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MORALITY BEFORE KNOWLEDGE

# Waste generation in Indonesia: How socioeconomic factors determine patterns in 2024?

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## ABSTRACT

**Background**: Rapid urbanization and economic growth in Indonesia have significantly increased municipal solid waste generation, posing environmental challenges. While prior studies have explored socioeconomic influences on waste, few have analyzed the combined effects of demographic and economic factors across all districts and cities using recent nationwide data. This study aims to provide empirical insights into the socioeconomic determinants of waste generation and to support the development of data-driven, sustainable waste management policies in Indonesia. **Methods**: This study analyzes daily waste generation in 2024, focusing on GRDP per capita, population density, average years of schooling, and poverty rate (P0). District- and city-level data were obtained from Statistics Indonesia and the National Waste Management Information System. Robust Linear Regression was applied to assess the effects of these variables. **Findings:** Population density increases waste generation, while higher average years of schooling and higher poverty rates are linked to lower waste production. GRDP per capita shows no significant effect. Social and demographic factors, therefore, play a stronger role than short-term economic output in shaping waste patterns. **Conclusion**: Average years of schooling, poverty rate, and population density are key drivers of waste generation, emphasizing the need to integrate socioeconomic and urban planning considerations into waste management strategies. **Novelty/Originality of this article:** The study provides nationwide empirical evidence on socioeconomic determinants of waste generation in Indonesia and offers practical insights for developing data-driven, sustainable waste management policies.

**KEYWORDS**: population density; socioeconomic determinants; waste generation.

## 1. Introduction

Since the early 2000s, Indonesia's population has increased beyond expectations due to a slowdown in the previously steady fertility decline that occurred during the 1970s to 1990s (Jones, 2014). This continued demographic expansion has unfolded alongside rapid economic development, collectively contributing to accelerated urbanization throughout the country. As industries grow and infrastructure, transportation networks, and public service provision improve, large numbers of Indonesians have migrated from rural areas to urban centers in search of better employment prospects, higher incomes, and improved living conditions. Although this urban shift has supported national economic transformation, it has simultaneously introduced significant environmental challenges. High population densities and intensified industrial activities in urban areas result in increased resource consumption, increased waste generation, and higher levels of air

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pollution, all of which pose significant threats to environmental sustainability (Afaz et al., 2024).

These growing environmental pressures highlight the need for a clear understanding of the waste being generated across the country. Before policymakers can strengthen current waste practices or design new management strategies, they must first understand the scale and characteristics of waste at the local and national levels. Identifying how much waste is produced and what types of materials dominate the waste generation is a fundamental step that determines the effectiveness of subsequent waste management planning (Aleluia & Ferrão, 2016; Gallardo et al., 2016; Khan et al., 2016; Miezah et al., 2015; Zhang et al., 2020). Without accurate information, waste reduction targets, recycling initiatives, and infrastructure investments risk being mismatched with actual conditions on the ground. This foundational knowledge ensures that interventions address real needs rather than relying on assumptions.

The urgency of understanding Indonesia's waste landscape becomes even more apparent when considering ongoing demographic and spatial changes. In 2010, approximately half of Indonesia's population resided in urban areas, and projections indicate that two-thirds will be urban by 2035, with the most rapid expansion expected in western Java (Jones, 2014). Between 2020 and 2025, the annual population growth rate is estimated at 1.09%, with five provinces in Java recording the highest in-migration rates (Badan Pusat Statistik, 2025). One of the most visible consequences of these demographic and spatial shifts is the substantial increase in waste generation (Wibisono et al., 2020), Indonesia's waste stream consists of various material categories, such as organic matter, paper, cardboard, metals, plastics, glass, and other residual materials (Lizárraga-Mendiola et al., 2022). According to 2024 data from the National Waste Management Information System (SIPSN), food waste constitutes the largest share of Indonesia's total waste at 37.84%, followed by plastic (19.52%), wood and branches (13.38%), paper and cardboard (11.17%), metal (3.30%), textiles (2.66%), rubber and leather (2.11%), glass (2.38%), and other materials (7.64%) (Fig. 1). The dominance of organic and plastic waste, which together account for over half of all waste, reflects prevailing consumption habits, dietary patterns, and purchasing behaviors across Indonesian households and industries.

Waste generation rates and composition vary widely across countries and cities, shaped by multiple factors including economic development levels, industrial structure, waste management regulations, demographic pressures, and lifestyle shifts (Win et al., 2024). A growing body of literature has examined how socioeconomic conditions influence both the quantity and composition of waste across different contexts (Adzania et al., 2022; Blagoeva et al., 2023; Nabil & Muljaningsih, 2025; Zambrano-Monserrate et al., 2021; Zhao et al., 2021). Despite the growing of research on waste generation, a substantial gap remains in studies that comprehensively assess how socioeconomic and demographic factors jointly influence waste generation across Indonesia. Much of the existing work is constrained by limited geographic coverage, outdated datasets, or a narrow focus on individual variables, making it difficult to capture the full complexity of Indonesia's rapidly changing socioeconomic landscape. As a result, there is limited understanding of the ways in which income, education, poverty, and population density collectively influence waste generation patterns when examined across the entire country. This lack of holistic and up-to-date analysis is increasingly problematic, as Indonesia's ongoing urbanization and shifting consumption behaviors amplify pressures on waste management systems. A clearer understanding of these determinants is therefore essential for developing effective, data-driven, and forward-looking waste management policies.

Furthermore, Indonesia's diverse regional contexts, ranging from densely populated metropolitan centers to rural districts with limited infrastructure, underscore the need for analyses that capture variation across space. Differences in local governance capacity, economic opportunities, and household characteristics may shape both waste generation behaviors and the efficiency of waste handling systems. Incorporating socioeconomic indicators across all districts and cities, therefore, enables a more nuanced understanding of the country's waste dynamics. This study contributes to addressing this gap by examining

the determinants of daily waste generation across Indonesia in 2024, focusing on the effects of Gross Regional Domestic Product (GRDP) per capita, population density, average years of schooling, and poverty rate (P0). By integrating updated district- and city-level data, this study provides empirical insights into the socioeconomic drivers shaping waste generation patterns and offers evidence-based guidance for improving the effectiveness and sustainability of Indonesia's waste management strategies.

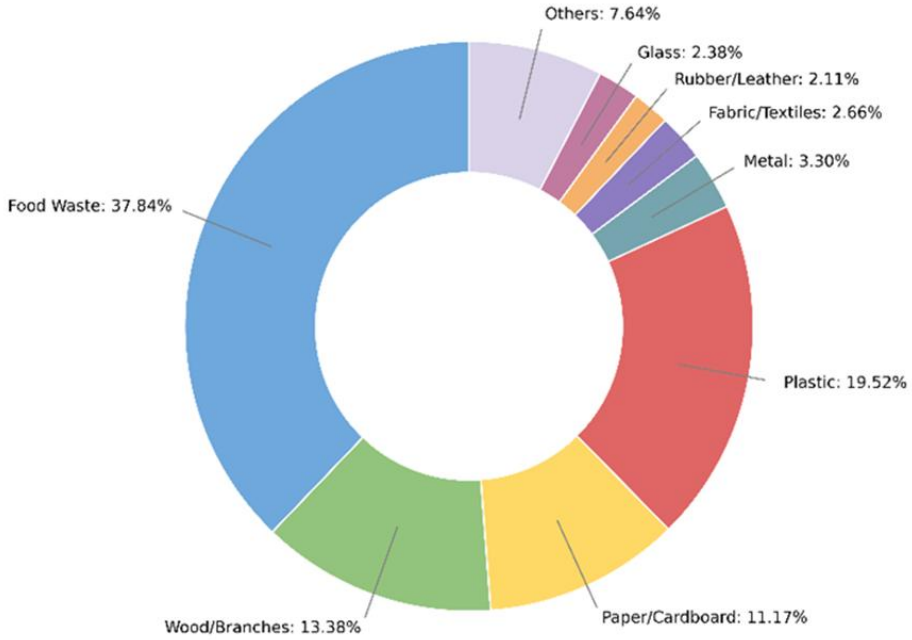


Fig. 1. Composition of Waste Generation in Indonesia, 2024
(Sistem Informasi Pengelolaan Sampah Nasional, 2024)

## 2. Methods

### *2.1 Study population*

The study population encompasses all 37 provinces in Indonesia, consisting of 331 districts and cities that form the administrative basis of the national dataset. This comprehensive selection reflects the full coverage of data available in the 2024 National Waste Management Information System (*Sistem Informasi Pengelolaan Sampah Nasional*/SIPSN), which provides systematically collected and standardized information on waste generation across the country. The inclusion of all districts and cities was determined by the availability of complete and up-to-date records on daily waste generation, which functions as the dependent variable in this analysis. These administrative units offer detailed measurements that capture variation across regions with differing socioeconomic characteristics, population structures, and levels of urbanization. Incorporating every province and its subordinate districts and cities ensures broad national representation and supports a more robust understanding of Indonesia's waste generation patterns. This approach not only ensures that the data reflects a wide variety of geographical and urban-rural contexts across Indonesia but also enhances the reliability and validity of the analysis.

### *2.2 Variable selection*

This study explores several variables to examine the factors influencing waste generation across districts and cities in Indonesia. The dependent variable is daily waste generation (tons per day), which represents the total amount of waste produced within each administrative area. This measure provides a consistent basis for comparing waste outputs between regions and reflects overall consumption and disposal patterns. Since waste

generation is shaped not only by population-driven activities but also by broader socioeconomic conditions, this study incorporates independent variables that represent both demographic pressures and regional economic characteristics. Previous research has shown that socioeconomic factors such as average years of schooling, literacy rates, per capita expenditures, and regional Gross Domestic Product (GDP) can significantly influence waste generation (Djuraidah et al., 2024). Four independent variables were selected to capture key socioeconomic and demographic characteristics: population density, average years of schooling, poverty rate, and GRDP per capita. These variables were chosen based on both theoretical relevance and empirical support from prior studies.

Population density, measured in people per square kilometer, captures the concentration of people in a given area. Higher population density is generally associated with greater waste generation (Monzambe et al., 2019). Higher density typically corresponds to more intensive human activity, faster resource turnover, and consequently greater waste production. The indicator is widely used in studies examining environmental pressures and waste-related outcomes because it reflects urbanization intensity and the spatial distribution of populations. Numerous studies have demonstrated that population density plays an important role in shaping waste generation, with denser regions tending to produce larger quantities of waste (Adzania et al., 2022; Ar'rida & Sopiana, 2023; Monzambe et al., 2019; Nurrobi, 2023; Vieira & Matheus, 2018).

Average years of schooling is used as a proxy for educational attainment, which influences environmental awareness, consumption practices, and waste-related behaviors. Higher educational levels are often associated with improved socioeconomic status and enhanced knowledge of environmental sustainability principles. At the same time, higher education may also correlate with consumption patterns that contribute to increased waste output. Previous studies provide evidence for the significance of education as a factor influencing waste generation across various settings (Adzania et al., 2022; Marinescu et al., 2016; Noufal et al., 2020; Trang et al., 2017; Vieira & Matheus, 2018).

The poverty rate, defined as the percentage of the population living below the poverty line, represents the extent of socioeconomic disadvantage within a district or city. One of the primary factors contributing to poverty is income level (Fitrawaty et al., 2024). It directly shapes consumption capacity, purchasing power, and lifestyle patterns. While poverty captures broader structural inequalities, previous studies focusing on waste generation in Syria have shown that higher income levels tend to increase waste production due to greater consumption of goods (Noufal et al., 2020). Building on this, this study employs the poverty rate as a regional-level indicator to examine its influence on waste generation patterns.

Gross Regional Domestic Product (GRDP) per capita serves as an indicator of regional income and economic activity. Regions with higher GRDP per capita generally experience greater industrial, commercial, and household consumption activities, all of which contribute to increased waste generation (Ar'rida & Sopiana, 2023). The relationship between GRDP and waste generation has been documented in various studies that highlight the relationship between economic expansion and waste generation (Ar'rida & Sopiana, 2023; Djuraidah et al., 2024; Nabil & Muljaningsih, 2025). Including GRDP per capita in the analysis makes it possible to assess the extent to which economic development influences waste generation across different regions.

These variables form an analytical framework that reflects demographic pressures, socioeconomic characteristics, and economic conditions across districts and cities. Their combined use allows the study to investigate the key factors that drive variation in waste generation across Indonesia's diverse regions.

### *2.3 Data collection*

The dependent variable, which represents daily waste generation, was obtained from the 2024 National Waste Management Information System (*Sistem Informasi Pengelolaan Sampah Nasional*/SIPSN) at the district and city level, covering all 37 provinces in Indonesia.

The SIPSN platform provides comprehensive, standardized, and up-to-date statistics on waste generation for each administrative unit, making it the most complete national source for waste-related data. These data are publicly accessible through the SIPSN portal at https://sipsn.kemenlh.go.id/sipsn/public/data/timbulan. The independent variables used in this study, namely Gross Regional Domestic Product (GRDP) per capita, population density, average years of schooling, and poverty rate (P0), were collected from the Statistics Indonesia [Badan Pusat Statistik, BPS], the national statistical authority responsible for publishing socioeconomic indicators. The BPS datasets offer consistent and reliable information across provinces and are available to the public at https://www.bps.go.id/id.

In the preprocessing stage, all independent variables were compiled and merged into a unified dataset to ensure compatibility across sources. The integration of variables was carried out by linking the socioeconomic data from BPS with the waste generation data from SIPSN using unique district and city identifiers provided in the SIPSN 2024 records. This matching process ensured that every district and city included in the study had complete information for both the dependent and independent variables. The resulting dataset contained aligned and comprehensive records for all regions, allowing for accurate descriptive analysis and robust inferential examination in the subsequent stages of the study.

### *2.4 Statistical analysis*

The analytical procedure consisted of two stages: descriptive analysis and inferential analysis. In the descriptive stage, spatial visualization techniques were employed to illustrate the distribution of daily waste generation across Indonesia. The mapping process utilized a color gradient ranging from red, representing areas with high levels of waste generation, to yellow, indicating areas with lower levels. This visual approach allowed for clear identification of regional patterns and disparities, enabling a more intuitive understanding of how waste generation varies geographically across provinces.

In the inferential stage, a Robust Linear Model (RLM) was used to examine the relationships between independent variables and daily waste generation. The independent variables included population density, average years of schooling, poverty rate, and Gross Regional Domestic Product (GRDP) per capita. The RLM approach was selected because the dataset contained outliers and exhibited violations of normality and homoscedasticity assumptions, conditions that could compromise the reliability of estimates produced by Ordinary Least Squares (OLS) regression. By applying Huber's M-estimator, the RLM reduces the influence of extreme observations, producing more stable and reliable coefficient estimates when classical OLS assumptions are not met (Huber, 1981, 2007).

The hypotheses were formulated to test whether each socioeconomic variable significantly influences daily waste generation. The null hypothesis ($H_0$) stated that an independent variable has no significant effect on daily waste generation ($\beta_i = 0$), while the alternative hypothesis ($H_1$) proposed that the variable has a significant effect on daily waste generation ($\beta_i \neq 0$). A variable was considered significant when its p-value was below the 0.05 significance level, leading to the rejection of the null hypothesis.

All analyses were conducted using Python version 3.11, with various specialized libraries supporting different components of the workflow. Data preprocessing and management were carried out using the pandas and NumPy libraries, while the statsmodels package was used for statistical estimation. Spatial and graphical visualizations were created using matplotlib and geopandas.

### *2.5 Study limitations*

This study is subject to several methodological limitations that should be acknowledged. The analysis is based on cross-sectional data from 2024, which captures conditions at a single point in time and does not reflect how socioeconomic factors or waste generation may evolve across different years. As a result, the relationships identified in this

study should not be interpreted as causal or indicative of long-term trends. Data consistency and reporting quality may also vary by region due to differences in technical capacity and local data collection practices. These variations introduce the possibility of measurement errors in the reported waste quantities. These limitations highlight the need for more comprehensive, fine-grained, and longitudinal datasets to support future research on the determinants of waste generation in Indonesia.

## 3. Results and Discussion

### *3.1 Results*

This section presents the analysis of the dependent variable, daily waste generation. It examines its relationship with independent socioeconomic factors, including Gross Regional Domestic Product (GRDP) per capita, population density, average years of schooling, and poverty rate. The raw datasets were obtained from authoritative national sources, with socioeconomic indicators sourced from Statistics Indonesia (*Badan Pusat Statistik*/BPS) and waste generation data retrieved from the National Waste Management Information System (*Sistem Informasi Pengelolaan Sampah Nasional*/SIPSN). After collection, all datasets were carefully preprocessed to ensure consistency and analytical readiness. The presentation of results is organized into two components: a descriptive analysis that employs spatial visualization to illustrate regional patterns of waste generation, followed by an inferential analysis using Robust Linear Regression to identify statistically significant relationships between waste generation and the selected socioeconomic variables.

#### *3.1.1 Descriptive analysis*

This subsection provides an overview of the key characteristics of the variables used in the study. The descriptive analysis offers an initial understanding of the distribution and variability of daily waste generation and its associated socioeconomic factors. These variables include GRDP per capita, population density, average years of schooling, and poverty rate. The descriptive statistics show that there are big differences between regions in both their daily waste generation and their socioeconomic conditions (Table 1). These differences help us understand what factors might influence how much waste each area produces.

Daily waste generation has the largest spread among all variables. The average is 290.8 tons, but the values range from only 11.7 tons to as high as 2187.4 tons. This means that while many districts and cities produce relatively small amounts of waste, a few produce extremely large amounts. These very high values likely come from major cities or industrial areas where there are more people, businesses, and daily activities. The difference between the median (156 tons) and the maximum also shows that the data are skewed toward a few very high-waste regions.

Population density also varies widely. The average is 1206 people/km$^2$, but the median is only 238 people/km$^2$, and the maximum reaches 15,389 people/km$^2$. This means most districts and cities have low or moderate population density, while a few have extremely high density. Densely populated areas usually generate more waste because more people live close together and use more goods and services. On the other hand, average years of schooling show smaller differences across districts and cities. The average is 8.9 years, with most districts and cities having similar levels of education. The values range from 5.1 to 13.1 years, but overall, the distribution is fairly even. This suggests that average years of schooling are more consistent compared with socioeconomic factors.

The poverty rate ranges from 2.2% to 30.8%, with an average of 9.9%. This shows that some districts and cities have very low poverty, while others have much higher levels. Districts and cities with higher poverty may have limited access to proper waste services or may rely more on informal waste disposal. GRDP per capita has the strongest variation

among the socioeconomic factors. The average is 74,972.6 thousand rupiah, but the highest value is more than 1,000,000 thousand rupiah. This large gap shows that a few very wealthy districts and cities raise the overall average.

Overall, the descriptive statistics show that districts and cities differ greatly in how much waste they produce, how dense their populations are, how wealthy they are, and how many people live in poverty. These differences suggest that the relationship between socioeconomic factors and average daily waste generation may be complex.

Table 1. Descriptive statistic of the data

| Variables | Mean (SD) | Min | Median | Max |
|---|---|---|---|---|
| Average daily waste generation (tons) | 290.8 (343.1) | 11.7 | 156 | 2,187.4 |
| Population density (people/km$^2$) | 1,206 (2,458.9) | 2 | 238 | 15,389 |
| Average years of schooling (years) | 8.9 (1.4) | 5.1 | 8.7 | 13.1 |
| Poverty rate (percent) | 9.9 (5.5) | 2.2 | 8.8 | 30.8 |
| GRDP per capita (thousand rupiah) | 74,972.6 (86,290.8) | 14,414 | 51,808 | 1,003,185 |

Building on these findings, the choropleth map provides a clear spatial visualization of average daily waste generation across Indonesia's provinces in 2024 (Fig. 2). The spatial visualization highlights the full range of values, from the lowest level of 47.18 tons to the highest level of 1,692.30 tons per day. The color gradient on the map, ranging from light yellow to deep red, shows the geographic pattern of waste production across the country. Darker shades represent provinces with higher waste volumes, while lighter shades indicate lower levels.

The three provinces with the highest average daily waste generation are concentrated in or around Java, the country's economic and urban heartland: DKI Jakarta (1,692.30 tons), which appears in the darkest red, followed by Banten (917.32 tons), which is in a deep brick red and West Java (790.93 tons), which is in a noticeable orange-red. This stark concentration correlates with population density data. For instance, DKI Jakarta's highest waste volume is mirrored by its extreme concentration, with an average density of 13,861 people per square kilometer across its districts and cities. West Java also reports a high average density across its districts and cities of 3,934 people per square kilometer. These visual and numerical patterns together show that provinces with large and dense populations generate much more waste because of higher consumption levels, greater commercial activity, and more intensive economic output.

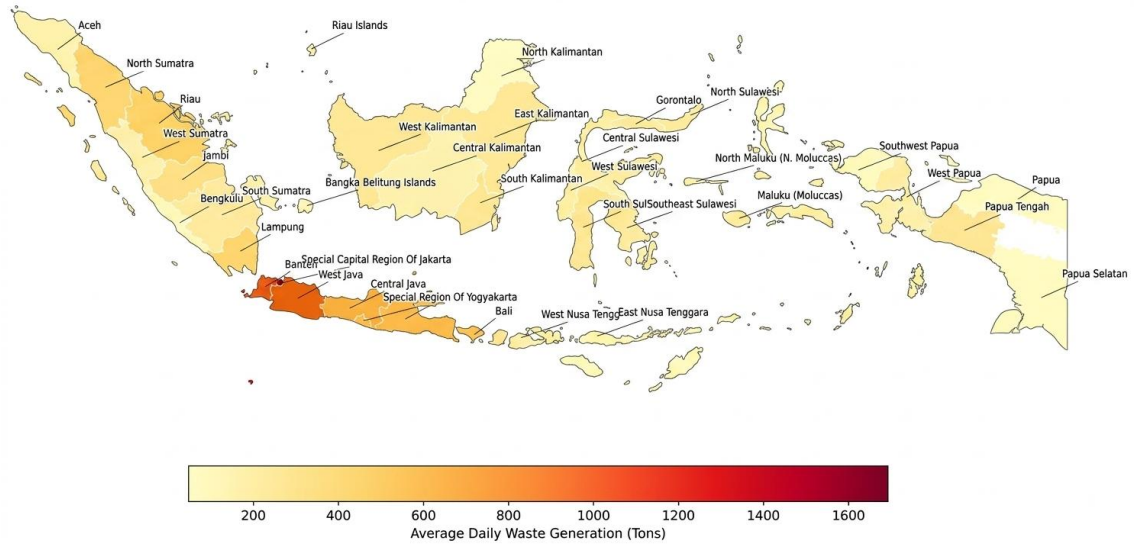


Fig. 2. Choropleth Map of Average Daily Waste Generation per Province in Indonesia, 2024

At the other end of the scale, the three provinces reporting the lowest average daily waste generation, North Kalimantan (47.18 tons), South Papua (47.41 tons), and Papua

(47.68 tons), demonstrate a striking difference in scale. These provinces are indicated on the map by the lightest yellow or near-white shades, representing values at the bottom of the waste generation scale. Their low waste volumes match their very low population densities, including an average density of only 11 people per square kilometer in North Kalimantan and 4 people per square kilometer in South Papua. These light areas on the map reflect small populations, large rural spaces, limited waste infrastructure, and the possibility that some waste may not be fully reported.

Overall, Fig. 2 makes the contrast across Indonesia visible at a glance. The provinces with the highest waste generation appear in strong red shades, while those with the lowest appear in very light tones. This spatial pattern shows that the country faces very different waste management needs. High-density urban provinces need stronger facilities and advanced processing systems, while low-density provinces need improved basic infrastructure and more complete and reliable data reporting.

### *3.1.2 Robust linear regression analysis*

The regression model analyzing daily waste generation included four independent socioeconomic variables: population density, average years of schooling, poverty rate, and gross regional domestic product (GRDP) per capita. The results are summarized in Table 2. The robust linear regression analysis indicates that population density has a significant and positive influence on daily waste generation ($p < 0.05$), with a coefficient value of 0.107. This means that an increase of one person per square kilometer is associated with an additional 0.107 tons of waste per day. Although the effect per person may appear small, the values become substantial in densely populated areas where increases in the thousands of people per square kilometer translate into hundreds of tons of additional waste. This result is consistent with theoretical expectations and previous empirical findings showing that high-density areas concentrate residential, commercial, and service activities that together elevate waste generation. The positive association also reflects the challenges faced by rapidly urbanizing districts, where population growth outpaces the expansion of waste management infrastructure.

The variable average years of schooling shows a significant negative relationship with waste generation ($p < 0.05$), with a coefficient value of –60.651. This indicates that a one-year increase in the average duration of schooling across a district or city corresponds to an estimated reduction of about 60.651 tons of waste per day. The magnitude of this coefficient highlights the strong role education may play in shaping environmental behaviors. Higher educational attainment is often linked with increased environmental awareness, better knowledge of proper waste management practices, and more responsible consumption patterns, all of which contribute to lower waste generation at the community level. Education may also influence lifestyle choices, such as the use of reusable products, reduced reliance on single-use plastics, and greater participation in waste segregation or recycling programs. These indirect behavioral pathways help explain the substantial impact observed in the regression model.

The poverty rate also has a significant negative association with daily waste generation ($p < 0.05$), with a coefficient of –4.738. A one-percentage-point increase in poverty is expected to reduce daily waste production by approximately 4.738 tons. This relationship can be interpreted through differences in consumption capacity. Poorer households generally purchase fewer goods, use fewer packaged products, and produce less overall disposable waste. As a result, regions with higher poverty levels tend to have lower waste volumes, not because of better waste practices, but because economic constraints inherently limit consumption.

In contrast, GRDP per capita does not show a statistically significant effect on daily waste generation ($p > 0.05$), with a very small coefficient of 5.5 (×10) ^ (-5). This suggests that after accounting for population density, education, and poverty, regional income differences do not meaningfully influence the amount of waste generated. The lack of significance indicates that economic output alone does not directly translate into higher

waste generation at the district and city level. To further verify this, a Spearman rank correlation test was conducted to assess the direct relationship between GRDP per capita and waste generation without controlling for other variables. The result of this correlation test also shows an insignificant relationship ($p > 0.05$), reinforcing the conclusion that GRDP per capita does not serve as a strong factor of waste generation in this dataset. One possible explanation is that GRDP, as a macroeconomic indicator, may not accurately reflect consumption behaviors, which are more directly tied to waste generation.

Taken together, the regression results indicate that socioeconomic factors, particularly population density, average years of schooling, and poverty rate, are the key determinants of waste generation across Indonesia's districts and cities, while GRDP per capita alone is not a reliable socioeconomic factor. These findings underscore the importance of designing waste management strategies that address population pressures and promote environmental education, in conjunction with economic development efforts.

Table 2. Robust linear regression model of daily waste generation

| Variables | Coefficient (β) | z | p-value |
|---|---|---|---|
| Constant | 720.171 | 9.667 | 0.000 |
| Population density | 0.107 | 24.823 | 0.000 |
| Average years of schooling | -60.651 | -7.691 | 0.000 |
| Poverty rate | -4.738 | -2.657 | 0.008 |
| GRDP per capita | 5.5e-05 | 0.500 | 0.617 |

### *3.2 Discussion*

The results of this study show that population density, average years of schooling, and poverty rate significantly influence waste generation across districts and cities, while GRDP per capita does not exhibit a statistically meaningful effect. These findings demonstrate that waste generation patterns in Indonesia are shaped by a combination of demographic pressures and behavioral factors, rather than economic performance alone.

Population density has a significant positive effect on waste generation, indicating that districts and cities with higher concentrations of people tend to generate substantially larger volumes of waste. This aligns with previous research showing that densely populated regions consistently experience higher waste generation (Monzambe et al., 2019; Nurrobi, 2023). High-density districts and cities typically display intensified consumption behaviors, reflecting patterns of modern consumer society in which rapid population growth, coupled with unsustainable consumption practices, leads to waste generation rising at a faster rate than population growth itself (Vieira & Matheus, 2018). These results suggest that waste management planning must be closely coordinated with population growth and urban development policies to ensure that infrastructure and service capacity can keep pace with expanding demographic pressures. As cities continue to grow, the challenge is not only handling the increasing volume of waste but also addressing spatial constraints that limit the expansion of waste management facilities. This further underscores the need for integrated urban planning approaches that balance population growth with resource efficiency.

The significant negative relationship between the average years of schooling and waste generation highlights the important role of education in reducing waste generation. Higher education levels are commonly associated with stronger environmental awareness, greater responsibility for sustainable consumption, and higher participation in waste reduction and recycling initiatives. This outcome is consistent with the findings of Noufal et al. (2020), who reported that education has a significant negative relationship with waste generation. Education also enhances the effectiveness of awareness campaigns aimed at improving solid waste management practices (Noufal et al., 2020). The more individuals are educated and informed about the negative consequences of improper waste management, the greater their recognition of the importance of effective waste management practices (Kayode & Omole, 2011). Moreover, education indirectly shapes waste-related outcomes by

influencing employment opportunities, income stability, and social engagement, which in turn affect lifestyle choices and consumption patterns. Investing in education therefore offers long-term environmental benefits by strengthening the capacity of individuals and communities to participate in sustainable waste management and adopt environmentally responsible behaviors.

The poverty rate also shows a significant negative relationship with waste generation, suggesting that regions with higher levels of poverty tend to produce less waste. Poverty is closely linked to income levels, as indicated by Fitrawaty et al. (2024), meaning that lower poverty rates generally imply higher income levels. As income increases, purchasing power and consumption expand, resulting in greater quantities and varieties of waste (Noufal et al., 2020). This pattern aligns with the findings of Chima & Nwabinye (2017), who observed that higher income shifts consumption behavior toward more diverse and packaged goods, thereby increasing waste generation that reflects lifestyle changes. It is also aligned with the study by Singh et al. (2025), who found a significant positive relationship between income and waste generation. These findings illustrate that waste generation is tightly connected to consumption capacity. As poverty decreases, policymakers must recognize that increased purchasing power will likely introduce new waste challenges. Therefore, interventions such as promoting sustainable packaging, incentivizing circular economy practices, and expanding community-based waste prevention programs are essential to mitigate the environmental consequences of rising incomes.

GRDP per capita, however, does not show a statistically significant relationship with waste generation in this study. Previous studies have reported a significant positive relationship between GRDP and waste generation (Nabil & Muljaningsih, 2025), as well as between Gross Domestic Product (GDP) and waste generation (Blagoeva et al., 2023), indicating that higher economic growth leads to increased waste generation. GRDP serves as the regional counterpart of GDP, representing local economic activities that collectively contribute to national output. This insignificance may be due to the use of cross-sectional data for a single year, which captures only short-term economic conditions. Short-run fluctuations in GRDP may not yet translate into observable changes in waste generation, a conclusion consistent with Shehu et al. (2024), who also found no significant short-run effect of GDP on waste production. In economic terms, the short run refers to a period during which structural adjustments and behavioral responses to economic growth have not fully materialized in environmental outcomes. Variations in regional economic performance within a one-year timeframe may therefore be insufficient to influence waste generation patterns, as such changes often occur gradually over time. A similar result was obtained by Djuraidah et al. (2024), who also found an insignificant relationship between GRDP and waste generation. GRDP per capita may obscure intra-regional inequality, where economic growth is concentrated in specific industries or areas without directly affecting household consumption patterns that drive waste generation.

These findings reveal that waste generation is shaped not only by economic factors but also by demographic conditions and human behavior. Population density increases waste generation, while average years of schooling and poverty rate influence sustainable consumption and engagement in waste management practices. Effective and equitable waste management strategies must therefore integrate these demographic and behavioral dimensions, ensuring that policy interventions respond to the specific social and environmental contexts of each district and city.

## 4. Conclusions

This study provides empirical insights into the socioeconomic determinants of waste generation across districts and cities in Indonesia in 2024, using official data from Statistics Indonesia (*Badan Pusat Statistik*/BPS) and the National Waste Management Information System (*Sistem Informasi Pengelolaan Sampah Nasional*/SIPSN). The findings show that population density, education level, and poverty rate have significant effects on waste generation, while GRDP per capita does not exhibit a statistically meaningful influence.

These results highlight that demographic pressures and behavioral factors shape waste generation more strongly than short-term economic performance.

Higher average years of schooling are associated with lower waste generation, emphasizing the importance of education in fostering environmentally responsible behavior, encouraging sustainable consumption, and improving participation in waste reduction initiatives. The negative relationship between poverty and waste generation indicates that increased income and purchasing power lead to higher consumption, which in turn produces more waste. This finding underscores the need for upstream waste prevention policies as poverty declines and consumption patterns shift. The positive effect of population density reflects the growing strain placed on waste management systems in rapidly urbanizing regions, where concentrated populations translate directly into higher waste volumes and greater pressure on existing infrastructure.

These insights contribute to a more nuanced understanding of how social, demographic, and economic conditions interact to shape waste generation patterns in Indonesia. They also offer clear implications for policy design. Strengthening environmental education, integrating waste management considerations into urban development plans, and ensuring that poverty alleviation efforts are accompanied by sustainable consumption strategies are crucial steps toward reducing waste generation. Policymakers should focus on tailored interventions that address the specific socioeconomic conditions of each district and city rather than applying uniform strategies across diverse local contexts. In addition, efforts to improve data quality and expand local reporting systems would provide municipalities with more accurate tools for monitoring waste trends and evaluating the effectiveness of policy interventions.

Future research could extend this analysis by incorporating longitudinal data to capture dynamic changes over time and better understand the long-term effects of economic development on waste generation. Examining additional factors, such as household consumption behavior, participation in recycling programs, cultural attitudes toward waste, and the effectiveness of local policy initiatives, would help build a more comprehensive model of waste generation. Such work would enhance the evidence base needed to design targeted, data-driven strategies for sustainable waste management and support Indonesia's broader environmental and development goals.

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## Author Contribution
O.D.R. was responsible for all aspects of the study, including conceptualization, methodology, data collection and analysis, writing, and project administration.

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## Informed Consent Statement
Not available.

## Data Availability Statement
The data supporting this study are publicly available. Waste generation data can be accessed from the National Waste Management Information System (*Sistem Informasi Pengelolaan Sampah Nasional*/SIPSN) at https://sipsn.kemenlh.go.id/sipsn/public/data/timbulan, and socioeconomic variables, including GRDP per capita, population density, average years of schooling, and poverty rate

(P0), are available from Statistics Indonesia (*Badan Pusat Statistik*/BPS) at https://www.bps.go.id/id.

## Conflicts of Interest

The authors declare no conflict of interest.

### Declaration of Generative AI Use

During the preparation of this work, the author used Grammarly to assist in improving the grammar and clarity of the manuscript. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

## Open Access



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