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Solid Waste Generation and Characterization in a State University

Merhanna D. Pangandaman*, Josua Meko B. Acabal, Cesar B. Anino Jr., Gerald D. Apat
Civil Engineering Department, Mindanao State University, Marawi City, Philippines

*Corresponding Author Email: merhanna.pangandaman@msumain.edu.ph

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Abstract. This study investigated the solid waste generation and characterization at Mindanao State University (MSU) - Main Campus in Marawi City, addressing the critical issues of unsustainable waste management practices. Despite the recent establishment of waste management facilities in Marawi City, including a Central Material Recovery Facility (CMRF) and a Category 4 Sanitary Landfill (SLF), the campus and much of the city need help with effective waste disposal. This has led to environmental challenges such as clogged drainage systems, open dumping, and air pollution from waste burning. The study fills an essential gap in solid waste generation and characterization data, which is crucial for effective solid waste management (SWM) planning as mandated by the Ecological Solid Waste Management Act of 2000 (RA 9003). Using a descriptive-comparative research design, the study surveyed 216 units, including residential buildings, rental properties, commercial establishments, and university facilities. The findings reveal that the MSU-Main Campus generates 9438.011 kg of waste daily, with a per capita waste generation rate of 0.9371 kg/day— significantly higher than the national average. Residential buildings are the primary waste generators, contributing nearly half of the total waste, followed by lodgings. Waste characterization reveals a substantial proportion of non-biodegradable waste (38.29%), with biodegradable waste accounting for 35.46% of the total. These findings highlight the urgent need for systematic waste management strategies, particularly focusing on waste segregation, recycling, and waste reduction to mitigate the environmental impact on campus. The study provides a comprehensive data foundation for developing a solid waste management plan and underscores the role of academic institutions in leading sustainable practices.

Keywords: Solid waste management; waste generation; waste characterization; Ecological Solid Waste Management Act; RA 9003; Marawi City.

1.0 Introduction

Solid waste management (SWM) is a continuing concern of Mindanao State University (MSU) - Main Campus in Marawi City. This regional higher education institution fosters academic pursuits and accommodates residential establishments within its premises, thereby drifting from its intended exclusive academic use. Like many areas in Marawi, the campus faces waste generation, worsened by unplanned areas and uncontrolled residency. Common problems include improper waste disposal, clogged canals, open dumping, and waste burning, which contribute to flooding, foul odors, and air pollution. Uncollected waste from bins attracts insects and pests, emits foul odors, and leaks chemicals that pollute water, while open burning of wastes causes air pollution (Abubakar et al., 2022).

Waste, defined as discarded materials with no value for everyday use (Bharadwaj et al., 2015), largely originates from households and commercial activities, contributing 55% to 80% and 10% to 30% of waste, respectively (Miezah et al., 2015). In the Philippines, solid waste continues to increase due to growing populations, poor enforcement of laws, limited landfill availability, and improper disposal practices (Coracero et al., 2021). Republic

Act 9003, the Ecological Solid Waste Management Act of 2000, mandates local government units and agencies like the Department of Environment and Natural Resources (DENR) to manage waste systematically (Official Gazette, 2001). Recent SWM initiatives in Marawi City, such as establishing a Central Material Recovery Facility (CMRF) and a Category 4 Sanitary Landfill (SLF) in 2023, reflect efforts to address these issues. However, MSU-Main remains burdened by unsustainable practices.

As academic hubs and drivers of social progress, universities are increasingly expected to play a leading role in sustainable waste management (Geng et al., 2013). Proper SWM planning begins with generating and characterizing solid waste, among others, but is unfortunately under-investigated, especially in developing countries (Ugwu et al., 2020). Efficient handling of solid wastes requires understanding the compositions and the waste generation rate (Arazo, 2015). At MSU-Main, the lack of comprehensive data on waste generation hinders compliance with Republic Act 9003 and challenges Marawi City's development of its first Comprehensive Solid Waste Management Plan (SWMP). Significant SWM challenges persist despite the university's recent initiatives—such as its zero single-use plastic policy and waste segregation efforts. Ongoing research at the university aligns with its commitment to becoming a model for sustainable development in the province by addressing these challenges.

This study aims to bridge this data gap by quantifying and characterizing the solid waste generated at MSU-Main Campus. The findings will enhance the university's SWM initiatives and contribute to the broader SWMP for Marawi City, offering a model for improved waste management in similar institutions and communities.

2.0 Methodology

2.1 Research Design

This study employed a descriptive-comparative approach to assess the waste composition and generation within MSU-Main Campus. The aim was to describe and compare the types and quantities of waste produced by different sectors (household and non-household) across various areas on campus. By quantifying and characterizing the waste, this method helps to understand the existing waste management challenges and identify effective improvement strategies.

2.2 Research Locale

MSU-Main Campus covers approximately 986 hectares in total, and about 31% (305 hectares) have only been occupied/utilized by the university, while a significant portion of the utilized area comprises privately owned buildings. The survey focused on highly populated areas within the campus, including residential, commercial zones, academic and community support facilities. Specifically, the selected barangays were Lomidong, Cabingan, Dimaluna, Rapasun, Cadayonan, and Bayeba-Damag.

2.3 Research Participants

Secondary data and information, such as the list of university buildings and dorms and university land map use from various offices in the university; registered residents, number of barangay population, and solid waste practices from the barangay halls and agencies in Marawi were gathered. These reports were necessary to determine the sample size of households and non-households in MSU. The two types of waste generators are household (HH) and non-household (NHH).

HH samples were drawn from residential and rental buildings in six barangays, while NHH samples came from commercial and institutional sources. The HH sample size was based on 2020 population projections from PhilAtlas. Using Krejcie and Morgan's (1970) formula for sample size determination, the required number of survey responses was calculated using this derived formula:

$$\text{Sample size} = \mathrm{X^2NP(1-P) + d^2(N-1) + X^2P(1-P)} \tag{1}$$

where X^2= the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841); N = population size; P = the population proportion; d = the degree of accuracy expressed as a proportion (0.05)

The survey required 154 HH units. For NHH, 276 registered businesses and data on 7,467 students in campus rentals were used to determine the sample. The study surveyed 216 units, consisting of 121 residential buildings, 55 rental properties, 16 commercial establishments, 7 dormitories, and 17 MSU buildings.

2.4 Research Instrument

This present study used a structured questionnaire that is composed of three parts, with the first part collecting the basic information about the respondents, the second assessing respondents' awareness of solid waste management, and the third part using a 'yes or no' and multiple Likert scale responses with added objective responses to collect the specific data needed for the assessment. The researchers also considered the local dialect ('Meranao') in the areas that had been conducted, especially in residential or community areas.

The questionnaire was reviewed and approved by MSU, the City Community General Services Office (CGSO), the City Environment and Natural Resources Office (CENRO), and local waste management personnel. To ensure the reliability of the research instrument, a pilot test involving 26 respondents was conducted in Barangay Cadayonan. Reliability was assessed using Cronbach's alpha to measure internal consistency.

The pilot test showed high reliability, particularly in Part III of the questionnaire (10 questions), with Cronbach's alpha value of 0.95, signifying an excellent level of reliability. The remaining components (Parts I and II), exhibited "acceptable" reliability, with alpha values surpassing 0.70. The average alpha of 0.81 denotes a commendable level of reliability. Consequently, no modifications were deemed necessary for the questionnaire.

2.5 Data Gathering Procedure

Data collection involved two groups: utility personnel from various MSU buildings and residents within campus communities. Interviews with utility personnel obtained data on daily waste generation from nine MSU dormitories and ten buildings. Field surveys employed structured questionnaires translated into the local dialect and disseminated house-to-house across residential, commercial, and educational buildings. The in-person survey approach was chosen to establish a personal connection with respondents, facilitating comprehensive data collection despite being time-consuming.

2.6 Data Analysis

SPSS Statistics software by IBM was utilized for qualitative and quantitative data analysis. Its user-friendly interface and efficiency in handling large datasets (IBM, SPSS Inc., 2022) made it a suitable tool for this study, offering in-depth analysis capabilities and faster processing times.

To determine the waste generation rate per person (per capita waste generation), the study utilized the formula:

$$\mathrm{PCG} = \frac{\text{weight of solid waste generated data household}}{\text{total number of person in the household}} \tag{2}$$

2.7 Ethical Considerations

This study followed strict ethical guidelines to protect MSU residents and constituents surveyed via questionnaires. Participation was voluntary, with respondents free to withdraw at any time. Informed consent was obtained, ensuring participants understood the study's purpose and procedures. Anonymity and confidentiality were maintained, and all efforts were made to minimize harm. The dignity and well-being of participants were prioritized, and data were kept confidential to ensure academic integrity. Proper result communication practices were followed to avoid plagiarism and research misconduct.

3.0 Results and Discussion

3.1 Demography of the Respondents

Figure 1 depicted a predominant participation of adult respondents who are self-employed/ entrepreneurs, professionals, college students, and a significant number of unemployed individuals. Among the 216 respondents, self-employed individuals, including entrepreneurs and business owners, constituted the majority, with 55 respondents. This group comprises adults and older adults, with minimal representation of adolescents. Following closely were students, accounting for 48 out of 216 respondents, largely composed of adults, with adolescents forming a minority within this category.

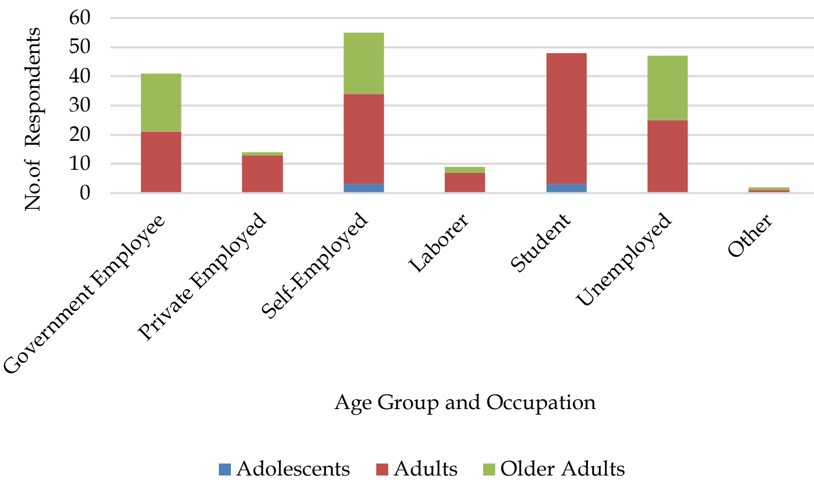

Figure 1. Age-occupation relationship of respondents

The concentration in self-employed and entrepreneurial roles suggests a vibrant economic activity within the community, likely generating waste related to business activities, such as packaging, office or school supplies, and general household/ establishment waste.

3.2 Composition of the Surveyed Buildings

Residential-type structures represent a significant portion of the survey at 56.02%, with rental properties following at 25.46% (see Figure 2). Conversely, MSU-owned buildings, such as administrative and support buildings and dormitories, constitute only 11.11% of the surveyed premises. This distribution explains the predominance of self-employed individuals and entrepreneurs among the respondents, many of whom are residents within the campus area, alongside a significant representation of students who primarily inhabit rental accommodations. The prevalence of residential structures and rental properties reflects a stable but somewhat mobile community, likely influenced by the needs of students and professionals.

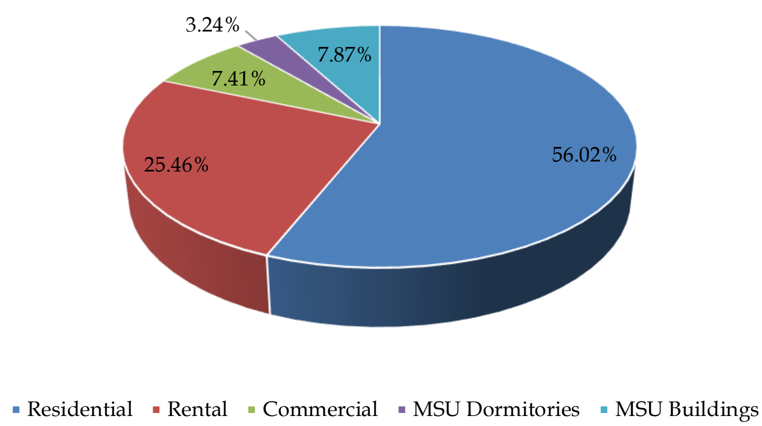

Figure 2. Composition of surveyed buildings

As shown in Figure 3, Barangay Dimaluna is the business and commercial district of MSU-Main Campus. It is the biggest barangay, so it accounted for 30% of the respondents, as shown in Figure 5. Barangay Cadayonan followed this at 20.48% and Barangay Cabingan at 14.29%. Barangays Lomidong, Bayeba-Damag, and Rapasun, primarily composed of residential and rental buildings, accounted for 13.81%, 10.95%, and 10.48% of the respondents, respectively. The distribution of respondents' locations supports the demographic findings, illustrating a community centered around educational and entrepreneurial activities.

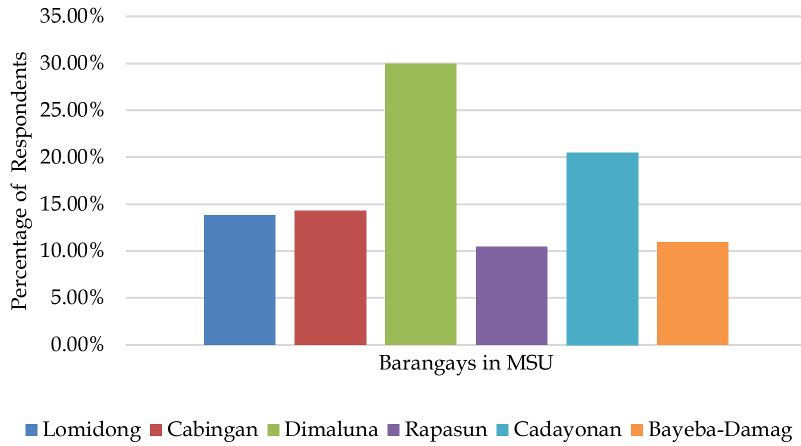

Figure 3. Location of Respondents

3.3 Waste Generation

Table 1 summarizes waste generation by building type across the MSU-Main Campus. The total waste generation is 66,066.08 kg/week (9,438.011 kg/day, 3,797.32 tons/year). The residential buildings were revealed to be the main waste generators in MSU, contributing 47.36% of waste, and it is estimated that every person generates 0.4438 kg/day of waste. Some residential buildings operate small home-based businesses, especially in Barangay Dimaluna. This is followed by lodgings like apartments, boarding houses, and cottages, which accommodate an estimated 7,467 MSU students, amounting to 35.39% of MSU waste with a PCG level of 0.3317 kg/day. The nine (9) MSU Dormitories, which house 1,622 students in School Year 2022-2023, are in third place, contributing 10.46% percent daily waste with a PCG of 0.0980 kg/day. At the fourth rank, commercial buildings, such as restaurants, markets, shops, and stores, produce 6.48% of waste with 0.0607 kg/day of waste per capita. Moreover, 0.9371 kg/day of waste per capita is generated at the MSU level. The remaining 0.31% constitutes the contribution from MSU academic, administrative, and support buildings, with a PCG level of 0.0980 kg/day.

Table 1. Waste generation by building type

Building Type	Generation			Percentage	PCG level (kg/day)
	kg/ week	kg/day	tons/year		
Residential	31,290.0	4,470.00	1,798.47	47.36%	0.4438
Lodgings	23,384.0	3,340.57	1,344.06	35.39%	0.3317
Commercial	4,278.00	611.143	245.890	6.480%	0.0607
MSU Dormitory	6,910.00	987.143	397.170	10.46%	0.0980
MSU Buildings	204.000	29.1543	11.7300	0.310%	0.0029
Total	**66,066.08**	**9,438.01**	**3,797.32**	**100.00%**	

The overall waste generation rate at MSU-Main Campus is alarmingly high at 0.9371 kg/day per capita, significantly higher than the 2010 national average of 0.40 kg/day but comparable to Metro Manila and highly urbanized cities (HUCs). Comparatively, the Baglung Municipality in Nepal reports municipal solid waste (MSW) generation rates in different settings of 0.43 kg per capita per day from households and 0.83 kg per day from institutions (Regmi, Ghimire, & Shrestha, 2021).

The significant presence of organic waste, particularly from residential buildings and lodgings in MSU, poses substantial challenges for solid waste management. In many countries, large quantities of solid waste, primarily organic, create major environmental issues such as flooding, pollution, and health impacts (Dharnaik and Pol, 2024). This situation is evident at MSU-Main Campus, where unsustainable waste management practices are prevalent, particularly in commercial and residential areas.

The comparative waste generation rates at other institutions in the Philippines highlight the distinct challenges at MSU. For instance, Caraga State University (CSU) generates 85.527 kg of waste per day with an average of 0.018 kg (Ciudad et al., 2022), significantly lower than the national average. Similarly, the University of Science and Technology of Southern Philippines shows a low waste generation rate of 126.01 kg over 12 days (Elayan et al., 2019). Misamis Oriental State College of Agriculture and Technology reports waste generation rates of 0.56 kg per capita per week in residential areas (Arazo, 2015), still lower than MSU's rate.

The significant difference in waste generation between MSU-Main Campus and other institutions can be attributed to the varied building types at MSU, including many residential, rental, institutional, and commercial buildings, making it comparable to a small town. Iojă et al. (2011) observed that the type of educational institution has a greater impact on waste generation than the number of students. The poor socio-economic conditions in Lanao del Sur, where 64% of the population lives in poverty (PSA, 2021), also exacerbate waste generation. Further studies reveal that socio-economic factors such as household income, education level, and local economic activity significantly influence waste generation and composition (Jou et al., 2024; Deshpande et al., 2024; Hidalgo et al., 2019). Lower-income households generate more waste, while higher education levels correlate with better recycling practices (Deshpande et al., 2024). The UNICEF Situation Analysis of Children in BARMM carried out in 2017 highlights that over 80% of children live in poverty, lacking access to basic rights, further compounding waste management challenges.

3.4 Waste Characterization

The analysis of waste composition at MSU-Main Campus reveals significant insights into the patterns and implications of waste generation across different building types, as detailed in Table 2. Residential buildings generate the highest amount of waste at 125,163 kg per month, comprising 43,844 kg of biodegradable waste, 46,929 kg of non-biodegradable waste, 23,340 kg of recyclables, and 11,049 kg of hazardous waste. Rental apartments follow with 93,536 kg per month, including 32,925 kg of biodegradable waste, 35,830 kg of non-biodegradable waste, 14,813 kg of recyclables, and 6,824 kg of hazardous waste. Commercial buildings contribute 17,112 kg per month, with 6,555 kg of biodegradable waste, 7,452 kg of non-biodegradable waste, 2,208 kg of recyclables, and 897 kg of hazardous waste. In total, these three building types generate 235,811 kg of waste monthly, with non-biodegradable waste (90,211 kg) making up the largest proportion at 38.58%, followed by biodegradable waste (83,324 kg) at 35.68%, recyclables (40,361 kg) at 17.48%, and hazardous waste (18,770 kg) at 8.26%.

Dormitories and MSU buildings collectively add 58,660 kg of waste per month. Dormitories contribute 27,640 kg, with 10,240 kg of biodegradable waste, 11,012 kg of non-biodegradable waste, 4,984 kg of recyclables, and 1,404 kg of hazardous waste. MSU buildings add 31,020 kg, including 10,850 kg of biodegradable waste, 11,517 kg of non-biodegradable waste, 7,448 kg of recyclables, and 1,204 kg of hazardous waste. Combined, these categories contribute 21,090 kg of biodegradable waste (35.95%), 22,529 kg of non-biodegradable waste (38.41%), 12,432 kg of recyclables (21.19%), and 2,608 kg of hazardous waste (4.45%).

Table 2. Final estimated weight of garbage collected each month

Building	Estimated waste	Types of Waste (kg)			
		Biodegradable	**Non-Biodegradable**	**Recyclables**	**Hazardous**
1. Residential	125,163	43,844	46,929	23,340	11,049
2. Rental	93,536	32,925	35,830	14,813	6,824
3. Commercial	17,112	6,555	7,452	2,208	897
Total$_{1\text{-}3}$	**235,811**	**83,324**	**90,211**	**40,361**	**18,770**
Percentage$_{1\text{-}3}$ *(%)*		35.68	38.58	17.48	8.26
4. Dormitory	27,640	10,240	11,012	4,984	1,404
5. MSU Bldg	31,020	10,850	11,517	7,448	1,204
Total$_{4\text{-}5}$	**58,660**	**21,090**	**22,529**	**12,432**	**2,608**
Percentage$_{4\text{-}5}$ *(%)*		35.95	38.41	21.19	4.45
Total$_{1\text{-}5}$	**294,471**	**104,414**	**112,740**	**52,793**	**21,378**
Percentage$_{1\text{-}5}$ *(%)*		35.46%	38.29%	17.92%	7.26%

Overall, the campus generates a total of 294,471 kg of waste per month, comprising 104,414 kg of biodegradable waste (35.46%), 112,740 kg of non-biodegradable waste (38.29%), 52,793 kg of recyclables (17.92%), and 21,378 kg of hazardous waste (7.26%).

Figure 4 shows the composition of solid waste in MSU-Main Campus, where plastics comprise the largest portion at 37.45%, followed by paper (20.38%) and food waste (20.14%). This finding aligns with the Waste Analysis and Characterization Study (WACS) in Ampayon, Butuan City, which reported a similar concentration of plastics at 39.50% in institutional areas. Comparable trends are observed at CSU, where plastics constitute 46% of waste (Ciudad et al., 2022), and at USTP, with a plastic concentration of 45.93% (Elayan et al., 2019). The prevalence of these three waste types can be attributed to the campus's residential, academic, food, and commercial establishments, where the convenience of packaged foods, school and office supplies, and other goods often leads to increased plastic use. This explains the massive presence of plastic on campus. Unfortunately, the high percentage of plastics is particularly concerning due to their non-biodegradable nature, which can take over 400 years to decompose, releasing toxins that contaminate water sources and harm ecosystems (Sampson, 2021). Additionally, only 17.92% of the waste stream is recycled, exacerbating the environmental impact of non-biodegradable waste on the MSU-Main Campus, which, according to Alhazmi et al. (2021), non-biodegradable waste poses problems both on land and in the seas.

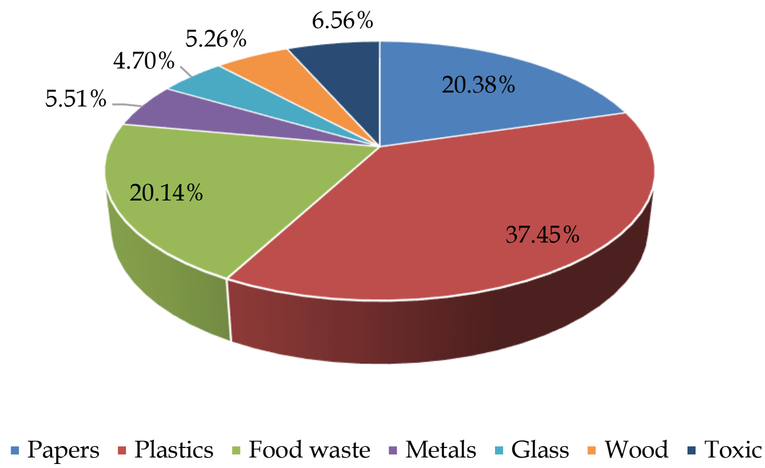

Figure 4. Solid waste composition at MSU-Main Campus

In the institutional areas, plastic/cellophane waste was the most abundant, obtaining a 39.50% concentration, followed by plastic bottles and other plastic types of waste. Biodegradable waste on the MSU-Main Campus comprises 20.14% food waste, 20.38% paper, and 5.26% wood. It may include kitchen, animal dung, and agricultural waste (Bharadwaj et al., 2015). Popoola (2022) explains that these materials break down naturally due to factors like bacteria, fungi, temperature, oxygen, and humidity, turning into simpler organic compounds that integrate into the soil with minimal environmental risks. Biodegradable waste includes green waste like food, paper, and biodegradable plastics. Other examples are sewage, manure, sewage sludge, human waste, and waste from slaughterhouses and hospitals; all establishments can be found on the MSU-Main Campus.

Hazardous waste, although constituting a smaller portion at 6.56%, includes household cleaning agents, pesticides, and e-waste, such as broken electronics and defective devices. The US Environmental Protection Agency (EPA) highlights the detrimental effects of hazardous waste, including its potential to kill organisms in water bodies, destroy plant and animal life in contaminated areas, and cause reproductive complications in animals. These wastes are particularly dangerous to human health and the environment due to their ignitability, corrosivity, reactivity, toxicity, and persistence (Abul Hasan et al., 2018; Bharadwaj, Yadav, & Varshney, 2015). While e-waste, including laptops, mobile phones, and electronic and mechanical parts, is also rapidly growing on the MSU-Main campus, Zhang et al. (2022) highlight the necessity of proper disposal protocols for e-waste management are crucial to prevent hazardous impacts.

Waste generation is an inevitable consequence of domestic and industrial activities, often having little or no alternative use. Ineffective waste disposal systems pose significant environmental and human health challenges (Popoola, 2022). Therefore, effective solid waste management (SWM) is crucial for mitigating adverse health and environmental impacts, conserving resources, and enhancing urban livability (Abubakar et al., 2022). The findings from MSU-Main Campus underscore the urgency for improved waste management practices to address the environmental implications of different waste types.

4.0 Conclusion

The study on solid waste generation and characterization at Mindanao State University-Main Campus, Marawi City, provides crucial insights into the waste management dynamics within the university. The research determined that the campus generates an average of 9438.011 kg (10.4 tons) of solid waste daily. Of this total, 47.36% originates from residential buildings, 35.39% from lodgings, 10.46% from MSU dormitories, and only 0.31% from academic and administrative buildings. This indicates that accommodation-related facilities are the primary contributors to waste generation on campus.

The waste composition includes approximately 35.46% biodegradable materials, 38.29% non-biodegradable waste, 17.92% recyclables, and 7.26% hazardous waste. Notably, the per capita generation (PCG) level at the university was calculated at 0.9371 kg per person per day, a figure significantly higher than the national average of 0.40 kg/day reported in 2010 but comparable to levels observed in Metro Manila and other highly urbanized cities (HUCs). The waste characterization data highlighted that plastics are the most prevalent, constituting 37.45% of the total waste, followed by paper and food waste, each accounting for 20%. The current absence of proper solid waste management practices means these plastics often end up in creeks or roadside, exacerbating environmental concerns.

These findings suggest a critical need for enhanced recycling facilities and composting systems to effectively manage these dominant waste streams. By implementing these measures, the university could potentially divert its waste from landfills, significantly reducing its environmental impact. Future research should focus on the behavioral aspects of waste disposal among students, faculty, and staff, which could provide deeper insights into optimizing waste segregation and promoting environmental sustainability on campus. This study is vital for improving waste management practices and fostering a more sustainable university environment.

5.0 Contributions of Authors

Merhanna D. Pangandaman – revision, editing, writing, supervising, data analysis
Josua Meko B. Acabal – writing or encoding, research assistant
Cesar B. Anino Jr. – writing or encoding, field assistant
Gerald D. Apat – writing or encoding, field assistant

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7.0 Conflict of Interests

The authors declare no conflicts of interest about the publication of this paper.

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