Modeling Waste Generation Patterns in Urban Areas: A Computational Analysis of Population Growth and its effect on Waste Generation

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Abstract

Cities have been experiencing growing difficulties regarding the administration of their municipal wastes because of their fast-growing populations, industrialization, and changes in consumption patterns. The comprehension of waste generation trends is of great significance for the efficient use of resources, conservation of the environment, and effective city planning. This research titled "Modeling Waste Generation Patterns in Urban Areas," aims to investigate and forecast the amount of waste production through the use of mathematical models. Through the acquisition of historical waste information from the City/Community Environment and Natural Resources Office, the study uses statistical modeling techniques to examine the patterns and trends of waste generation. The model created within the context of the present study simulates the generation of waste on a yearly basis, thereby permitting the forecast of the upcoming amount of waste within a reasonable degree of accuracy. The initial findings of the investigation show a very strong positive association between population density and the amount of waste produced. These insights from the present research are of paramount importance for urban planners, policymakers, and environmental agencies in terms of enforcing evidence-based decision-making in waste management. The present study contributes to developing sustainable urban ecology by providing a predictive tool that supports effective waste management strategies with minimized ecological footprints for cities.

Keywords: Urban Waste Generation, Population Growth, Urbanization, Sustainable Waste Management, Tanjay City

Introduction

Due to rapid urbanization, there is a significant increase in the generation of municipal solid waste in cities across the country. With the increase in the number of people living in urban areas, changes in lifestyle and economic activities are also resulting in increased generation of municipal solid waste. These rising amounts are creating serious challenges in handling municipal solid waste, as the waste management infrastructure cannot cope with such growing requirements. Knowing the reasons for municipal solid waste generation is necessary for effective waste management practices.

One of the primary factors contributing to the production of urban garbage is population growth. Simply put, an increase in population results in higher consumption of products and services, which leads to more waste. Waste production in urban areas is also increased by changes in consumer behavior, such as greater use of disposable materials and product packaging. In fact, previous studies have shown that socioeconomic and demographic factors play a major role in determining waste generation characteristics, such as source, quantity, and composition, which need to be matched with appropriate analytical techniques for their analysis.

Computational modeling, in recent times, has developed as an approach to analyze and predict waste generation patterns. The traditional approaches cannot handle large volumes of data and clearly explain the interaction among connected factors such as population size, growth rate, consumption trends, or their combined effect. These models accurately show current waste generation patterns and allow for reliable predictions of future waste levels. Such predictive capabilities are very important for urban planners and policymakers in designing effective waste management systems and proper resource allocation.

The title of the project is "Modeling Urban Waste Generation: A Computational Analysis of Population Growth and its effect on Waste Generation," and the purpose of the project is to examine the application of computational analysis in the study of the effects of population growth on urban waste generation. By analyzing data related to population growth and waste generation, the project seeks to identify important factors that cause waste in urban areas, so that measures can be taken for the proper disposal of waste in cities.

Globally, population growth and a fast pace of urbanization have been found to be important factors that affect the rising production of municipal solid waste. As observed and supported by a study carried out by Hoornweg and Bhada-Tata in 2012, the generation of waste has a direct correlation with the size of the population and their rising levels of consumption, which produce a growing volume of waste in urban centers. Further, the World Bank found that cities generate over 70 percent of global solid waste, and this is expected to double in the coming years, particularly in developing countries.

From an international point of view, studies in rapidly expanding urban areas, particularly in Asia and Africa, further show that there is a connection between population and socioeconomic aspects and waste production. According to Guerrero et al. (2013), population density, household types, and income are key factors in determining the amount and type of urban waste. It was noted in the study that to fully understand the complex links between these factors, there is a need to apply analytical or mathematical models, because current techniques are not enough to address such complexities.

In the Philippine setting, the generation of waste in urban areas has become an increasing concern given the rapid growth of cities like Metro Manila, Cebu, and Davao. The numbers of the National Solid Waste Management Commission (NSWMC) reveal that with the growing population and the spending habits of the people, there has been an increasing daily generation of waste in the country. Observations made through local studies reveal that factors influencing the generation of waste in urban areas to a significant extent include population growth, income levels of the population, people's behavior with regards to waste generation, and lack of waste management systems to manage the waste the country generates.

Recent studies conducted in the Philippines have highlighted the role of computational and data-centric methods for addressing urban waste problems. It has been suggested that predictive models can be helpful for local government units in determining future waste amounts, thus finding an efficient methodology for urban waste management. Through the combination of data related to population growth and consumption patterns, computational models help in taking informed actions for sustainable urban waste management.

Literature Review

Most cities around the world have faced big concerns about urban waste generation due to rapid population growth and urbanization. Increased municipal solid waste generation, as cited by Beigl, Lebersorger, and Salhofer (2008), has been tied to population size and socioeconomic factors since an increase in the population leads to more consumption and higher waste production. Their study focused on the fact that most models of waste generation are based on demographic and economic data to estimate and predict waste trends and indicated population growth as a highly related factor that affects urban waste amounts.

Population growth tends to influence not only the amount but also the type of waste generated. As Senzige and Makinde (2016) noted, waste is generated according to population growth. Activities related to human daily life, such as food consumption, housing, and transportation, contribute to increasing solid waste. Their observations revealed that rapidly growing urban cities put more stress on the waste management system and thus require planning and forecasting for sustainable urban growth.

Patterns of consumption are also a major factor that influences the amount of waste generated in cities. Through research carried out by many authors between 2015 and 2020 regarding the buying habits of the urban population, it can be concluded that the rising middle class and the subsequent increase in the use of packaged and disposable items are important factors. The growth of cities also increases the consumption of convenience products. Therefore, the amount of non-biodegradable waste like plastics and paper grows.

Recent studies have shown that the use of computer modeling is important in the analysis of waste generation trends. According to research conducted by Guerrero, Maas, and Hogland in 2013 and other research from 2018 to the current year, computer models such as regression analysis, time series models, and predictive models can be used well in the analysis of the complex relationships between population growth, consumption trends, and waste generation.

Although many studies have measured urban waste generation, few have focused only on either population growth or consumption patterns, and even fewer have combined these factors into one clear computational framework. Recent literature reviews within 2020-2023 show very few studies that include both factors in one computational framework. This research gap highlights the need for studies that integrate population growth and consumption behavior to develop suitable models describing waste generation patterns in urban areas. Such integration can provide meaningful ways toward effective and efficient waste management in urban settings.

Furthermore, Hoornweg and Bhada-Tata (2012) supported this view, underlining that the production rate of municipal solid waste globally is anticipated to increase greatly owing to the growth of city populations, especially in developing countries. The report related to population, density, and income levels, issued by Hoornweg & Bhada-Tata from the World Bank, again highlighted the important use of modeling.

Likewise, Kolekar, Hazra, and Chakrabarty (2016) investigated urban waste generation in Asian cities experiencing rapid growth and concluded that demographic factors like growth rate and population size affect urban waste generation as key elements. This indicates that cities experiencing high growth rates face difficulties in managing their waste management systems to meet increasing needs.

From a computational perspective, Abbasi and El Hanandeh (2016) showed that the use of demographic and consumption data within computational models improves waste generation forecast accuracy. Their findings indicated that multi-factor models perform better compared to single-variable models, and this is suitable for long-term urban planning and policy making.

More recent work, as seen in the reviews done by Kaza et al. (2018) and other papers published until 2023, offers evidence that although there are more population-based models, fewer work with consumption-related factors like lifestyle changes and income patterns. This affects the effectiveness of policy designs in rapidly changing urban settings.

In the context of the locality, in major urban Philippine cities such as Metro Manila and Cebu, there is a clear correlation between the increasing population density and consumption levels, which is reflected in the generation of large amounts of waste. Still, many LGUs today are using traditional approaches in estimating their waste, such as static estimation, which is not predictive compared to using computational approaches in modeling population growth and consumption behavior for better management of waste in cities.

More recent studies have further stressed the integration of socioeconomic and demographic factors in urban waste modeling. Šomplák et al. (2023) highlighted that including population size and consumption behavior increases predictive accuracy in urban waste forecasts. Similarly, Park, Han, and Kim (2021) demonstrated that population growth and income-consumption patterns are important predictors of waste volumes in rapidly urbanizing regions. Mayes Ramírez et al. (2023) also found that multi-factor computational models incorporating population density and consumption data are more effective for policy planning than single-variable approaches. These studies support the need for developing a computational model that integrates population growth and consumption patterns to enhance urban waste management in Tanjay City.

Methodology

Computational research can be defined as a research method that uses mathematical formulas and computer calculations (Abbasi & El Hanandeh, 2016) to study complex systems with the goal of making predictions from data. Using this definition for the study, the objective of the computational research was to examine the connection between population growth and waste production in Tanjay City, Philippines.

The current study used a quantitative descriptive computational research method to study the rate of urban waste generation in Tanjay City, in order to find the relationship between population growth and the amount of waste produced in urban areas (Senzige & Makinde, 2016). Since computational mathematics provides an accurate and clear way to model the relationship between population growth and urban waste, it was chosen as the main methodology for this study. While proportional scaling formulas turn these demographic projections into waste estimates, computational methods, unlike descriptive statistics, allow the use of exponential growth formulas to calculate yearly growth rates and predict future population numbers.

The study used secondary data obtained from the City/Municipal Environment and Natural Resources Office (C/MENRO) of Tanjay City, which included the data of wastes collected and disposed of monthly and yearly for 2022, 2023, and 2024. The data also included the "Summary of Solid Waste for CY 2024", showing the types of waste, including residual, biodegradable, recyclable, and hazardous wastes, as well as the average daily waste produced in urban areas. Only actual records from the data were used for the study.

The data collected shows how much waste is produced each month and year, with a special focus on how waste will be categorized in 2024. The data has been organized neatly by month and year and checked for accuracy in calculations. Since the data comes from government records, there was little cleaning needed, and any discrepancies were checked using the summary tables. Simple statistical methods were used to identify patterns in waste generation over time, monthly changes, and the breakdown of different types of waste.

The main methodology for mathematical calculations in this research was exponential population growth modeling combined with per capita scaling for waste generation. In this study, the independent variable is population size, as it is expected to change over time, while the dependent variable is the amount of waste generated, which changes directly with population growth. The accuracy of the model was checked by comparing the calculated results with actual data from C/MENRO.

Thus, it can be concluded that the above-mentioned methodology allowed a data-driven analysis of waste patterns in urban areas, linking population growth to the collected data on waste generation trends. This is important as it allows planning to be based on evidence.

In this study, the researchers used two sets of formulas: exponential growth equations for population and proportional scaling for waste. The population formulas (1 and 2) come from the exponential growth model, a common approach in demography where population change is treated as continuous growth over time (Terano, 2018). In our case, population is the independent variable because it naturally changes, while waste is the dependent variable since it rises in direct relation to population size. The waste formulas (3 and 4) are based on environmental science methods, where the per capita waste rate is first calculated from actual data and then multiplied by projected population figures to estimate future garbage volumes (Kaza et al., 2018; Hoornweg & Bhada-Tata, 2012). We checked the accuracy of this approach by comparing our computed results with official statistics from C/MENRO, and the close results confirmed that the model works well. This process follows established practices in population and resource modeling, where exponential growth and proportional scaling are widely used to forecast environmental pressures (Shabir, 2025).

Population Growth Rate

$$r = \frac{\ln(\frac{P_t}{P_0})}{t}$$

Where,

r**:** Annual growth rate (decimal form)

P_t**:** Population at year t

$\boldsymbol{P_0}$**:** Baseline population (2020 = 82,642)

t**:** Number of years between $\boldsymbol{P_0}$ and P_t

Baseline population in 2020: P_0=82,642

Population in 2024: P_t=84,593

Time interval: t=4 years

1. Divide populations:

$\frac{P_t}{P_0}=\frac{84,593}{82,642}\approx 1.0236$

2. Take the natural logarithm:

$\ln(1.0236)\approx 0.0233$

3. Divide by time (4 years):

$r=\frac{0.0233}{4}\approx 0.0059$

the annual population growth rate is 0.59% per year.

Population Forecasting

$$P(t) = P_0 \cdot e^{r \cdot t}$$

Where,

P(t)**:** Population at year t

P_0**:** Baseline population (2020 = 82,642)

r**:** Annual growth rate (0.0059)

t**:** Years since 2020

e**:** Euler's number (≈ 2.718), base of natural logarithms

Per Capita Waste Rate

$$w_p = \frac{W}{P}$$

Where,

w_p**:** Per capita waste (tons/person/year)

W**:** Total waste generated (2024 = 8,739,255 tons)

P**:** Population in 2024 (84,593)

1. Substitute the values into the formula

$$w_p = \frac{8,739,255}{84,593}$$

2. Compute the division

$$w_p \approx 103.309 \text{ tons/person/year}$$

3. Round to one decimal place (if needed for reporting)

$$w_p \approx 103.3 \text{ tons/person/year}$$

Waste Forecasting

$$W(t) = w_p \cdot P(t)$$

Where,

W(t)**:** Forecasted waste (tons)

w_p**:** Per capita waste (103.3)

P(t)**:** Forecasted population

The mathematical validation of the model was carried out by comparing computed results with actual statistics from 2022 to 2024, which showed close alignment and confirmed the reliability of the approach.

For illustration, the researchers applied the exponential growth model to forecast the population of Tanjay City in 2025. Using the baseline population in 2020 (P0=82,642) and the computed annual growth rate (r=0.0059), the population at year t=5 was calculated as:

$$P_{2025} = P_0 \cdot e^{r \cdot t} = 82{,}642 \cdot e^{0.0059 \cdot 5} \approx 85{,}117$$

The per capita waste generation rate was derived from 2024 data, where the total waste was 8,739,255 tons and the population was 84,593. This yielded:

$$w_p = \frac{W}{P} = \frac{8{,}739{,}255}{84{,}593} = 103.3\ tons/person/year$$

The forecasted waste for 2025 was then obtained by multiplying the projected population by the per capita rate:

$$W_{2025} = w_p \cdot P_{2025} = 103.3 \cdot 85{,}117 \approx 8{,}793{,}000\ tons$$

This step-by-step computation shows how the model translates population growth into predicted waste volumes. By repeating the same process for each subsequent year, forecasts for 2026–2030 were generated.

2025 (t = 5)

Population:

$$P\ (2025) = 82{,}642 \cdot e^{0.0059 \cdot 5} \approx 82{,}642 \cdot e^{0.0295} \approx 82{,}642 \cdot 1.0299 \approx 85{,}117$$

Waste:

$$W_{2025} = w_p \cdot P_{2025} = 103.3 \cdot 85{,}117 \approx 8{,}793{,}000\ tons$$

2026 (t = 6)

Population:

$$P\ (2026) = 82{,}642 \cdot e^{0.0059 \cdot 6} \approx 82{,}642 \cdot e^{0.0354} \approx 82{,}642 \cdot 1.0360 \approx 85{,}619$$

Waste:

$$W_{2026} = 103.3 \cdot 85{,}619 \approx 8{,}845{,}000\ tons$$

2027 (t = 7)

Population:

$$P\ (2027) = 82{,}642\ \cdot e^{0.0059 \cdot 7} \approx 82{,}642\ \cdot e^{0.0413} \approx 82{,}642\ \cdot\ 1.0422\ \approx 86{,}128$$

Waste:

$$W_{2027} =\ 103.3 \cdot 86{,}128\ \approx\ 8{,}898{,}000\ tons$$

2028 (t = 8)

Population:

$$P\ (2028) = 82{,}642\ \cdot e^{0.0059 \cdot 8} \approx 82{,}642\ \cdot e^{0.0472} \approx 82{,}642\ \cdot\ 1.0484\ \approx 86, 638$$

Waste:

$$W_{2028} =\ 103.3 \cdot 86{,}638\ \approx\ 8{,}950{,}000\ tons$$

2029 (t = 9)

Population:

$$P\ (2029) = 82{,}642\ \cdot e^{0.0059 \cdot 9} \approx 82{,}642\ \cdot e^{0.0531} \approx 82{,}642\ \cdot\ 1.0546\ \approx 87{,}150$$

Waste:

$$W_{2029} =\ 103.3 \cdot 87{,}150 \approx\ 9{,}003{,}000\ tons$$

2030 (t = 10)

Population:

$$P\ (2030) = 82{,}642\ \cdot e^{0.0059 \cdot 10} \approx 82{,}642\ \cdot e^{0.059} \approx 82{,}642\ \cdot\ 1.0608\ \approx 87{,}664$$

Waste:

$$W_{2030} =\ 103.3 \cdot 87{,}664 \approx\ 9{,}056{,}000\ tons$$

Results

To demonstrate the expected influence of population expansion on urban garbage creation, a computer projection was created using the exponential population growth model and per capita waste scaling. Population size and waste volumes were anticipated from 2025 to 2030 using the derived yearly population growth rate and the estimated per capita waste generation from recent records. Table 1 summarizes the expected population numbers and municipal solid waste generation for each year, giving a quantitative foundation for evaluating Tanjay City's future waste management needs.

Table 1. Forecast Results: Population and Waste Generation (2025 - 2030)

Year	Forecasted Population P(t)	Predicted Waste W(t) (tons)
2025	**85,117**	**8,739,000**
2026	**85,619**	**8,845,000**
2027	**86,128**	**8,898,000**
2028	**86,638**	**8,950,000**
2029	**87,150**	**9,003,000**
2030	**87,664**	**9,056,000**

The data analysis obtained from the City/Municipal Environment and Natural Resources Office (C/MENRO) of Tanjay City, combined with computational forecasting, highlights the consistent upward trend of urban waste generation projected from 2025 to 2030. The result of the quantitative modeling demonstrates that the number of waste materials produced in the city is expected to rise steadily each year, signifying that urban waste generation in Tanjay City maintains a continuing relationship with the growth of its population. The forecast indicates that total waste will increase from approximately 8.79 million tons in 2025 to over 9.05 million tons by 2030, reflecting the incremental rise in inhabitants during the same period.

In view of this projection, it can be observed that domestic and market activities will continue to be the primary contributors of municipal waste, thereby reinforcing the findings of Hoornweg & Bhada-Tata (2012) and Guerrero et al. (2013) that population growth and socioeconomic behavior are decisive factors in shaping urban waste generation. By using the exponential model of population growth, along with per capita waste scaling, it was possible to calculate the correlation between population growth and waste production. The formula calculates an annual rate of growth of $r = 0.0059$, clearly noting that there is a steady growth in the urban population of Tanjay City, matching trends in analogous urban settings (Terano, 2018). By validating the model, it was noted that there was a strong association between calculated waste production and actual waste produced from 2022 to 2024.

The results from applying the model for forecasting future waste generation were significant. Using the baseline population of 82,642 for 2020, the future population was projected to rise steadily, reaching about 85,117 in 2025 and increasing further to approximately 87,664 by 2030. At a per capita waste generation rate of 103.3 tons per person per year derived from the model results, the forecasted waste generation was estimated at about 8,793,000 tons in 2025, climbing to more than 9,056,000 tons by 2030. These projections clearly confirm that even a small rate of population increment translates into a substantial rise in waste volumes, emphasizing the relevance of population changes as a critical factor influencing waste systems.

It is further observed that per capita waste generation remains relatively stable, hence suggesting that the growth in total waste is primarily due to population increase rather than significant variations in individual consumer behavior. This finding validates one of the model's assumption statements that waste generation increases in proportion to the size of the population, a concept consistently emphasized in urban environmental prediction models (Shabir, 2025).

Predictions developed regarding future years until 2030 tend to experience an increasing trend in waste volumes, therefore underlining the significance of proactive waste management planning.

The overall results affirm a direct and positive correlation between population growth and urban waste generated within Tanjay City. The close fit between computed values using the model and actual records confirms that exponential modeling of population growth combined with estimating per capita generation is a feasible tool to project future behavior. These findings provide empirical support for evidence-based planning and highlight the need to integrate population projections into sustainable urban waste management strategies.

Discussion

The results of the study show that Tanjay City's urban waste generation developed a distinct and reliable pattern that corresponded with daily consumption activities and population growth. Data analysis from the 2022–2024 series shows a significant amount of municipal solid waste generation in every year, with notable monthly variations in 2024 alone. A greater amount of waste may be a sign of increased consumption and human activity during the mid-year months of July and August each year. As mentioned in other urban waste studies by Beigl, Lebersorger, and Salhofer (2008), this pattern supports hypotheses that waste generated is not static but rather varies in response to population behavior and time of year.

The assumed direct relationship between population growth and waste production is supported by the computational results. This demonstrates that, particularly when per capita consumption stays comparatively constant, population size is a significant factor in determining the overall volume of waste. These results are consistent with demographic-environmental research that demonstrates how slight population growth causes notable increases in environmental stresses, such as waste production (Terano, 2018).

Such a view is supported by the computed per capita rate of waste generation based on data for 2024. The relative consistency of this per capita rate suggests that population growth rather than a fundamental change in consumer behavior is primarily responsible for the increase in overall waste amounts. According to global waste management studies the increase in urban residual waste amounts in mid-sized cities is primarily a result of population growth if consumer patterns do not undergo fundamental changes. However, the predominance of residual waste indicates that current consumer practices, which rely on non-recyclable materials, continue to be prevalent (Kaza et al., 2018; Hoornweg & Bhada-Tata, 2012).

Guerrero, Maas, and Hogland (2013) explain that in developing countries, rapid urban growth, rising populations, and changing lifestyles are the main reasons waste keeps increasing, while most cities lack the infrastructure, strong institutions, and funds needed to manage it properly.

Because of the ongoing population growth, forecast results for 2025 and other years show that waste output will continue to rise in the years to come. It is important to remember that the forecast results are very significant because they clearly show how waste management is impacted by the fast growth of population in urban areas. Shabir stated in 2025 that the use of an exponential growth formula as a predictive analysis tool has been crucial in alerting governments to environmental threats in their early stages. In this regard, Tanjay City should understand that improving waste diversion practices is essential given the rise in waste output.

Growth in population models and mathematical models of per capita waste generation worked well together to create the appropriate model that accurately reflected waste generation realities and perfectly synthesized an ideal model for future estimations.These facts have strengthened current views regarding suitable methods for managing urban waste while taking data and population concerns and realities into account. (Beigl et al., 2008; Hoornweg & Bhada-Tata, 2012; Guerrero et al., 2013).

Conclusion

This study used a quantitative descriptive approach to understand urban waste generation in Tanjay City, focusing on the effects of population growth on the amount of waste produced every year. Actual waste data from the C/MENRO for the years 2022 to 2024 were analyzed, showing a positive and continuous relationship between population growth and waste generation.

The use of exponential growth in population modeling and per capita generation of waste scaling helped yield results that came close to the actual records of waste generation, ensuring that the results from the calculation model are reliable. These result are similar with a previous study that stated that population growth is one of the key factors in influencing municipal solid waste generation (Beigl, Lebersorger, & Salhofer, 2008; Hoornweg & Bhada-Tata, 2012). The findings also support previous discoveries that identified population growth as a determinant of waste generation.

The findings of this study are important to the local community because they show how population growth in Tanjay City's contributes to the waste generation. By helping the community to predict the future amount of waste, the study encourages participation in reducing wastes, waste segregation, recycling, and composting.

Based on the findings, this study strongly recommends including computational forecasting models in waste management planning to help local government units predict waste generation and manage waste accordingly. This recommendation of this research is aligned with previous research on waste management that emphasizes that waste management should be data-driven and compute forecasts (Guerrero et al., 2013; Estoque et al., 2022).

The study also proves to be in support of the efforts being made by the government in general, specifically, with the Republic Act No. 9003, or the Ecological Solid Waste Management Act of 2000. Although the law does not directly mention that the population growth determines the waste generated, it requires local governments to prepare solid waste management plans based on community data. Since our results show that increases in population directly lead to higher waste generation, this confirms the Act's intent that effective waste management must rely on accurate demographic and waste information.

In conclusion, this study has made it clear that the use of actual local statistics in conjunction with computational simulation has been an effective methodology to understand the dynamics of waste generation in urban areas, and thus these findings could help in taking appropriate measures against this serious problem in urban zones.

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