
**HOLY CROSS COLLEGE OF CALINAN, INC.**
**DAVAO-BUKIDNON HIGHWAY, CALINAN POBLACION, DAVAO CITY**

# ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS

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**August 2023**

# ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS

A Research Paper
Presented to the Faculty of the Basic Education Department
of the Holy Cross College of Calinan, Inc.

In Partial Fulfillment of the Requirements
in Practical Research 2

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## APPROVAL SHEET

In partial fulfillment of the requirements in Practical Research 2, this study entitled **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS**, prepared and submitted by Richard Nash C. Mercadal, Sophia Bianca D. Bariquit, Louie Miko O. Artigas, Reigh Alfred S. Ganzon, and Lorenz Edward B. Cañada, is hereby recommended for oral examination, approval, and acceptance.

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Approved by the panel of examiners, after the presentation of the study with the grade of **PASSED**.

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Date of Oral Examination: February 10, 2023

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## ACKNOWLEDGEMENT

This study was made possible with the kind support and assistance of many individuals. Without them, the researchers might not have achieved the objectives of this study. With that, the researchers would like to extend their sincere gratitude to all of them:

To their research teacher, Ms. Vallerie Joy Escolano, for the invaluable supervision, encouragement, and instruction she gave them while conducting their research;

To their research adviser, Mrs. Jessica Rabang, for her guidance and invaluable suggestions, which have contributed significantly to the improvement of the study;

To the school administration, Sr. Cherie Eloisa Garrote, PM, the school president, and Dr. Ma. Corazon Suñga, the school principal, for granting them to conduct this study;

To the distinguished research panelists, Dr. Melina Gonzales and Ms. Trisha Marie Oxales, who have read through the manuscript and for giving them suggestions and comments for the improvement of the study;

To Engr. Lakandiwa Orcullo and Mr. Randolph Anthony Gales, for allowing them to gain access to the data needed for this research;

To Mr. Raffy Centeno, for extending his time and effort to share his knowledge about this study and guide them throughout the analysis of the results;

To their teachers, classmates, and friends, who directly and indirectly touched their lives and supported them in this study, especially to Ms. Rialyn Baguio, for assisting them in contacting the crucial individuals for this study;

To their parents and families, for their endless provision in giving them financial and moral support, guidance, and understanding during the entire course of this study, especially to Mrs. Mary Emlea Ganzon, who assisted them in reaching the crucial organizations for this study and covered their transportation and treated their lunch during the data collection; and

Above everyone else, to Almighty God, for enabling them to overcome all circumstances and for bestowing them with direction, knowledge, wisdom, good health, and opportunities to accomplish this research.

**The Researchers**

## ABSTRACT

Solid waste generation and population growth are massive issues that cover worldwide. Population growth has demonstrated a direct relationship with an increase in waste generation, which affects the stability of the dumping sites and challenges the government in managing waste. This research aimed to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years. It was quantitative in nature and used the descriptive type of research design. Descriptive statistics such as Line Plot, Autoregressive Integrated Moving Average (ARIMA), and Ratio and Proportion were utilized to analyze the data. The data were obtained from the City Environment and Natural Resources Office (CENRO) and Philippine Statistics Authority (PSA). Findings showed that the solid waste generation and the population growth of Davao City in the past eleven years are increasing trends. Also, the forecasted solid waste generation and the population growth for the next five years will expand, with growth rates of 58.12% and 11.31%, respectively. Correspondingly, the total capacity of the existing and proposed landfills is not greater than or equal to the predicted solid waste generation. In conclusion, it suggested that the projected solid waste generation of Davao City will surpass the capacity of the New Carmen Sanitary Landfill for the next five years. With that, the researchers recommended that policymakers can further strengthen the enforcement and application of the initiatives to mitigate the rise of population and trash production.

**Keywords:** ***solid waste generation, population growth, landfill, New Carmen Sanitary Landfill, Davao City, Line Plot, ARIMA, Ratio and Proportion***

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# INTRODUCTION

## Background of the Study

Even before, inappropriate trash disposal, poor waste collection, and shortage of disposal sites stayed massive issues in the solid waste management (SWM) of the Philippines, particularly in metropolitan locations (Senate of the Philippines, 2017). Idaho Public Health (2022) stated that any discarded substance thrown off, burned, recycled, or regarded as *"trash-like"* is considered solid waste. Leblanc (2020) also added that solid waste is produced from industrial, residential, and commercial activities in a particular area. As a result, landfills are often divided into four categories: sanitary, municipal, construction and demolition, and industrial waste sites.

Gee (2018) asserted that population growth refers to the change in population size over time based on the balance of births and deaths. Many individuals are concerned that uncontrolled population growth may eventually result in a disaster for the environment (Australian Academy of Science, 2015). Meanwhile, there have been reports stating that as the population of the world increases, so does the amount of trash generated. Therefore, this poses a challenge for the authorities in managing waste, which might strain the condition of the environment and may eventually result in a significant effect on humankind and wildlife (Wowrzeczka, 2021).

Waste generation rates are increasing all around the world. In 2016, cities worldwide created 2.01 billion tons of solid waste, or 0.74 kilograms per person daily. Annual waste generation is anticipated to increase by 70% from 2016 to 3.4 billion tons in

2050 due to the growing population and urbanization (World Bank, 2022). Further, Ellis (2018) stated that rich countries like the United States, Canada, and the European Union members accounted for only 16% of the global population yet created 34% of global trash. Additionally, the United States produces the most garbage per capita globally, generating an average of 808 kilograms per year with each individual and more than twice that of Japanese citizens (Sensoneo, 2022).

Like many rapidly developing countries, the Philippines grapples with unsustainable plastic generation and insufficient SWM infrastructure. Every year, the country produces 2.7 million tons of plastic waste, an estimated 20% in the ocean (World Bank, 2021). Moreover, the National Solid Waste Management Commission (NSWMC) estimated that the country would generate 23 million tons of trash in 2020 (Sarmiento, 2018). Relative to this, Kangasmäki (2022) explained that Metro Manila had the highest population density, with over 13 million people as of 2019. More than 10,000 tons of trash are produced daily in the region, and is anticipated to double by 2030. A substantial percentage of this waste is either openly burnt or disposed of in rivers, creeks, and Manila Bay, aggravating the pollution in the city.

Davao City is not excused from these kinds of problems as it also contributes to waste generation annually. The Interface Development Interventions (IDIS) reported that the city generated 1,012 tons of waste daily, based on the 2018 statistics from the City Environment and Natural Resources Office (CENRO). Moreover, the city landfill in Carmen, Tugbok District, only has a capacity of 700,000 to 800,000 tons. Still, it has already surpassed almost 900,000 tons, according to an IDIS policy advocate ("Editorial: Davao", 2019). Additionally, Llemit (2021) reported that the average volume of collected

waste in the city had been approximately 600 to 650 tons per day since the COVID-19 pandemic reached its location in March 2020 until the present.

Consequently, since factors such as population growth have demonstrated a direct relationship with an increase in waste generation, this could affect the stability and capacity of the dumping sites and challenge the government in managing waste. Moreover, according to recent reports from CENRO, a new dumping site will be opened at the exact location. These aspects encouraged the researchers to conduct a study on this matter. Hence, this research aimed to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years.

**Statement of the Problem**

This study generally aimed to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years. Specifically, this sought to answer the following questions:

1. What are the annual solid waste generation and the population growth of Davao City in the past eleven years, from 2011 to 2021?
2. What are the forecasted solid waste generation and the population growth of Davao City for the next five years, from 2022 to 2026?
3. What is the capacity of the New Carmen Sanitary Landfill?
4. Can the New Carmen Sanitary Landfill still hold the forecasted solid waste generation of Davao City for the next five years?

## Review of Related Literature

This section contains relevant pieces of literature and studies that were gathered, reviewed, and considered valuable, which provide a strong frame of reference for the variables under study. Hence, research and articles about population growth and solid waste generation are presented.

### Causes of population growth

One of the causes of population growth is changes in the mortality rate. Specifically, it refers to the ratio of annual deaths to the average yearly population (Insee, 2021). Recent events have shown that the global population has rapidly increased to 7 billion and counting. The primary explanation for the dramatic increase in population over the last several decades is lower mortality (Shelton, 2014). Similarly, Miladinov (2021) further supported that the population has aged over time due to decreasing mortality brought about by longer lifespans and lower birth rates. He also noted that the evident reason for the population aging might be the increase in lifespan and improved life expectancy.

In addition, the total fertility rate is also a significant determinant of population growth. Notably, it refers to the average total number of children that a woman in a population will have throughout her life, depending on her birth rate at any given moment (Götmark & Andersson, 2020). Reda, Bune, and Shaka (2020) found that high and slowly decreasing fertility would most likely result in a remarkable increase in the projected population. In the Philippines, the country is still having difficulty finding practical solutions to control its population growth. Empirical investigation connects population

growth with poverty, highlighting chronically high fertility rates as a major impediment to poverty reduction (David, Legara, Atun, & Monterola, 2014).

Further, overpopulation has fueled migration across national and continental borders. Rees et al. (2017) explained that international migration contributes significantly to population growth in urbanized metropolitan areas but slightly to population redistribution in less developed countries. Relative to this, Rogers and Borsella (2016) defined *migration* as the movement of people from one location to another. It can be expressed as net migration, the difference between the number of people moving into and out of a given area. They further demonstrated that when net migration is positive, more people move in than out of a population.

**Impacts of population growth**

It stands to reason that rising populations will put more strain on available resources. The need for food, water, housing, energy, healthcare, transportation, and other resources will rise as the population grows, which increases the likelihood of significant catastrophes like environmental degradation. Further, population growth will inevitably contribute to pressures that worsen climate change by increasing deforestation, reducing biodiversity, and increasing pollution and emissions (Bish, 2020). As urban populations continue to grow and consumer habits change, solid waste management (SWM) is a problem that the world is becoming more concerned about (Marshall & Farahbakhsh, 2013).

Further, the increasing population of the world is harming the environment. The global demands that this growth is placing on the environment threaten the continuation of

sustainable human life (Mittal & Mittal, 2013). In addition, the danger to the sustainable use of natural resources emerges from rapid population growth, which continues to be a significant driving force behind environmental deterioration. Through abuse, intensive farming, and land fragmentation, the amount and quality of natural resources are decreased (Maja & Ayano, 2021).

Unsurprisingly, as the population grows in the Philippines, living standards rise, and urban and rural regions are developed, the country produces additional solid waste. The Senate Economic Planning Office (SEPO) reported that garbage production in the nation climbed steadily from 37,427.46 tons per day in 2012 to 40,087.45 tons in 2016 (Mawis, 2019). Relative to this, Olalo, Nakatani, and Fujita (2022) asserted that Davao City is likely to experience the effects of increased waste generation and a lack of waste-related infrastructure. The waste generation in the city has already reached 991 tons per day, with a predicted population of 1.7 million in 2017, and is anticipated to rise further as its population and economy expand.

**Sources of solid waste generation**

One of the sources of solid waste generation is population growth. Omololu and Lawal (2013) asserted that population increase has a relationship with waste in urban areas, as the combination of human settlements has the potential to generate a significant amount of solid waste. Rapid population growth is also an environmental concern because it poses a considerable challenge and severe threats to the ecological balance, including the underground water (Dahiya, 2015). Humans generate millions of tons of waste each year, which has become a significant issue worldwide (Tiseo, 2022).

In addition, household waste is typically generated from various sources where several human activities occur. Numerous studies have found that most municipal solid waste (MSW) generated in developing countries comes from households, followed by the market or commercial areas (Abdel-Shafy & Mansour, 2018). Relative to this, environmental issues relating to waste generation are part of societal changes in which households play an essential role. These societal changes impact household characteristics such as family size, monthly income, social status, education level, residential location, and community status. Many studies have demonstrated the relationship between household socioeconomic factors and solid waste generation and composition (Noufal, Yuanyuan, Maalla, & Adipah, 2020).

Moreover, most industries generate waste to meet technological advancements and consumer demands. The three industrial sectors, namely food, agriculture, and the oil industry, are among the primary producers of organic waste that impact urban health and economic growth (Sharma et al., 2022). Rapid industrialization has resulted in the generation of hazardous industrial wastes. However, authorities needed to adequately implement management activities to reduce these industrial wastes due to the lack of treatment plants, comprehensive solid waste management (SWM) plans, resources, and the problem of rapid population growth (Menbere & Menbere, 2019).

Further, commercial waste is the solid waste generated by stores, offices, institutions, restaurants, warehouses, and non-manufacturing activities at industrial facilities (Riyad, Hassan, Rahat, Alam, & Akid, 2014). Commercial solid waste generation has also increased proportionately with the growth of the urban population. The increased amount of commercial solid waste generated by a large population is dumped

indiscriminately at nearby places like open dumping sites (RoyDas et al., 2013). Due to poor management, solid waste generated from commercial activities is the most prominent in recent years. Massive piles of solid waste can be seen in open marketplaces and buildings engaged in one or more business activities (Igbinomwanhia, 2012).

**Highly populated countries and solid waste generation**

As the most populous country in the world, China is responsible for the largest share of global municipal solid waste (MSW), more than 15% (Tiseo, 2021). According to Statista Research Department (2022), the amount of waste in the country has increased dramatically over the past few decades, reaching 242 million tons as of 2019. For the first time in many years, the yearly volume of waste declined in 2020, falling to almost 235 million tons. The annual growth rate of MSW output is now predicted to be between 8 and 10%, reaching 323 million metric tons by 2030 (Kurniawan et al., 2022).

In addition, with slightly under 1.4 billion people, India has the second-largest population in the world. By the middle of the decade, experts believe India will surpass China as the most populous country in the world, with a difference of fewer than 20 million people (O'Neill, 2022). Due to population growth and changing lifestyles, the metropolitan regions of the country currently generate roughly 170,000 tons of waste per day, or 62 million tons annually, and are predicted to rise by 5% annually. By 2050, it is anticipated that around 27 billion tons of trash will be produced yearly, with Asia accounting for one-third of that total, with China and India making up the majority of that region (Kumar et al., 2017).

Further, the United States produces the most waste relative to its population. In contrast to China and India, the population of the country is anticipated to increase during the coming century without any sign of a decline. With that, the estimated population will top 400 million by 2067. In terms of waste production, the country has less than 5% of the global population but generates roughly 12% of global MSW and is the largest generator of MSW per capita. Every year, Americans generate slightly more than 800 kilograms of waste (Tiseo, 2021; World Population Review, 2022). Turrentine (2019) further supported that every American generates more than 1,700 pounds of MSW yearly, totaling 239 million tons.

**Highly urbanized countries and solid waste generation**

Emerging nations struggle with the management of municipal solid waste (MSW), which is a challenge on a worldwide scale. In most emerging countries, waste is dispersed across urban areas and carelessly dumped in open landfills or low-lying locations (Srivastava, Ismail, Singh, & Singh, 2015). Similarly, Alfaia, Costa, and Campos (2017) asserted that the situation in Brazil regarding solid waste management (SWM) is still inadequate. Only 58.7% of MSW collected in cities was adequately disposed of in 2015. However, despite the economic downturn in 2015, the total annual quantity of MSW generated nationally climbed by 1.7%, while the population in the country expanded by 0.8%, and its economic activity declined by 3.8%.

Law et al. (2020) and Lee, Kim, and Chong (2016) examined that in 2013, the United States created the most waste per capita among the Organization for Economic Cooperation and Development (OECD) nations accounting for 730 kilograms. Further, the

country is the second-largest exporter of plastic scrap in the world. The environmental inputs of the plastic waste produced in the United States may be significantly larger than previously estimated if the imported material needs to be adequately handled. Meanwhile, the quantity of waste produced in the country was not reduced, and the recycling rate is just 26%, which was lower than that of other OECD nations.

In addition, Qatar also has one of the highest per capita solid waste generation rates in the world. According to recent studies, the country generated over 2,000,000 tons of MSW annually, equal to 2.5 kilograms of waste per person daily. This MSW comprises around 60% organic waste, while the rest consists of recyclable materials like glass, paper, metals, and plastics, with approximately 300 kilograms produced daily. Moreover, municipalities collect solid waste in the country directly via their logistics and indirectly through contracts with the private sector (Al-Maaded, Madi, Kahraman, Hodzic, & Ozerkan, 2012; Zafar, 2019).

**Impacts of solid waste generation**

The generation of solid waste is an unavoidable result of human activity, and its management directly influences the health of the people around it. Postconsumer waste endangers public health by drawing disease vectors and exposing those near the waste to hazardous materials (Vergara & Tchobanoglous, 2012). The World Health Organization (WHO) has emphasized the hazards of improper solid waste disposal in soil, water, and air pollution and the associated health implications for populations living in the affected regions (Vinti et al., 2021). Relative to this, the health pathway linked with inadequate solid waste management (SWM) mainly manifests itself through direct human exposure

and surface and groundwater contamination due to leachate from open dumps (Department of Environment and Natural Resources [DENR], 2018).

According to Lee (2018), improper waste disposal is more than simply a nuisance; it poses a severe environmental hazard. Uncontrolled solid waste burning and inefficient incineration significantly contribute to urban air pollution. Greenhouse gases are produced during the breakdown of organic wastes in landfills, open waste burning, and untreated drainage, which pollutes the soil and water bodies around them (Omang, John, Inah, & Bisong, 2021). Also, the by-products of solid waste dumped in landfills negatively impact the environment (Njoku, Edokpayi, & Odiyo, 2019).

Further, several studies have found that improper garbage disposal in natural places impacts all wildlife. These wastes disrupt animal onshore and aquatic habitats (Ahmadipari, Pazoki, & Ghobadi, 2020). Plastics in rubbish are consumed by wild animals, causing deadly injuries and digestive system damage, resulting in malnutrition, stomach ulcers, poor fitness, growth issues, and early death (Altaf, 2019). Downs and Acevedo (2019) further explained that one of the most dramatic impacts of the worldwide trash crisis is seen in marine life and rivers. It affects fish, seals, turtles, whales, and many other aquatic creatures since scientists have discovered several plastic particles in over a thousand different species.

**Ethics of solid waste management**

Chan (2016) emphasized that the landfill is the most apparent and geographical evidence of the growing challenge in urban waste management. In his investigation of the Semakau Landfill off the coast of Singapore, he found that this case raised several ethical

concerns about conceptualizing, taming, and solving the problem with solid waste generation. Additionally, it highlighted why ethics is required for a deeper understanding of the problem of waste, which involves various adaptive techniques and large-scale environmental design initiatives. In Uganda, municipal solid waste (MSW) collection is one of the most vital public services currently lacking in its slum regions, and its low coverage has caused public outrage. Solid waste management (SWM) factors in the slums include lack of access, unaffordability for the cost of services, and inadequate cleanliness (Mukama et al., 2016).

Considering the high desire to participate in programs to improve waste management, residents of slums have poor trash disposal and separation habits, which underline the need for authorities to involve slum residents in improving their behaviors (Ramanathan, Dharmalingam, & Thangarasu, 2020). It was further supported by George et al. (2022) that the health of SWM and environmental consequences are increasingly more severe, especially in developing nations. In this way, sustainable and integrated SWM is a viable solution to the expanding global problem of MSW disposal.

As indicated, understanding the problem from an ethical perspective will help avoid the various moral dangers of the problem with solid waste generation. It outlines tools and strategies for achieving waste management sustainability. Waste characterization is a valuable method for determining the volume and pattern of waste production. It may be used as a decision-making tool for institutions to create sustainable waste management initiatives (Dahlawi & El Sharkawy, 2021).

**Importance of establishing dumping sites**

The absence of adequate dumping sites may impact the health of the people and the quality of the urban environment. Locals use municipal water sources, highways, ditches, and small streams as disposal sites for solid waste. Consequently, people suffer from the waste produced by residential areas, state prisons, religious sites, open marketplaces, and commercial hubs (Tadese, Wagari, & Tamiru, 2022). Ebistu and Minale (2013) further supported that solid waste dumping is a significant issue in metropolitan areas since most solid wastes are not dumped in appropriate locations. Identifying solid waste dumping sites proved problematic in Bahir Dar Town, North Western Ethiopia, so it is essential to select possible locations for ecologically suitable solid waste dumping sites.

Landfill site selection is a crucial task that authorities must handle with utmost care since it may pose a risk to human health and the environment. However, selecting an appropriate landfill site is challenging because it depends on several factors and criteria (Rezaeisabzevar, Bazargan, & Zohourian, 2020). Further, Yildirim, Memisoglu, Bediroglu, and Colak (2018) stated that selecting an appropriate site necessitates study and various factor analyses. Therefore, environmental, economic, and societal aspects must be considered while choosing a landfill site.

Relative to this, Alavi, Goudarzi, Babaei, Jaafarzadeh, and Hosseinzadeh (2013) presented the standards following rules and laws for deciding on a landfill site. It includes surface water, delicate ecosystems, land cover, urban and rural regions, land uses, distance from highways, slope, and land type. Since choosing a landfill site is a complex process that must consider many local and remote conditions, it urges a workable method to

connect them to aid engineers in selecting the best landfill site (Mortazavi Chamchali, Mohebbi Tafreshi, & Mohebbi Tafreshi, 2021). Correspondingly, it has become a problem in India that urban centers are expected to create 165 million tons of trash yearly by 2031 and 463 million tons by 2050. As a result, the local government predicts that in the next years, the garbage output of the nation may exceed the capacity of its landfills. As a result, to handle the garbage generated in the following years, around $2.5 \times 10^7$ cu.m of landfill space, or 1,175 hectares of land area, will be required (Joshi & Ahmed, 2016).

**Initiatives in addressing waste management issues**

Every country has its unique waste management strategy, yet practically every nation struggles to deal with the waste problem. The government should not overlook traditional knowledge; they should include it in policy formulations (Perera & Perera, 2016). Further, many people believe that reducing household resource use is a cost-effective step toward urban sustainability (Breadsell, Eon, & Morrison, 2019). Therefore, waste management strategies should be inventive, decisive, and context-sensitive to respond to local conditions (Noufal et al., 2020).

All municipal solid waste management (MSWM) options include recycling, incineration, waste-to-energy conversion, composting, and landfilling. However, many communities across the world favor landfilling for solid waste disposal. Landfills serve as ecological reactors, transforming garbage via physical, chemical, and biological processes (Nanda & Berruti, 2021). The primary drivers of the rising municipal solid waste (MSW) generation in China are rapid urbanization and economic expansion. Consequently, landfilling accounts for the substantial treatment for Chinese MSWM with 60.16%, while

incineration, untreated discharge, and other strategies account for 29.84%, 8.21%, and 1.79%, respectively (Mian, Zeng, Nasry, & Al-Hamadani, 2017).

On the other hand, Das et al. (2019) mentioned that solid waste management (SWM) is a component that is essential for any environmental management system. Based on the *"reduce," "reuse,"* and *"recycle"* (3R) principles, SWM techniques have been adapted into a more practical and effective choice for establishing sustainability. Similarly, municipal corporations and the public health department in India play a critical role in waste management. The Municipal Corporation manages the MSW created in the city, among its other responsibilities. The Central and State Governments and local authorities of the country have recently focused on SWM (Agarwal, Chaudhary, & Singh, 2015).

Similar patterns have been observed in the Philippines. Domingo and Manejar (2021) stated that the Ecological Solid Waste Management Act of 2000, or Republic Act 9003, was enacted to preserve public health and the environment while fostering the conservation of resources and recovery and public collaboration and responsibility. The official devolution of waste management to local levels, including the forced closure of illegal dumpsites, investment in facilities, and the minimization and appropriate treatment of solid wastes, were vital features. Aside from that, Wynne, Nieves, Vulava, Qirko, & Callahan (2018) added that the law decentralized management and required Local Government Units (LGUs) to establish new integrated SWM plans.

**Effectiveness of the initiatives on solid waste management**

A study conducted by Yukalang, Clarke, and Ross (2017), wherein it focused on identifying the obstacles to efficient municipal solid waste management (MSWM) in a

region of Thailand that is rapidly urbanizing, found that a reasonable budget and appropriate policies are in place. However, infrastructure is lacking, strategic planning, personnel capacity, registration, information systems, and program involvement needs to be improved, and waste management and fee-collecting mechanisms need to be more organized. Moreover, Hong Kong is not an exception. The government and its executive branches have developed various construction waste management (CWM) regulations over the years, including rules, guidelines, and projects. However, when the region successfully adopted the construction waste disposal cost plan in 2006, recent actions were necessary to improve the depressing situation (Lu & Tam, 2013).

In addition, several measures have been implemented in the Philippines to address the problem of solid waste management (SWM), including policies outlined in the Ecological Solid Waste Management Act of 2001. These measures may include the strict implementation and enforcement of SWM policies at the community level, which necessitates the active participation of community and waste management stakeholders to ensure successful outcomes. However, implementing these policies has always been difficult, even at the barangay level (Camarillo & Bellotindos, 2021). Relative to this, Garay and Bernardo (2020) and Garcia (2022) reported that in Davao City, the landfill in New Carmen has already gathered 900,000 tons of trash since 2016, despite the maximum capacity level reportedly being between 700,000 and 800,000. In response to the trash crisis of the city, the local administration proposes to build a P2.5 billion waste-to-energy (WTE) facility on a 10-hectare land in Biao Escuela, Tugbok District, with funding from a Japanese loan. The local administration sees the WTE incinerator as a *"long-term solution"* to their solid waste issue. However, environmental organizations like Greenpeace and the

Plastic-Free Pilipinas Project are against this technique because burning non-biodegradable garbage is the same as burning fossil fuels.

As indicated, human activities play a significant role in waste management. Effective SWM strategies should consider the full range of SWM process options and the policy implications for system-level cost and environmental performance (Jaunich, Levis, DeCarolis, Barlaz, & Ranjithan, 2019). Although, the mentality toward cleanliness, the sense of responsibility toward proper waste management, and public concerns about the consequences of not separating waste for recycling still need to be improved (Moh & Abd Manaf, 2017).

**Solid waste management methods**

Solid waste management (SWM) is the collection, treatment, and disposal of solid waste that is often discarded because it has reached its useful life or is no longer needed (Nathanson, 2020). One of the most common SWM methods is landfill. It is where garbage is disposed of, which contains unique features that help keep the surrounding soil and water clean. Moreover, municipal solid waste (MSW) disposed of in landfills can take decades or even hundreds of years to decompose completely, experiencing extensive physical, chemical, and biological changes before being transformed into liquids and gases in the form of leachate and landfill gas (Youcai, 2018). The New Carmen Sanitary Landfill in Tugbok District is an example of a landfill.

Some more SWM method is incineration. Incineration systems were designed to minimize the volume of MSW by providing controlled burning at high temperatures (Trabold & Babbitt, 2018). Colina (2019) reported that the local government of Davao City

planned to construct a waste-to-energy (WTE) incineration project costing 2.5 billion pesos in Biao Escuela, Tugbok District. The proposed facility will be a grant from the Japanese government and is expected to process 600 tons of waste daily (Rosauro, 2021). Although, some studies have argued that this approach is not a desirable disposal method since it releases dioxins and other pollutants into the atmosphere that contributes to global warming and impact the health of the people (Niaounakis, 2013).

Another SWM strategy is recycling. It is the process of separating, collecting, remanufacturing, or turning waste items into new resources. This method extends the life and utility of something that has previously served its original function by reducing it to its raw ingredients and then repurposing those materials to create something valuable. It is one of the three golden commandments of sustainability (reduce, reuse, and recycle) and offers several advantages for humans and the environment (Koop, 2021). In addition, recycling reduces landfill trash, conserves energy, and reduces carbon emissions, which helps lessen the effects of global warming (Pizza, 2022).

Throughout this entire section, issues regarding population growth and solid waste generation were gathered from other resources, including their sources and impacts, to strengthen this study further. It also discusses the link between the most populated and wealthy nations to solid waste generation, the ethics of solid waste management (SWM), and the significance of selecting dumping sites. With this, various government initiatives and approaches to SWM were conducted, requiring much effort and investments in facilities to support waste management. Thus, the study aims to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years.

## Theoretical Framework

This study was anchored on the Malthusian growth model theorized by Thomas Robert Malthus, which explicitly focused on an exponential formula for predicting population growth (Kagan, 2021). This model stated that the human population increased in a geometrical progression while food, as it produced waste, increased in an arithmetical progression. Additionally, this study was also based on the Waste Management Theory, which Pongrácz, Phillips, and Keiski (2004) introduced to provide a more in-depth description of the domain, including conceptual assessments of waste-related activities and a broad perspective of waste management goals. This theory supposed that waste management would prevent waste from harming the health of the people and the environment.

The theories of the prominent authors support the conduct of this study, for it suggests that the population has an impact on waste, such as coming from food. This study determined the possible amount of solid waste generation and population growth, implying a relationship between the two variables. It is widely known that waste directly results from human interactions and activity. Meanwhile, the theories claim that waste management will keep waste from causing harm to the health of the people and the environment. Since factors such as population growth have shown a direct link between food and an increase in waste generation, these theories can assist in developing the topic, direct the selection of appropriate data, analyze the findings, and explain the underlying causes or impacts of the problem.

**Conceptual Framework**

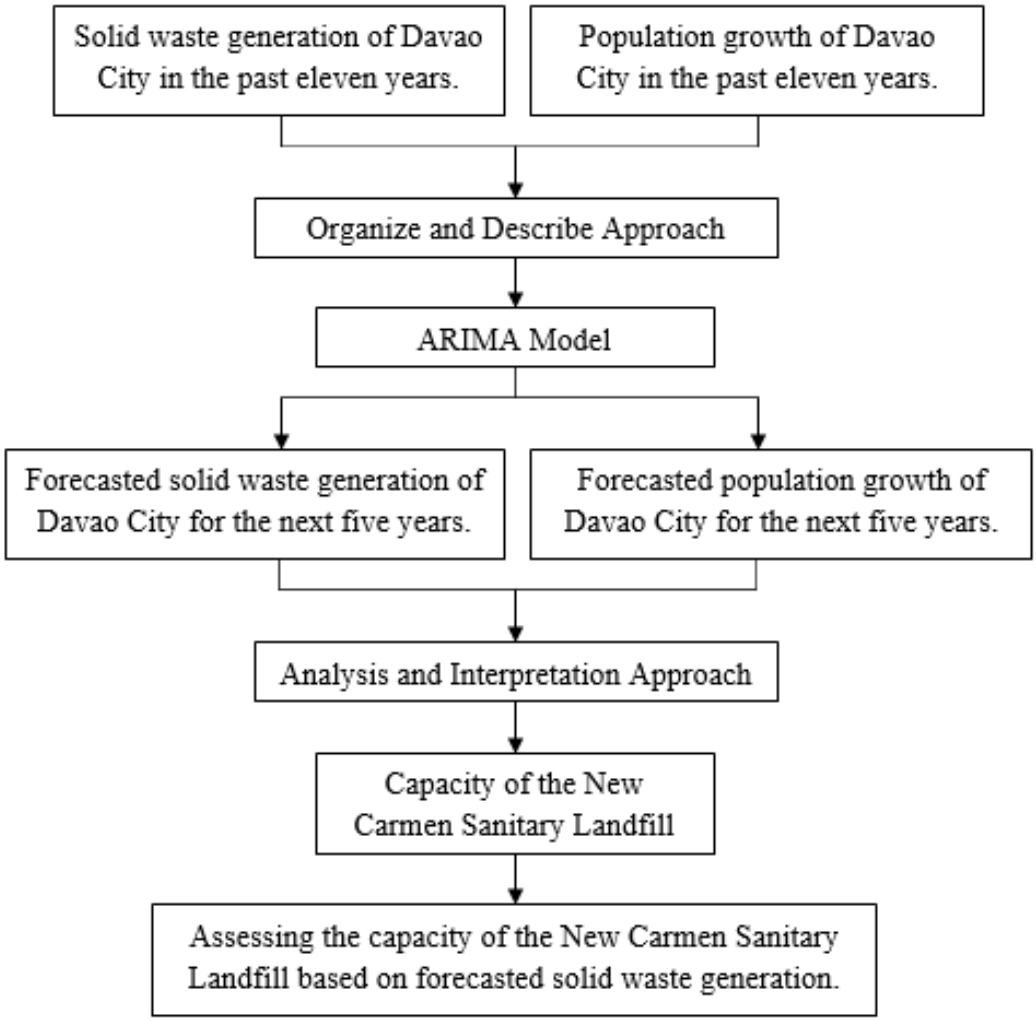


**Figure 1. Conceptual Framework**

Figure 1 shows the visual representation of the step-by-step process of how the study would be conducted. It also explained the main points that would be studied, which include the key factors, concepts, and variables and the presumed relationship among them. Specifically, the solid waste generation and the population growth of Davao City in the past eleven years served as the primary input. Then, the organize and describe approach served as a method to examine the trend of the collected data. After that, the ARIMA model

was used to forecast the solid waste generation and the population growth of Davao City for the next five years. Next, the researchers used the analysis and interpretation approach to analyze the trend of the forecasted data. Lastly, the capacity of the New Carmen Sanitary Landfill served as another input to assess if it can still accommodate the predicted solid waste generation.

**Significance of the Study**

This research aimed to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years. Also, the findings of the study may contribute to further knowledge about strengthening solid waste management (SWM) for the local residents. It may be a reference or guide for the citizens and parents in developing SWM in the community and at home. They can employ mitigation activities and adaptation measures in addressing solid waste generation. Parents can also encourage their children to practice proper waste disposal to help reduce the effect of trash on the environment and their health and help think of various strategies to lessen the amount of waste they produce at home.

Further, this may benefit the policymakers, such as the Department of Environment and Natural Resources (DENR) and City Environment and Natural Resources Office (CENRO), to have more insights into how they will respond to the issue. They can also develop programs that will help decrease waste generation and eliminate the harmful effects of waste products on human health and the environment. Moreover, this research will also provide necessary details to support the administrators and other academic leaders in educating their teachers, staff, and students about the importance of managing waste.

Lastly, the results of the study may help future researchers learn and understand more about the possible amount of solid waste generated by the residents of Davao City and its population growth over the next five years. Further, the research forecast may provide important data that researchers in the future may find helpful in their studies and will help them become better analysts.

## Scope and Limitation

This study focused on assessing the capacity of the New Carmen Sanitary Landfill by forecasting the solid waste generation and the population growth of Davao City for the next five years, from 2022 to 2026. The data used in forecasting was limited to the past eleven years, from 2011 to 2021. Also, the study only focused on biodegradable, recyclable, residual, and special types of waste.

On the other hand, the years that exceeded or fell behind from 2011 to 2026 were not included and used in interpreting the data since the available data was only from 2011 to 2021 and was intended to forecast the values for the next five years. Additionally, this research did not cover further aspects, such as other sanitary landfills and locations, to explicitly cover Davao City. Lastly, this study excluded the types of waste, such as medical and toxic wastes, because these are being dumped in separate landfills intended for these types of waste.

## Definition of Terms

For a better understanding of this research, the following terms are defined in the context of this study.

**Akaike Information Criterion (AIC) -** It refers to the basis for rejecting the p, d, and q values if the values from PACF and ACF visual checking of lags and auto.arima functions are not the same.

**Analysis and interpretation approach -** It refers to an approach that will be used to analyze and understand the trend of the forecasted data of the solid waste generation and the population growth of Davao City for the next five years

**Autocorrelation Function (ACF) -** It helps to determine the q (MA) order of the model.

**Autoregressive Integrated Moving Average (ARIMA) -** It refers to a statistical model that will be used in forecasting the solid waste generation and population growth of Davao City for the next five years, from 2022 to 2026.

**Best-fit model -** It refers to the ARIMA model with the least AIC value.

**Differencing -** It refers to the technique used to convert non-stationary data to stationary data. It also helps to determine the value of d (I) of the model.

**Forecast -** It refers to the predicted amount of solid waste generation and the population growth of Davao City for the next five years.

**Forecast interval -** It refers to the predicted amount of solid waste generation and the population growth of Davao City for the next five years with interval.

**Lag -** It helps to determine the values of p (AR) and q (MA) of the model.

**Landfill** - It refers to a sanitary dumping site located at New Carmen, Tugbok District.

**Line Plot** - It refers to a statistical method that will be used to graph the data points of the solid waste generation and the population growth of Davao City in the past eleven years, from 2011 to 2021.

**Margin of error** - It refers to the range of values above and below the forecast interval, denoted with a confidence level of 95%.

**Organize and describe approach** - It refers to an approach that will be used to analyze and understand the trend of the previous data of the solid waste generation and the population growth of Davao City in the past eleven years.

**p, d, and q values** - These refer to the model values through visual inspection of PACF and ACF and are validated with the help of auto.arima function.

**Partial Autocorrelation Function (PACF)** - It helps to determine the p (AR) order of the model.

**Point forecast** - It refers to the exact predicted amount of solid waste generation and the population growth.

**Population** - It refers to the number of people living in Davao City.

**Population growth** - It refers to the annual increase in the population of Davao City.

**Ratio and Proportion** - It refers to a statistical tool that will be used to assess if the New Carmen Sanitary Landfill can still accommodate the forecasted solid waste generation of Davao City for the next five years.

**Significant trend** – It refers to the group of data points with almost the same pattern.

**Solid waste** - It refers to the biodegradable, recyclable, residual, and special wastes that are dumped in the New Carmen Sanitary Landfill.

**Solid waste generation** - It refers to the annual generated solid waste of Davao City.

**White noise –** It refers to the insignificant variation in the trend.

# Chapter 2

# METHODS

This chapter discussed the research design and procedure the researchers utilized to carry out this study. Further, it covered the sources of data, the locale of the study, the process of gathering the data, the ethics that need to be considered, and the research data analysis.

## Research Design

This study was quantitative in nature and used the descriptive type of research design. Watson (2015) defined quantitative research as a type of study that includes a variety of techniques that uses statistical or numerical data to investigate social phenomena systematically. It also aims to analyze data for trends and relationships and validate the measurements. Meanwhile, Sahin and Mete (2021) explained that descriptive research is a form of non-experimental research that describes the characteristics of the population or phenomenon under study. With this methodology, the *"what"* is given more attention than the *"why"* of the research topic.

Therefore, the descriptive research design was applicable in this study since it aimed to assess the capacity of the New Carmen Sanitary Landfill to hold the solid waste generated vis-à-vis the population growth for the next five years. It also used scientific methods to make detailed observations and document the variables under study. Moreover, researchers could use quantitative data to perform simple to highly complex quantification and analysis of variables to arrive at conclusions about the issue.

## Data Source

Research data are facts that researchers must gather to achieve the research goals. These are collected using various scientific techniques and tools. There are different methods for collecting data: the researcher might use observation, interview, survey questionnaire, documentary, and other approaches depending on the study goal and its limitations. Further, raw data are information from numerous sources and methods (Baral, 2017).

In this study, the researchers acquired the needed data from government offices. Specifically, the researchers obtained the data for the population growth of Davao City from 2011 to 2021 from the Philippine Statistics Authority (PSA). Then, the researchers acquired the data for the solid waste generation of Davao City from 2011 to 2021 and the capacity of the New Carmen Sanitary Landfill from the City Environment and Natural Resources Office (CENRO).

## Research Locale

This study was conducted within the vicinity of Davao City, the third-largest city in the Philippines and the most populated city in Mindanao. It is the home of the first Mindanaoan president, Rodrigo Roa Duterte. Known for its thriving economic activities, urban development, and contemporary facilities, Davao City is also one of the largest producers and exporters of exotic fruits such as durian and mangosteen. Its top attractions are the Philippine Eagle, one of the most massive eagles in the world, which can be an unforgettable experience for visitors of all ages.

According to Raine Catague, the capacity of the city landfill in Carmen, Tugbok District, is only 700,000 to 800,000 tons, but it has already exceeded over 900,000 tons ("Editorial: Davao", 2019). Moreover, according to recent reports from CENRO, the government will open a new dumping site at the exact location. Hence, the target area of the researchers was in New Carmen Sanitary Landfill, located explicitly in Davao City, and regions outside its geological map were not included. For more information on the location, refer to the picture below.

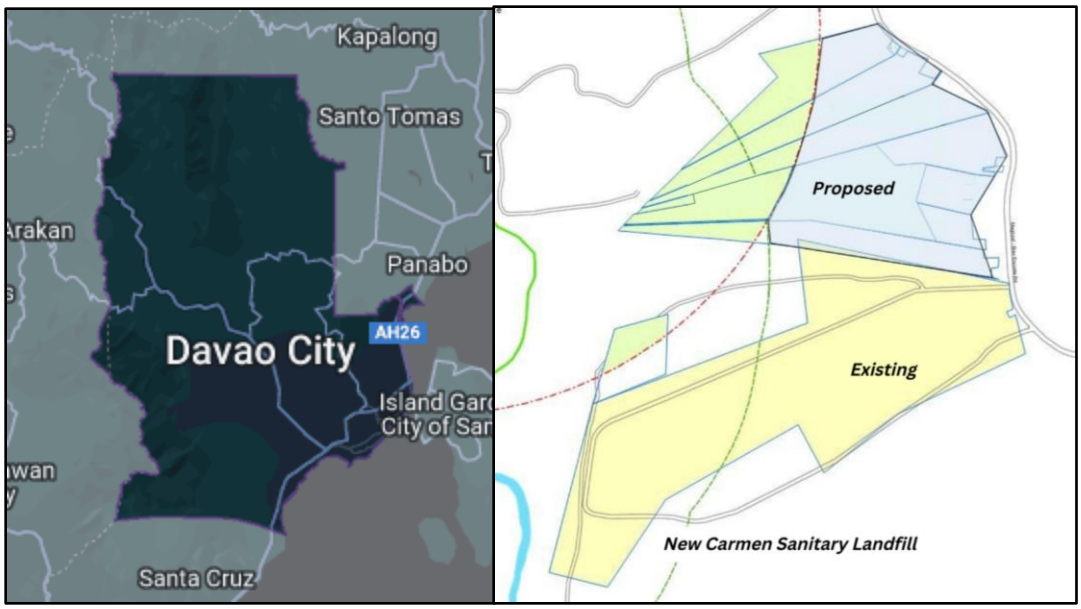


**Figure 2. Research Locale**

**Data Gathering Procedure**

This study followed some procedures for the researchers to attain the objectives. The researchers first sought approval from the school principal and the school president to conduct this study by giving a letter of permission. Also, the researchers submitted a letter to the City Environment and Natural Resources Office (CENRO) to ask for approval to get the data, particularly the annual solid waste generation of Davao City from 2011 to 2021

and the capacity of the New Carmen Sanitary Landfill. Then, the researchers prepared another letter for the Philippine Statistics Authority (PSA) to ask for their consent to obtain the data, specifically about the population growth of Davao City from 2011 to 2021. After acquiring the data needed, the researchers compiled and sealed them for further analysis, computation, and interpretation.

**Ethical Considerations**

According to DePoy and Gitlin (2016), research ethics is a concept that most commonly refers to guidelines for proper behavior during research thoughts and action processes, specifically human subject protection. Thus, ethical considerations play a vital role in promoting the aim of the researchers in this study, such as knowledge, truth, and error avoidance. As studies frequently require considerable collaboration and coordination among individuals from many fields and organizations, the researchers applied the qualities and ethical principles vital to the study, such as social justice, honesty, and confidentiality.

**Social Justice** is one of the fundamental principles of research dictating that all individuals should have equal rights and opportunities. It fosters societal equity and fairness (Online MSW Programs, 2022). Further, Mollenkamp (2022) explained that it is a subtype of justice that refers to the division of resources, opportunities, and advantages. Its perspectives emphasize the role of fairness or impartiality in how those things are distributed. Hence, this study has a social significance or value, for it talked about the survival of beings and involved the environment.

**Honesty** is an ethical obligation that entails being accurate and truthful about oneself, personal work, and the work of others (American Speech-Language-Hearing

Association, 2018). Resnik (2020) stated that it is crucial to strive for honesty in all scientific communications, accurately describe the information, findings, methods, and status of publications, and avoid making up, falsifying, or representing data incorrectly. In this study, the researchers should avoid manipulating the data gathered to maintain the integrity and objectivity of the research. Correspondingly, the tables, graphs, figures, numbers, and information should remain the same and not be tampered with by any change.

**Confidentiality** is an ethical duty that refers to the obligation of the researchers to keep private information secure and protect against illegal access, use, disclosure, alteration, loss, or theft (Government of Canada, 2018). It is also defined as protecting private correspondence, including papers or grants submitted for publication, employee records, trade, and patient records (Resnik, 2020). In this study, the needed data may be sensitive to be acquired for the public, which is why a consent form with complete details and objectives of the study should be submitted and approved before the organizations involved can cooperate and give the necessary data. Moreover, confidentiality must be maintained wherein the researchers must safeguard the data to ensure the privacy of information.

## Data Analysis

The researchers used the Line Plot to address research question 1 in determining and analyzing the trend and frequency of each variable. Peters (2021) asserts that line plots connect separate data points with lines, displaying quantitative values over a set time interval. It is used to visualize changes over time and as a comparison tool to contrast differences for more than one group.

On the other hand, the researchers used another forecasting method the called Autoregressive Integrated Moving Average (ARIMA) for research question 2 to predict the possible amount of each variable. ARIMA model is used in statistics and econometrics to quantify events that occur over time. It is a type of regression analysis that measures the strength of one dependent variable with other variables that change. In a series, the model is used to interpret previous data or forecast future data (Hayes, 2021). Specifically, the researchers applied lag differencing to the non-stationary Line Plots. With this, the p, d, and q values were set by visual inspection of the Autocorrelation Function (ACF) and the Partial Autocorrelation Function (PACF). Then, the researchers used auto.arima function to identify the possible best-fit models. After identifying five candidates of models, the Aikake Information Criterion (AIC) was compared. The model with the least AIC value was used to forecast the variables.

Moreover, the researchers employed no statistical tools to research question 3 since the needed data from the City Environment and Natural Resources (CENRO) already provided the answer. Lastly, the researchers employed the Ratio and Proportion to address research question 4 in assessing the capacity of the New Carmen Sanitary Landfill based on the forecasted solid waste generation. The concept of ratio and proportion are crucial in mathematics and many other academic disciplines. Many phenomena may be described as a proportionate connection between certain factors, which produces a brand-new, original entity. Mathematical awareness is facilitated by conceptualization, knowledge, abilities, and expertise with these ideas. More significantly, these abilities support relational or proportional reasoning, which is essential for the growth of analytical mathematical reasoning (Ben-Chaim, Keret, & Ilany, 2012).

# Chapter 3

## RESULTS AND DISCUSSION

This chapter contains the results and discussion after the collection of data and their analysis. This chapter also answered the questions found in the statement of the problem of this research paper.

***Research Question Number 1: What are the annual solid waste generation and the population growth of Davao City in the past eleven years, from 2011 to 2021?***

**Figure 3. Solid Waste Generation of Davao City from 2011 to 2021**

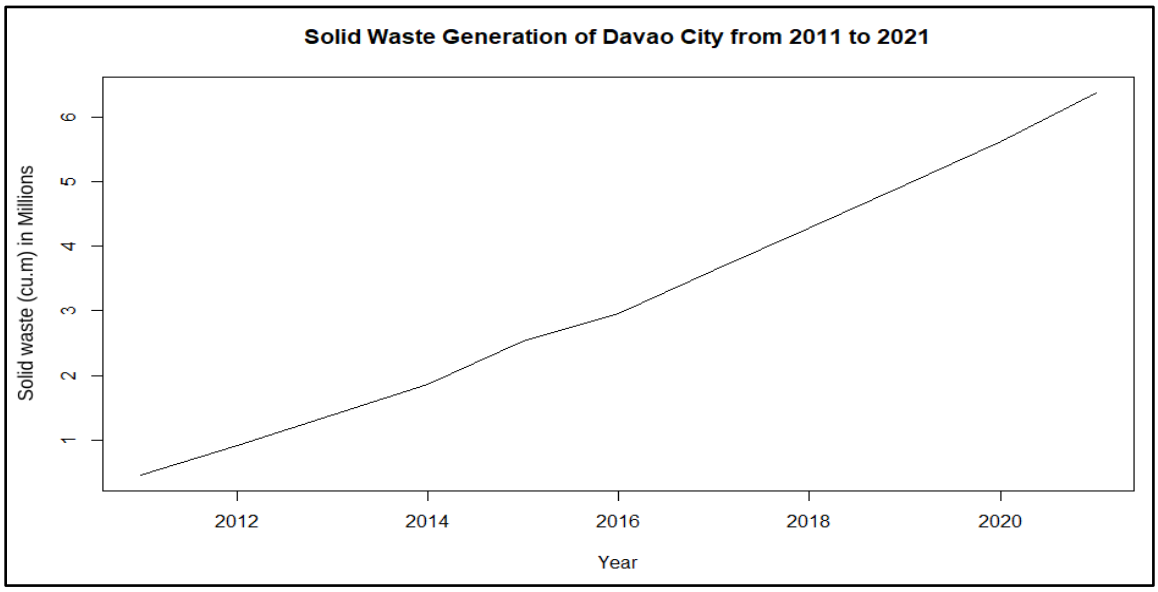


Figure 3 shows the Line Plot of the solid waste generation in Davao City from 2011 to 2021. Remarkably, this graph presented one significant trend, which could be seen from 2011 to 2021. This graph segment showed an increasing trend with a growth ranging from 436,218.00 cu.m to 750,958.62 cu.m each year, making the solid waste generation 457,960.00 cu.m in 2011 and 6,371,878.82 cu.m in 2021. Nevertheless, certain data points decreased in growth since variations in the trend can be observed in the figure, which is

considered white noise. From this, it implies that the solid waste generation in Davao City in the past eleven years has been continually increasing.

The increasing trend of solid waste generation can be seen in various studies and observed in some countries. Tiseo (2022) asserted that millions of tons of trash are produced annually by humans, which has become a massive problem on a global scale. It has been further supported by his later investigation, which found that China generates more than 15% of municipal solid waste (MSW) in the world (Tiseo, 2021). Specifically, the volume of waste in the nation has rapidly increased, reaching 242 million tons in 2019 during the previous few decades (Statista Research Department, 2022). Kumar et al. (2017) also discovered that the urban areas in India presently produce about 170,000 tons of waste each day or 62 million tons yearly, which is expected to increase by 5% annually. Moreover, Al-Maaded et al. (2012) stated that Qatar generates a considerable amount of solid waste per person in the world and produces about 2,000,000 tons of MSW yearly or 2.5 kg of garbage per person.

**Figure 4. Population Growth of Davao City from 2011 to 2021**

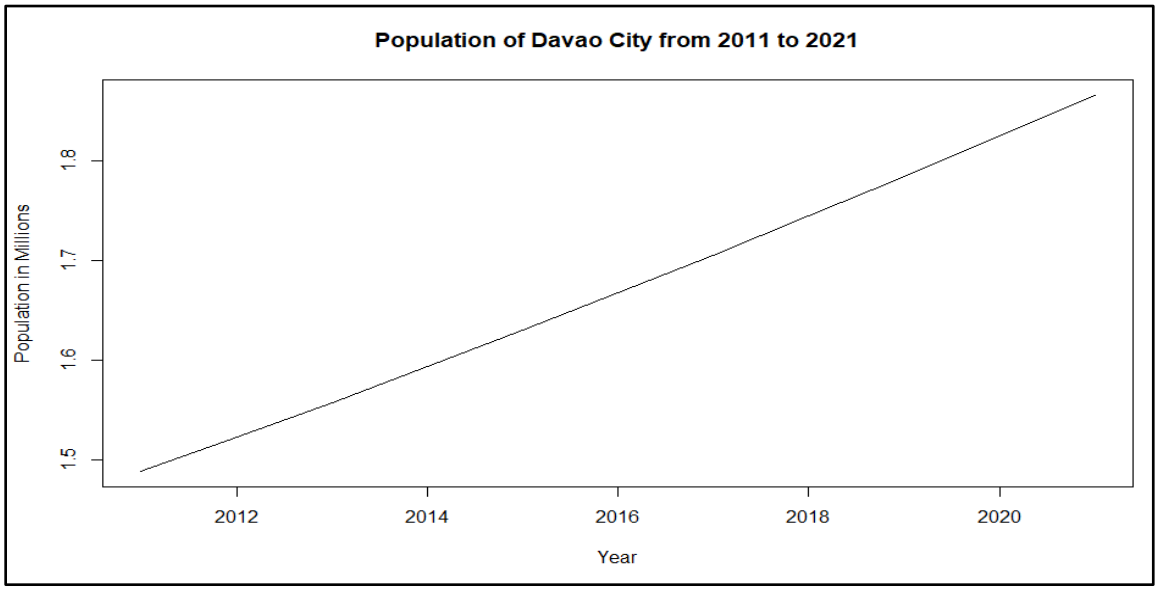

Figure 4 shows the Line Plot of the population growth of Davao City from 2011 to 2021. Remarkably, this graph presented one significant trend, which could be seen from 2011 to 2021. This graph segment showed a constantly increasing trend with a growth ranging from 34,250 to 40,951 each year, making the population 1,488,244 in 2011 to 1,866,401 in 2021. From this, it implies that the population growth of Davao City in the past eleven years has been continually increasing.

The direct trend of population growth and solid waste generation coincides with various studies stating that the amount of waste produced increases along with the rise of population. It can be seen from the studies of Bish (2020) and Marshall and Farahbakhsh (2013) that as the urban population keeps increasing, the consumption of resources grows, which may worsen the risk of environmental damage and could make solid waste management (SWM) an issue to be concerned about. Further, the same scenario is observed in the Philippines, where the nation generates more solid waste as its population, living standards, and urban and rural areas expand (Mawis, 2019). As a result, population growth and waste production in urban settings have demonstrated a relationship such that human settlements can produce a significant amount of solid waste (Omololu & Lawal, 2013).

***Research Question Number 2: What are the forecasted solid waste generation and the population growth of Davao City for the next five years, from 2022 to 2026?***

**Table 1. Top Five Models for Solid Waste Generation**

| Models | AIC |
|---|---|
| ARIMA (0,2,2) | 27.26 |
| ARIMA (1,2,0) | 28.71 |
| ARIMA (0,2,3) | 29.26 |
| ARIMA (2,2,3) | 29.89 |
| ARIMA (2,2,2) | 30.01 |

Auto-regressive Integrated Moving Average (ARIMA) was used to model the solid waste generation of Davao City using the data from 2011 to 2021. Further, the Akaike Information Criterion (AIC) was used to identify the best model specification to model the dataset. Table 1 shows that ARIMA (0,2,2) has the lowest AIC score, with a value of 27.26 among the models considered by the researcher. From this, it suggests that ARIMA (0,2,2) may be regarded to forecast the solid waste generation of Davao City for the next five years.

Table 2 shows the forecasted solid waste generation of Davao City from 2022 to 2026 in millions. These values were predicted using the ARIMA model with p, d, and q values of (0,2,2). In 2022, the forecasted solid waste generation will be 7,094,300 ± 155,800 cu.m; the value 155,800 is the margin of error, and 7,094,300 is the point forecast.

**Table 2. Forecasted Solid Waste Generation for 2022 to 2026 using ARIMA (0,2,2)**

| Year | 95% Confidence Interval (In Millions) |
|---|---|
| 2022 | 7.0943 ± 0.1558 |
| 2023 | 7.8395 ± 0.2204 |
| 2024 | 8.5847 ± 0.3606 |
| 2025 | 9.3299 ± 0.5497 |
| 2026 | 10.0751 ± 0.7738 |

Adding and subtracting the point forecast with the margin of error will result in its high value of 7,250,100 and low value of 6,938,500, which is the forecast interval. In 2023, the forecasted solid waste generation will be 7,839,500 ± 220,400 cu.m. In 2024, the predicted solid waste generation will be 8,584,700 ± 360,600 cu.m. In 2025, the forecasted solid waste generation will be 9,329,900 ± 549,700 cu.m. Lastly, in 2026, the predicted solid waste generation will be 10,075,100 ± 773,800 cu.m. With this, it implies that the

forecasted solid waste generation of Davao City for the next five years will still be in an increasing trend, with a percentage growth of 58.12%. For the visual representation, refer to Appendix 6.

Similar conditions are evident in some countries and the findings of several studies with the increasing trend of solid waste generation. Olalo et al. (2022) found that the rising waste production and a lack of waste-related infrastructure would likely impact Davao City. As its population and economy grow, more waste is being produced in the city. Also, according to the Senate Economic Planning Office (SEPO), the amount of waste produced daily in the Philippines increased substantially from 37,427,46 tons in 2012 to 40,087,45 tons in 2016 (Mawis, 2019). In the United States, the amount of waste created did not decrease and may even be much more than initially estimated (Law et al., 2020; Lee et al., 2016). With that, the constant rise of solid waste generation in the coming years will most likely impact the health of the people, environment, and wildlife (Altaf, 2019; Omang et al., 2021; Vinti et al., 2021).

**Table 3. Top Five Models for Population Growth**

| Models | AIC |
|---|---|
| ARIMA (1,2,0) | – 130.20 |
| ARIMA (3,2,0) | – 130.00 |
| ARIMA (2,2,0) | – 129.64 |
| ARIMA (3,2,1) | – 129.23 |
| ARIMA (1,2,2) | – 128.83 |

Table 3 shows that ARIMA (1,2,0) has the lowest AIC score, with a value of – 130.20 among the models considered by the researcher. From this, it suggests that ARIMA

(1,2,0) may be regarded to forecast the population growth of Davao City for the next five years.

Table 4 shows the forecasted population growth of Davao City from 2022 to 2026 in millions. These values were predicted using the ARIMA model with p, d, and q values of (1,2,0). In 2022, the forecasted population growth will be 1,907,800 ± 1,400; the value 1,400 is the margin of error, and 1,907,800 is the point forecast.

**Table 4. Forecasted Population Growth for 2022 to 2026 using ARIMA (1,2,0)**

| Year | 95% Confidence Interval (In Millions) |
|---|---|
| 2022 | 1.9078 ± 0.0014 |
| 2023 | 1.9496 ± 0.0045 |
| 2024 | 1.9918 ± 0.0096 |
| 2025 | 2.0345 ± 0.0169 |
| 2026 | 2.0775 ± 0.0269 |

Adding and subtracting the point forecast with the margin of error will result in its high value of 1,909,200 and low value of 1,906,400, which is the forecast interval. In 2023, the forecasted population growth will be 1,949,600 ± 4,500. In 2024, the predicted population growth will be 1,991,800 ± 9,600. In 2025, the forecasted population growth will be 2,034,500 ± 16,900. Lastly, in 2026, the predicted population growth will be 2,077,500 ± 26,900. With this, it implies that the forecasted population growth of Davao City for the next five years will still be in an increasing trend, with a percentage growth of 11.31%. For the visual representation, refer to Appendix 7.

Similar patterns are observed in several studies with the increasing trend of population growth. David et al. (2014) found that the Philippines is still struggling to find effective methods to manage population growth. Evidence linking population expansion to

poverty highlights persistently high fertility rates as a significant barrier to poverty reduction. According to the World Population Review (2022), there will be no evidence of a population drop in the United States during the next century. As a result, the constant rise of population growth in the coming years would most likely impact the environment and the people. Bish (2020) stated that the growing population would unavoidably add to pressures that exacerbate climate change by accelerating deforestation, decreasing biodiversity, and increasing pollution and emissions. Relative to this, the same studies realized that the hazard to the sustainable use of natural resources arises from rapid population increase will become a significant factor in the deterioration of the environment and poses a threat to the continuation of sustainable human life (Maja & Ayano, 2021; Mittal & Mittal, 2013).

***Research Question Number 3: What is the capacity of the New Carmen Sanitary Landfill?***

**Figure 5. Map of the New Carmen Sanitary Landfill (Existing and Proposed)**

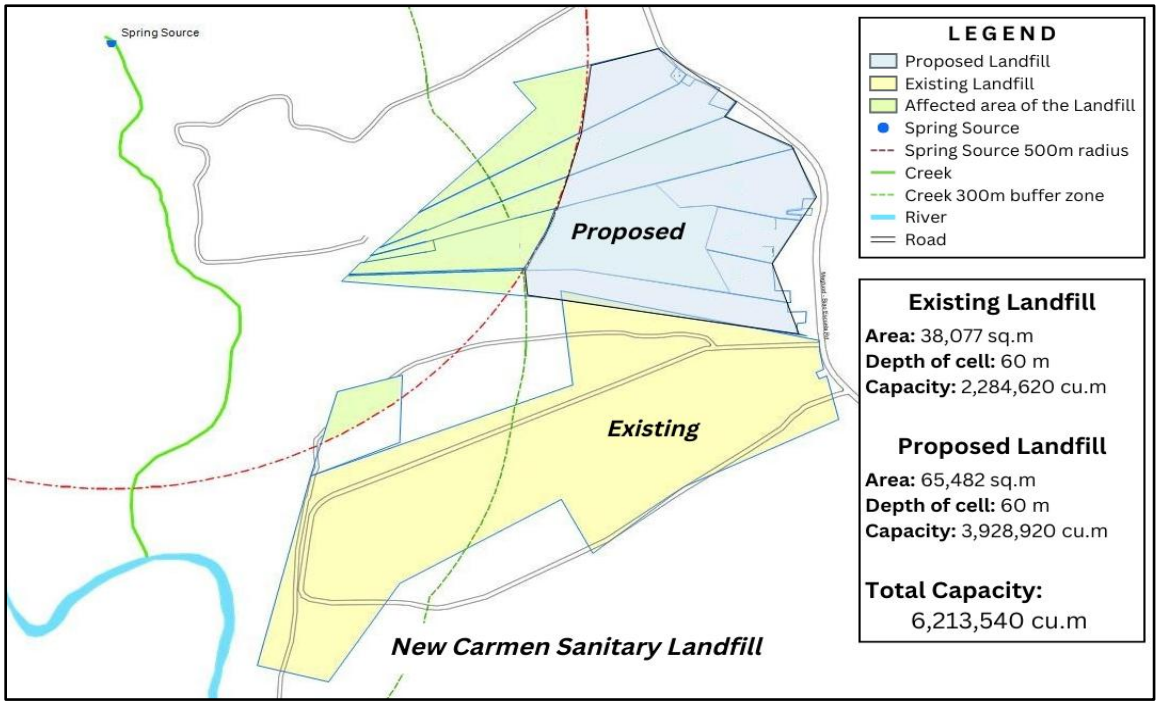

Figure 5 illustrates the map showing the properties of the New Carmen Sanitary Landfill, both existing, which was opened in 2010, and proposed, which may be opened in 2023. Considering the surrounding area of the location, the spring source has a 500 m radius that affects 28,920 sq.m of the proposed landfill, which will not be used as a potential site for dumping the wastes. With that, the proposed landfill will have an area of 65,482 sq.m and a cell depth of 60 meters. Multiplying the area and the cell depth will result in its capacity of 3,928,920 cu.m. Moreover, the current landfill has an area of 38,077 sq.m and a cell depth of 60 meters. Multiplying the area and the cell depth will result in its capacity of 2,284,620 cu.m. Adding the capacity of the existing and proposed landfill will result in a total capacity of 6,213,540 cu.m.

Landfilling is one of the most common solid waste management techniques. It is where trash is disposed of, and it has special qualities that keep the land and water in the area clean. Before selecting the proposed landfill site, CENRO chose potential locations that were ecologically compatible. Several studies support this notion that choosing a suitable landfill location depends on various standards and conditions, necessitating research and multiple-factor assessments (Rezaeisabzevar et al., 2020; Yildirim et al., 2018). Alavi et al. (2013) outlined the criteria for selecting a landfill site following the laws and regulations. These include surface water, delicate ecosystems, land cover, urban and rural areas, land uses, proximity to highways, slope, and land type. Since selecting a landfill site is a challenging procedure that must consider various factors, it is imperative to find a practical way to link engineers to choose the optimal landfill location (Mortazavi Chamchali et al., 2021).

***Research Question Number 4: Can the New Carmen Sanitary Landfill still hold the forecasted solid waste generation of Davao City for the next five years?***

**Table 5. Ratio and proportion of the capacity of the New Carmen Sanitary Landfill to the forecasted solid waste generation**

| **Ratio:** 1 cu.m of the capacity : 1 cu.m of solid waste | |
|---|---|
| Let $a =$ capacity<br>$b =$ solid waste | $a \geq b$<br>1 cu.m of the capacity $\geq$ 1 cu.m of solid waste<br>$\therefore$ **TRUE** |
| **Capacity of the landfill:**<br>6,213,540 cu.m<br>**Solid waste generation (2026):**<br>10,075,100 cu.m | $a \geq b$<br>6,213,540 cu.m $\geq$ 10,075,100 cu.m<br>$\therefore$ **FALSE** |

Table 5 shows the ratio and proportion of the capacity of the New Carmen Sanitary Landfill to the predicted solid waste generation for the next five years. The ratio of the capacity to the solid waste is 1:1, meaning that for every cubic meter of the capacity, there is also a cubic meter of solid waste. Also, the capacity should be greater than or equal to the generated solid waste to accommodate the waste being dumped in the landfill. Based on the findings of the gathered data, the total capacity of the existing and proposed landfill, which is 6,213,540 cu.m, is not greater than or equal to the predicted solid waste generation, which is 10,075,100 cu.m. Therefore, it indicates that the forecasted solid waste generation of Davao City will exceed the capacity of the New Carmen Sanitary Landfill for the next five years.

The problem with waste generation exceeding the capacity of its landfill can be seen in various studies. Youcai (2018) found that waste dumped in landfills might take decades or even hundreds of years to decompose, which can contribute to the need for much more storage space for the landfill to accommodate the increasing volume of waste being dumped every day. In India, it is anticipated that by 2031, urban areas of the nation will produce 165 million tons of waste annually and 463 million tons by 2050. Due to this, the local government foresees that the waste generation of the country might surpass its landfill capacity in the following years. As a result, around $2.5 \times 10^7$ cu.m of landfill space, or 1,175 hectares of land area, will be needed to accommodate the amount of waste produced in the subsequent years (Joshi & Ahmed, 2016).

It has been the same case in Davao City that the landfill in New Carmen has already accumulated 900,000 tons of waste since 2016 despite having a maximum capacity of between 700,000 and 800,000 tons. In response, the local government has proposed a waste-to-energy (WTE) facility at Biao Escuela, Tugbok District (Garay & Bernardo, 2020; Garcia, 2022). This facility will burn and convert non-hazardous wastes into usable forms of energy. As stated by George et al. (2022), Pongrácz et al. (2004), and Tadese et al. (2022), the lack of sufficient disposal sites may impact the population and the urban environment, which makes sustainable and integrated solid waste management (SWM) an effective solution for the worldwide issue of the rapid growth of solid waste.

# Chapter 4

# CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations drawn from the data discussed and analyzed in the previous chapter.

## Conclusion

Based on the findings of the study, the annual solid waste generation and the population growth of Davao City have both been increasing over the previous eleven years. Similarly, its forecasted solid waste generation and population growth are also expected to expand over the next five years, with growth rates of 58.12% and 11.31%, respectively. The researchers can therefore deduce that the production of waste may rise along with the increase in the population, which exhibits a direct increasing trend with each other. Additionally, the total capacity of the existing and proposed landfills is not greater than or equal to the predicted solid waste generation. The data suggest that the projected solid waste generation of Davao City will surpass the capacity of the New Carmen Sanitary Landfill for the next five years.

## Recommendations

The following are the recommendations of the researchers for the improvement of this paper. Firstly, future researchers can conduct a study on the factors affecting the rise in solid waste generation and population growth in Davao City. Secondly, future researchers can compare the predicted values produced by the ARIMA model using other

statistical methods. Thirdly, future researchers are recommended to gather thirty to fifty years of past data on the variables to have more accurate forecasted values.

Fourthly, even though policymakers have already developed several orders, policies, and other strategies to address the issue, there is still a problem with its implementation and monitoring since the projected solid waste generation with the population growth have constantly increased over the years. With that, they can further strengthen the enforcement and application of these initiatives to mitigate the rise of population and trash production. Lastly, given the forecasted number of solid waste generation and population growth for the next five years, this can be a reference and guide to call the inventors and engineers of the country to develop new and advanced technologies that can reduce the size or bulk of the waste to lessen the space it will occupy on the landfill.

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Appendix 1a: Letter of Permission (School President)

**HOLY CROSS COLLEGE OF CALINAN**
**Davao-Bukidnon Highway, Calinan, Davao City**

October 21, 2022

SR. CHERIE ELOISA GAROTTE, PM
School President
This Institution

Dear Sister,

Greetings of peace and solidarity!

We are writing this letter to inform you that we will be conducting a research study entitled: **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS** as the major requirement in our Practical Research 1 and 2. The objective of this study is to assess the capacity of the New Carmen Sanitary Landfill to handle the solid waste generated in relation to the projected population growth for the next five years. The result of this study will be part of our contribution to further knowledge about strengthening solid waste management (SWM) for the locality residents.

With this, we are asking permission to allow us to conduct our study outside the school and secure data from the agencies involved in our study. This endeavor may not harm or disturb any part of the community outside. Also, the confidentiality of the information obtained is assured as there will be no individuals who will have access to this except us, the researchers, and our research adviser.

Should you wish to know more about the study, please feel free to contact:

**Richard Nash C. Mercadal – 09507593085 / richardnashmercadal@gmail.com**

We hope that this request will merit your kind approval. Thank you, and may God bless you.

Very truly yours,

Richard Nash C. Mercadal
Researcher

Sophia Bianca D. Bariquit
Researcher

Louie Miko O. Artigas
Researcher

Reigh Alfred S. Ganzon
Researcher

Lorenz Edward B. Cañada
Researcher

Noted by:

Mrs. Jessica O. Rabang
Research Adviser

Ma. Corazon C. Suñga, PhD
School Principal

Approved by:

Sr. Cherie Eloisa Garotte, PM
School President

Appendix 1b: Letter of Permission (School Principal)

**HOLY CROSS COLLEGE OF CALINAN**
**Davao-Bukidnon Highway, Calinan, Davao City**

October 21, 2022

MA. CORAZON C. SUÑGA, PHD
School Principal
This Institution

Dear Dr. Suñga,

Greetings of peace and solidarity!

We are writing this letter to inform you that we will be conducting a research study entitled: **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS** as the major requirement in our Practical Research 1 and 2. The objective of this study is to assess the capacity of the New Carmen Sanitary Landfill to handle the solid waste generated in relation to the projected population growth for the next five years. The result of this study will be part of our contribution to further knowledge about strengthening solid waste management (SWM) for the locality residents.

With this, we are asking permission to allow us to conduct our study outside the school and secure data from the agencies involved in our study. This endeavor may not harm or disturb any part of the community outside. Also, the confidentiality of the information obtained is assured as there will be no individuals who will have access to this except us, the researchers, and our research adviser.

Should you wish to know more about the study, please feel free to contact:

**Richard Nash C. Mercadal – 09507593085 / richardnashmercadal@gmail.com**

We hope that this request will merit your kind approval. Thank you, and may God bless you.

Very truly yours,

Richard Nash C. Mercadal
Researcher

Sophia Bianca D. Bariquit
Researcher

Louie Miko O. Artigas
Researcher

Reigh Alfred S. Ganzon
Researcher

Lorenz Edward B. Cañada
Researcher

Noted by:

Mrs. Jessica O. Rabang
Research Adviser

Approved by:

Ma. Corazon C. Suñga, PhD
School Principal

Appendix 1c: Letter of Permission (CENRO)

**HOLY CROSS COLLEGE OF CALINAN**
**Davao-Bukidnon Highway, Calinan, Davao City**

October 21, 2022

ENGR. MARIVIC L. REYES
Department Head
CENRO Motorpool Compound,
Barangay Maa, Davao City

Dear Engr. Reyes,

Greetings of peace and solidarity!

We, Richard Nash Mercadal, Sophia Bianca Bariquit, Louie Miko Artigas, Reigh Alfred Ganzon, and Lorenz Edward Cañada, Grade 12 – STEM students of Holy Cross College of Calinan are writing this letter to inform you that we will be conducting a research study entitled: **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS** as the major requirement in our Practical Research 1 and 2. The objective of this study is to assess the capacity of the New Carmen Sanitary Landfill to handle the solid waste generated in relation to the projected population growth for the next five years. The result of this study will be part of our contribution to further knowledge about strengthening solid waste management (SWM) for the locality residents.

In line with this, we would like to ask permission to get the solid waste generation of Davao City from 2011 to 2021. Aside from that, we would also like to ask permission to get the area and capacity of the New Carmen Sanitary Landfill and its ratio and proportion to the generated solid waste. Confidentiality of the information obtained is assured as there will be no individuals who will have access to this except us, the researchers, and our research adviser.

Should you wish to know more about the study, please feel free to contact:

**Richard Nash C. Mercadal – 09507593085 / richardnashmercadal@gmail.com**

We hope that this request will merit your kind approval. Thank you, and may God bless you.

Very truly yours,

Richard Nash C. Mercadal
Researcher

Sophia Bianca D. Bariquit
Researcher

Louie Miko O. Artigas
Researcher

Reigh Alfred S. Ganzon
Researcher

Lorenz Edward B. Cañada
Researcher

Noted by:

Mrs. Jessica Q. Rabang
Research Adviser

Ma. Corazon C. Suñga, PhD
School Principal

Sr. Cherie Eloisa Garotte, PM
School President

Approved by:

Engr. Marivic L. Reyes
Department Head

by:
Engr. Estrellina R. Orcullo
Acting Division Head-EWMD

**Complaints about this research:**

The Holy Cross College of Calinan requires that all the participants are informed and if they have complaints regarding the manner in which the research is conducted, it may be given to the researcher, or if an independent person is preferred, to the Research and Publication Head, Research Office, Holy Cross College of Calinan with the following numbers: 295-0797 or 09491985644.

Appendix 1d: Letter of Permission (PSA)

**HOLY CROSS COLLEGE OF CALINAN**
**Davao-Bukidnon Highway, Calinan, Davao City**

October 21, 2022

RANDOLPH ANTHONY B. GALES
OIC-Regional Director
J.P. Cabaguio Avenue, Davao City

Dear Sir Gales,

Greetings of peace and solidarity!

We, Richard Nash Mercadal, Sophia Bianca Bariquit, Louie Miko Artigas, Reigh Alfred Ganzon, and Lorenz Edward Cañada, Grade 12 – STEM students of Holy Cross College of Calinan are writing this letter to inform you that we will be conducting a research study entitled: **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS** as the major requirement in our Practical Research 1 and 2. The objective of this study is to assess the capacity of the New Carmen Sanitary Landfill to handle the solid waste generated in relation to the projected population growth for the next five years. The result of this study will be part of our contribution to further knowledge about strengthening solid waste management (SWM) for the locality residents.

In line with this, we would like to ask permission to get the data on the population growth of Davao City from 2011 to 2021. Confidentiality of the information obtained is assured as there will be no individuals who will have access to this except us, the researchers, and our research adviser.

Should you wish to know more about the study, please feel free to contact:

**Richard Nash C. Mercadal – 09507593085 / richardnashmercadal@gmail.com**

We hope that this request will merit your kind approval. Thank you, and may God bless you.

Very truly yours,

Richard Nash C. Mercadal
Researcher

Sophia Bianca D. Bariquit
Researcher

Louie Miko O. Artigas
Researcher

Reigh Alfred S. Ganzon
Researcher

Lorenz Edward B. Cañada
Researcher

Noted by:

Mrs. Jessica D. Rabang
Research Adviser

Ma. Corazon C. Suñga, PhD
School Principal

Sr. Cherie Eloisa Garotte, PM
School President

Approved by:

Randolph Anthony B. Gales
OIC-Regional Director

**Complaints about this research:**

The Holy Cross College of Calinan requires that all the participants are informed and if they have complaints regarding the manner in which the research is conducted, it may be given to the researcher, or if an independent person is preferred, to the Research and Publication Head, Research Office, Holy Cross College of Calinan with the following numbers: 295-0797 or 09491985644.

Appendix 2: Growth and Percentage Growth of the Solid Waste Generation

| Year | Solid Waste Generation (cu.m) | Growth | Percentage Growth |
|---|---|---|---|
| 2011 | 457,960.00 | 453,602.00 | 99.05% |
| 2012 | 911,562.00 | 484,594.00 | 53.16% |
| 2013 | 1,396,156.00 | 467,885.00 | 33.51% |
| 2014 | 1,864,041.00 | 663,425.00 | 35.59% |
| 2015 | 2,527,466.00 | 436,218.00 | 17.26% |
| 2016 | 2,963,684.00 | 656,999.00 | 22.17% |
| 2017 | 3,620,683.00 | 657,001.00 | 18.15% |
| 2018 | 4,277,684.00 | 672,940.40 | 15.73% |
| 2019 | 4,950,624.40 | 670,295.80 | 13.54% |
| 2020 | 5,620,920.20 | 750,958.62 | 13.36% |
| 2021 | 6,371,878.82 | | |

Appendix 3: Forecast Interval of the Forecasted Solid Waste Generation (In Millions)

| Year | Point Forecast | Margin of Error | High Value | Low Value |
|---|---|---|---|---|
| 2022 | 7.0943 | ± 0.1558 | 7.2501 | 6.9385 |
| 2023 | 7.8395 | ± 0.2204 | 8.0599 | 7.6191 |
| 2024 | 8.5847 | ± 0.3606 | 8.9453 | 8.2241 |
| 2025 | 9.3299 | ± 0.5497 | 9.8796 | 8.7802 |
| 2026 | 10.0751 | ± 0.0.7738 | 10.8489 | 9.3013 |

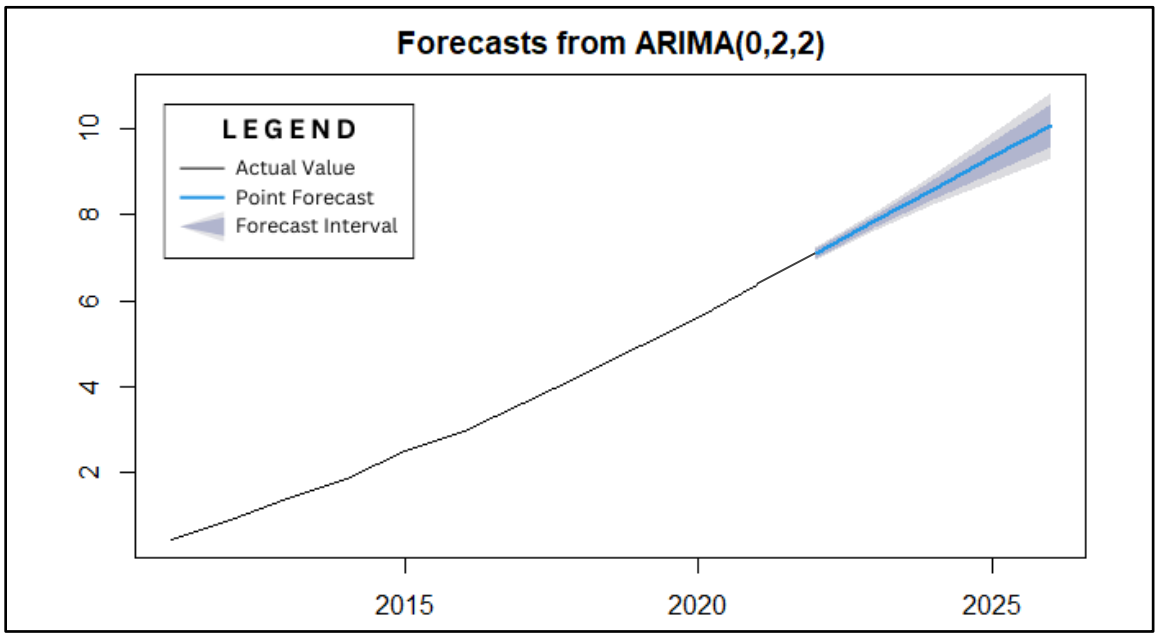
Appendix 4: Growth and Percentage Growth of the Population

| Year | Population | Growth | Percentage Growth |
|---|---|---|---|
| 2011 | 1,488,244 | 34,250 | 2.30% |
| 2012 | 1,522,494 | 34,941 | 2.29% |
| 2013 | 1,557,435 | 35,793 | 2.30% |
| 2014 | 1,593,228 | 36,615 | 2.30% |
| 2015 | 1,629,843 | 37,509 | 2.30% |
| 2016 | 1,667,352 | 38,372 | 2.30% |
| 2017 | 1,705,724 | 39,256 | 2.30% |
| 2018 | 1,744,980 | 39,962 | 2.29% |
| 2019 | 1,784,942 | 40,508 | 2.27% |
| 2020 | 1,825,450 | 40,951 | 2.24% |
| 2021 | 1,866,401 | | |

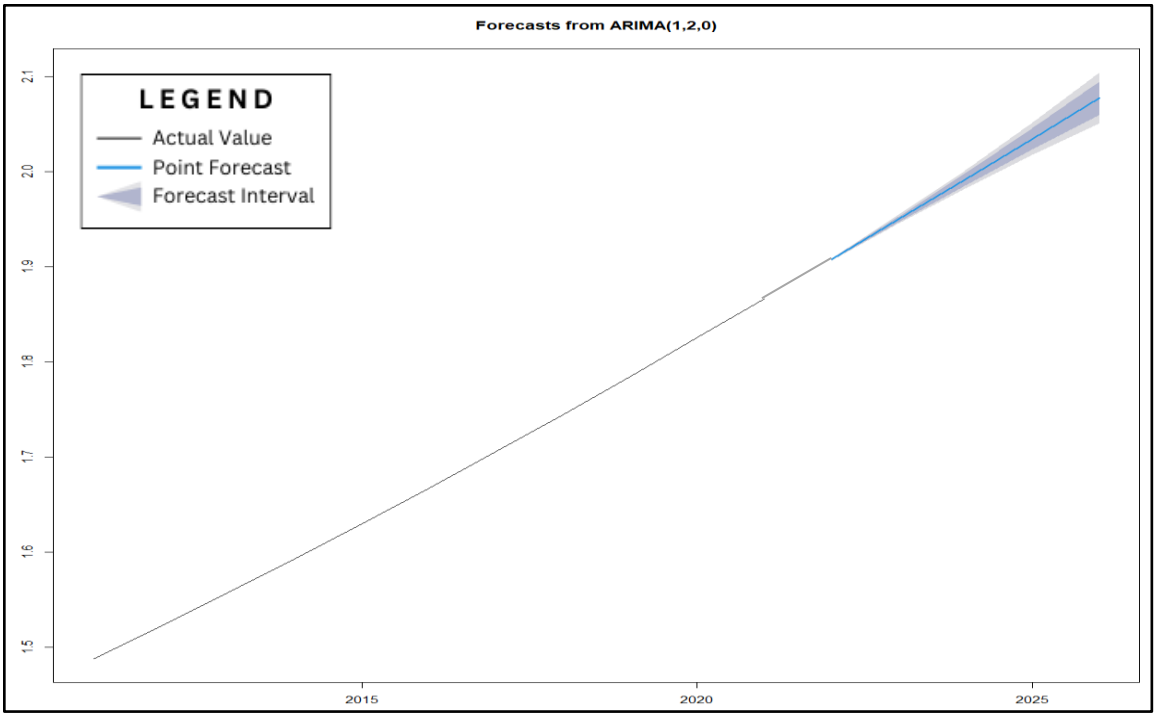
Appendix 5: Forecast Interval of the Forecasted Population Growth (In Millions)

| Year | Point Forecast | Margin of Error | High Value | Low Value |
|---|---|---|---|---|
| 2022 | 1.9078 | ± 0.0014 | 1.9092 | 1.9064 |
| 2023 | 1.9496 | ± 0.0045 | 1.9541 | 1.9451 |
| 2024 | 1.9918 | ± 0.0096 | 2.0014 | 1.9822 |
| 2025 | 2.0345 | ± 0.0169 | 2.0514 | 2.0176 |
| 2026 | 2.0775 | ± 0.0269 | 2.1044 | 2.0506 |

Appendix 6: Graph of the Forecasted Solid Waste Generation




Appendix 7: Graph of the Forecasted Population Growth



Appendix 8: Documentation


Appendix 9: Editor's Certificate

**Holy Cross College of Calinan, Inc.**
Davao-Bukidnon Highway, Calinan, Davao City
**RESEARCH AND PUBLICATION OFFICE**

## CERTIFICATION

This is to certify that the research paper of Richard Nash C. Mercadal, Sophia Bianca D. Bariquit, Louie Miko O. Artigas, Reigh Alfred S. Ganzon, and Lorenz Edward B. Cañada entitled **ASSESSING THE CAPACITY OF THE NEW CARMEN SANITARY LANDFILL TO HOLD THE SOLID WASTE GENERATED VIS-À-VIS THE POPULATION GROWTH FOR THE NEXT FIVE YEARS** has undergone the editing process and been approved by the undersigned.

This certification is issued upon the request by the researcher on August 4, 2023.

**Ms. Angelie L. Mamites**
Editor

# CURRICULUM VITAE

## PERSONAL DATA

**Name:** Richard Nash C. Mercadal

**Address:** Purok 2A Malagos, Baguio District, Davao City

**Sex:** Male

**Civil Status:** Single

**Date of Birth:** July 19, 2005

**Place of Birth:** Agbisit Maternity Clinic, Calinan, Davao City

**Religion:** Roman Catholic

**Father's Name:** Richard P. Mercadal **Occupation:** Mechanic

**Mother's Name:** Paz C. Mercadal **Occupation:** Bookkeeper

## EDUCATIONAL ATTAINMENT

| | SCHOOL | YEAR GRADUATED |
|---|---|---|
| **Elementary:** | Malagos Elementary School SPED Center | 2017 |
| **Junior High School:** | Holy Cross College of Calinan, Inc. | 2021 |
| **Senior High School:** | Holy Cross College of Calinan, Inc. | 2023 |

# CURRICULUM VITAE

## PERSONAL DATA

**Name:** Sophia Bianca D. Bariquit

**Address:** Purok 11 Los Amigos, Tugbok Davao City

**Sex:** Female

**Civil Status:** Single

**Date of Birth:** November 12, 2004

**Place of Birth:** Southern Philippines Medical Center, Davao City

**Religion:** Roman Catholic

**Father's Name:** Oliver I. Bariquit **Occupation:** N/A

**Mother's Name:** Donna D. Bariquit **Occupation:** OFW

## EDUCATIONAL ATTAINMENT

| | SCHOOL | YEAR GRADUATED |
|---|---|---|
| **Elementary:** | Biao Guianga Elementary School | 2017 |
| **Junior High School:** | Holy Cross College of Calinan, Inc. | 2021 |
| **Senior High School:** | Holy Cross College of Calinan, Inc. | 2023 |

# CURRICULUM VITAE

## PERSONAL DATA

**Name:** Louie Miko O. Artigas

**Address:** Hilsha Ph. II Calinan, Davao City

**Sex:** Male

**Civil Status:** Single

**Date of Birth:** May 16, 2005

**Place of Birth:** Ricardo Limso Hospital

**Religion:** Roman Catholic

**Father's Name:** Leonard Kai Artigas **Occupation:** Welder

**Mother's Name:** Mary Ann Ong Artigas **Occupation:** Housewife

## EDUCATIONAL ATTAINMENT

| | SCHOOL | YEAR GRADUATED |
|---|---|---|
| **Elementary:** | Philippine Nikkei Jin Kai School of Calinan | 2017 |
| **Junior High School:** | Philippine Nikkei Jin Kai School of Calinan | 2021 |
| **Senior High School:** | Holy Cross College of Calinan, Inc. | 2023 |

# CURRICULUM VITAE

## PERSONAL DATA

**Name:** Reigh Alfred S. Ganzon

**Address:** Ramon Magsaysay St., Calinan, Davao City

**Sex:** Male

**Civil Status:** Single

**Date of Birth:** April 16, 2005

**Place of Birth:** Agbisit Maternity Clinic, Calinan, Davao City

**Religion:** Roman Catholic

**Father's Name:** Reyland E. Ganzon **Occupation:** Soldier

**Mother's Name:** Mary Emlea S. Ganzon **Occupation:** Government worker

## EDUCATIONAL ATTAINMENT

| | SCHOOL | YEAR GRADUATED |
|---|---|---|
| **Elementary:** | Philippine Nikkei Jin Kai School of Calinan | 2017 |
| **Junior High School:** | Holy Cross College of Calinan, Inc. | 2021 |
| **Senior High School:** | Holy Cross College of Calinan, Inc. | 2023 |

# CURRICULUM VITAE

## PERSONAL DATA

**Name:** Lorenz Edward B. Cañada

**Address:** Biao Escuela, Tugbok, Davao City

**Sex:** Male

**Civil Status:** Single

**Date of Birth:** December 12, 2004

**Place of Birth:** Davao City

**Religion:** Roman Catholic

**Father's Name:** Evsent A. Cañada **Occupation:** Teacher

**Mother's Name:** Liezzelda B. Cañada **Occupation:** Teacher

## EDUCATIONAL ATTAINMENT

| | SCHOOL | YEAR GRADUATED |
|---|---|---|
| **Elementary:** | Biao Elementary School | 2017 |
| **Junior High School:** | Holy Cross College of Calinan, Inc | 2021 |
| **Senior High School:** | Holy Cross College of Calinan, Inc. | 2023 |