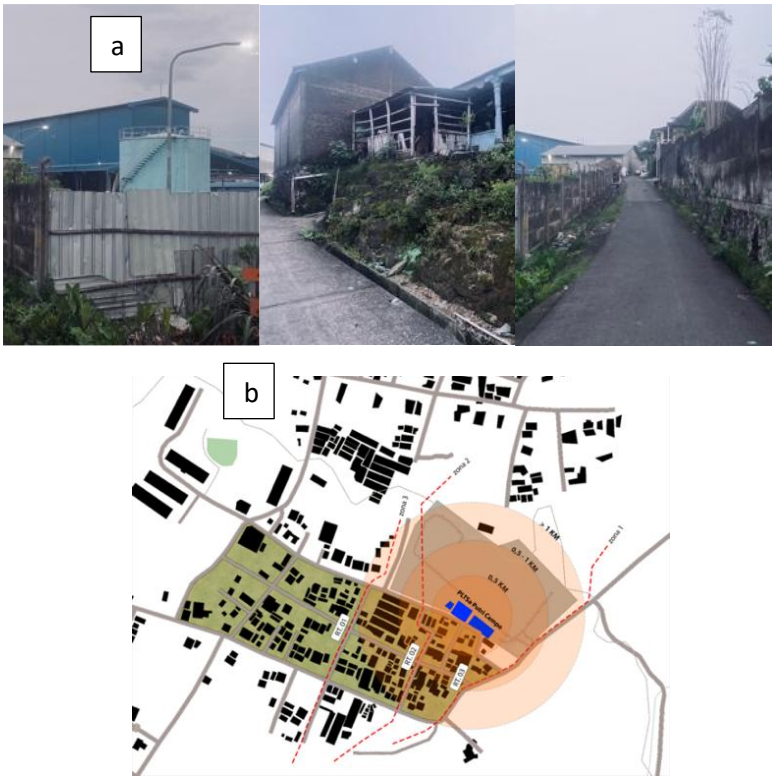

Figure 3. (a) Residential Conditions of RT 3 Adjacent to PLTSa and (b) Condition of Settlement Distance at PLTSa Putri Cempo
Source: Author, 2024

The comfort of the residential environment around the PLTSa, especially for residents of RT 3 in the Core Zone (radius 0-500 m), has experienced significant disturbances due to air pollution, pungent odors, and noise. According to the standards of the Indonesian Ministry of

Manpower (2012), this Core Zone is indeed at high risk of experiencing pungent odors, groundwater pollution, health risks, and poor housing conditions. The intensity of the impact is decreasing as the distance from the PLTSa increases, where the Buffer Zone (radius 500-1000 m) which includes RT 1 and RT 2 is still experiencing disturbances in the form of odors and the possibility of groundwater pollution, but with a lower intensity (Figure 4). The Safe Zone (>1000 m) has had minimal impact, although it still depends on the effectiveness of landfill management. As revealed by Rahmawati and Haryanto (2022), environmental comfort is greatly influenced by the distance from pollutant sources and the existence of vegetation buffers, which in the context of the Putri Cempo PLTSa are inadequate, so they cannot mitigate negative impacts on critical zones according to the national standard classification.

Figure 4. Impact Area Exposed
Source: Author, 2024

Accessibility in the area is disrupted by garbage transportation activities, as revealed by the Chairman of RT 1 in an interview. The main problems include road damage due to heavy vehicles and congestion due to the high frequency of garbage transport vehicles, which has an impact on the mobility and daily activities of residents (Figure 5). (Martono & Setiadi, 2020) emphasized the importance of integrated accessibility planning in residential areas around waste treatment facilities, where traffic systems and infrastructure conditions must be designed to minimize disruption to residents' activities.

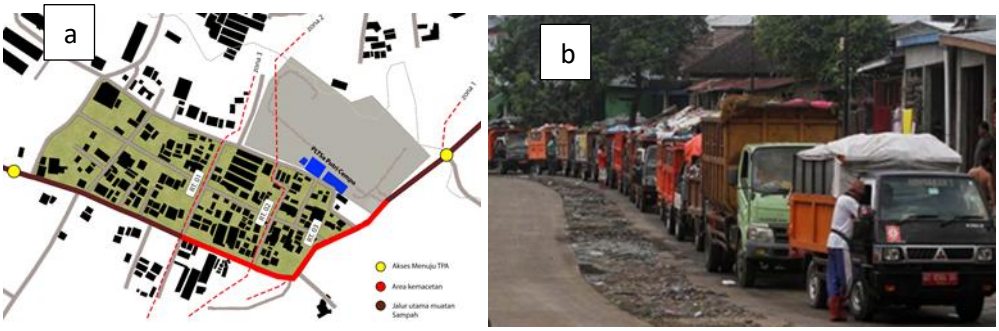

Figure 5. (a) Transportation Flow Map and (b) Waste Transportation Queue Activity
Source: Author, 2024

The spatial aspect includes architectural characteristics, building conditions, and spatial organization that provide an overview of the physical condition of the settlements around the

Putri Cempo Landfill PLTSa. The existence of PLTSa has a significant impact on spatial patterns and environmental quality, especially in RT 3 which is located closest to the facility. The observation results show that the accumulation of garbage around settlements is one of the main challenges (Figure 6.). The limited land in RT 3 causes untreated waste to be often stored around or even inside the house, creating a disorganized building layout with many barracks being built without clear planning (Khasanah & Saputra, 2022).

Figure 6. Distribution Map of Waste Collection Houses
Source: Author, 2024

According to Iwan, Chairman of RT 2 (2024), PLTSa's need for 550 tons of waste every day causes waste from other areas to be transported directly to the Putri Cempo Landfill, ignoring local waste processing. This condition worsens the situation in RT 1 and RT 2, where the accumulated garbage interferes with the quality of life of residents, with some residents starting to store garbage in their homes or in their yards. (Wahyuni & Mulyani, 2023) stated that the accumulation of garbage in residential areas can cause environmental quality degradation and affect the spatial behavior of people in arranging their residences.

The operationalization of PLTSa has led to a reduction in scavenger activities that previously relied on manual waste management. This loss of income sources results in most citizens losing their main livelihoods without a clear alternative. As a survival strategy, some scavengers are forced to store garbage in their homes as "waste savings" to sell later, although this strategy does not guarantee economic sustainability and instead increases the slums of settlements (Fajriyah, Kuntjoro, & Millatie, 2023).

The community around PLTSa has submitted a request for compensation funds to improve infrastructure and improve the quality of the residential environment, but there has been no follow-up from the management. The absence of this compensation program shows that the implementation of corporate social responsibility (CSR) in the economic aspect is still not optimal. (Wirawan et al., 2021) emphasized the importance of a comprehensive CSR program in waste treatment facilities, including financial compensation, economic empowerment, and infrastructure improvement.

Although PLTSa has the potential to support local MSMEs, there has been no integration of small businesses in the company's value chain. Sumono, Chairman of RT 3 (2024), revealed that until now there has been no initiative from PLTSa to help the community in the development of small businesses, even though with clear support, residents have the potential to switch to a more sustainable economic sector (Nurhayati et al., 2022).

The by-products of the gasification process have the potential to have economic value, but there has been no in-depth study of its use by the community. Without clear planning, this potential cannot be optimized, causing new business opportunities that should arise from the existence of PLTSa not being realized, so that the community remains in a vulnerable economic condition (Santoso & Rahmawati, 2022).

Although the operation of PLTSa Putri Cempo is expected to open new jobs for the community, there is still skepticism about its contribution to increasing employment opportunities. The lack of understanding of the mechanism for recruiting local workers is a major factor that raises doubts. According to (Anggraini, Herawati, & Rinaldi, 2022), intensive socialization is needed so that the public can obtain clear information about job opportunities and the recruitment process.

Although the community around the Putri Cempo Landfill has an organizational structure that supports social and environmental activities, there are still obstacles in organized waste management. Non-governmental initiatives in managing waste are still limited, with most of the economically valuable waste being simply sorted and sold without further processing. (Nurhayati et al., 2022) stated that limited facilities and lack of creative space for waste utilization caused the economic potential of waste to not be utilized optimally.

Adaptation and the Role of Society

The community around PLTSa, especially in RT 3 which is most affected by the impact, shows a form of adaptation that is more oriented towards waste management than physical changes in houses or migration. The observation results show three main adaptation patterns carried out by the community in responding to environmental changes due to PLTSa operations. The first adaptation (By Adjustment) involves adjusting behavior without making significant structural changes. Residents in RT 1 and RT 2 reduce the impact of air pollution and noise by closing windows, installing additional ventilation, and avoiding outdoor activities at certain hours (Figure 7). While this strategy can slightly reduce inconvenience, the impact of solar power plants is still felt, and the adjustments are limited to the individual and household levels (Angelika et al., 2024).

Figure 7. (a) Environmental Conditions and (b) Residents' Houses around PLTsa
Source: Author, 2024

The second adaptation (By Reaction) involves physical adjustments to reduce environmental impacts, especially in waste management. The community makes a garbage dump area in the yard as an effort to sort household waste, utilizing open areas to accommodate waste that will be resold. There has been no major effort to improve the structure of the building due to limited resources and access to adequate facilities (Widowati et al., 2021). The third adaptation (By Withdrawal) in the form of migration or relocation of residence, is almost invisible in the community around the Putri Cempo Landfill. Although the impact of PLTSa is very disturbing, most people choose to stay in their homes due to economic limitations and dependence on the environment they already live in. (Kusumawardhani, Sutjahjo, Dewi, & Panjaitan, 2020) stated that financial limitations and the absence of affordable housing alternatives around Surakarta are the main obstacles for people to move. Table 1 summarizes the community adaptation patterns and the impact of PLTSa on the physical quality of settlements.

Table 1. Adaptation and Impact of PLTSa

Types of Adaptations	Description of Adaptation	Impact Conclusion
By Adjustment	Behavioral adjustments such as closing windows, reducing outdoor activities, and independent waste management.	Reducing the impact of pollution and noise in a limited way; RT 3 is still significantly affected.
By Reaction	Sorting household waste and reselling it in lieu of income due to the decline in scavenger work due to PLTSa.	The main focus is on the economic recovery of the family; does not solve pollution or noise problems.
By Withdrawal	Almost no residents migrate due to economic constraints, limited housing alternatives, and dependence on the current location.	Residents continue to survive despite declining quality of life; The move is difficult to do, especially in RT 3.

Source: Author, 2024

CONCLUSION

The operation of the PLTSa at Putri Cempo Landfill significantly degrades the physical quality of nearby residential environments, affecting contextual, spatial, economic, and social dimensions, with the most severe impacts in Zone 1 (≤500 m radius) due to absent buffer zones amplifying air pollution, noise, poor drainage, and garbage accumulation. Economically, it has curtailed scavenger activities without viable livelihood substitutes, as CSR initiatives and

MSME support remain unrealized, while communities adapt primarily through behavioral adjustments and independent waste management rather than relocation, driven by financial constraints, prioritizing economic recovery over environmental mitigation. For future research, longitudinal studies could evaluate the long-term efficacy of proposed buffer zones and economic empowerment programs in reducing these impacts and enhancing community resilience.

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