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Characterization of Waste Generated by Households in the Poblacion of Irosin, Sorsogon: A Case Study

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Abstract

Improper solid waste management is a common concern for developing municipalities in the Philippines like Irosin, Sorsogon. However, addressing this problem requires informed decisions that cannot be made without current information on the generation of solid waste. Recognizing this information gap, the researchers conducted a waste analysis and characterization study to determine the per capita waste generation rate and the composition of waste generated by the population. The study found that the population's per capita waste generation rate is 0.331 kgs/day, consisting of 62.52% biodegradable, 23.51% residuals, 9.56% recyclable and 4.41% special waste. The researcher also found that a significant portion of the total waste collected per day (72.09%) could be diverted. Population projections also indicate that the daily waste generation per capita could increase by 139.95 kg / day by 2033. Based on these findings, the study recommends ways in which the local government can handle concerns about solid waste management. The results indicate that the local government should focus on waste separation at the source and waste diversion to alleviate the municipality's waste problems. Decentralized composting and private-public partnerships were among the recommendations made.

Keywords— domestic waste, municipal solid waste, waste classification, waste management

1 Introduction

The Philippines, like other developing countries with a large population, faces a persistent problem with solid waste management (SWM), which only worsens as urbanization intensifies. According to a 2023 Commission on Audit report [1], the nation's population of over 100 million people generates around 16.63 metric tons of waste per year. In general, the largest contributors to the total waste generated by municipalities are household sources, which account for 55-80% of the total [2]. Factors influencing waste generation and composition in the domestic sector are population growth, culture, quality of education, household income range, industry type in the locale, technology, climate, and geography [3, 4, 5, 6, 7]. These results in significant variability between each site, which, in addition to some local governments' limited financial and logistical capacity, make it challenging to develop effective SWM strategies that address localized concerns. The Ecological Solid Waste Management Act of 2000, or R.A. 9003 [8], outlines the responsibilities and services that local governments must provide for SWM. Still, compliance with the policy remained lackluster for most municipalities [1, 9]. The challenges usually faced by local governments in the Philippines are increasing amounts of solid waste generated by the growing population, scarcity of sanitary landfills, improper disposal of solid waste, and weak law implementation [10]. Therefore, there is a need to strategize allocating resources toward SWM goals by relying on localized data collection.

A Waste Analysis and Characterization Study (WACS) is a study that seeks to determine the average waste generation rate of a locale first in terms of aggregate total and then per waste type category [11]. Policymakers then use data from this study to design tailored interventions for SWM concerns. Conducting a WACS is a critical component of formulating a Municipal Solid Waste Management Plan (MSWMP), which should be updated every five (5) years. However, independent studies have also been conducted either as a standalone or as a part of a larger study. In 2019, Lunag et al. [12] conducted a WACS for Baguio City, a highly urbanized city in the Cordillera Administrative Region of the Philippines. Their study included households and non-households, formulating a comprehensive waste characterization of the entire city. On the other hand, Breva [13] conducted WACS for the 4th-class municipality of Magsaysay in Misamis Oriental. The study featured households and non-households in their data collection, aiming for a comprehensive overview of their municipality's solid waste generation patterns. Both studies follow a similar methodology, viewing the SWM situation of their respective locales at a macro-level, albeit with different sample sizes.

This study also follows a similar methodology but narrows the scope to the characteristics of waste generated by households, discussing potential factors that influence the waste generation pattern and providing an overview of the ongoing and planned efforts made by the local government of Irosin to address their SWM concerns. In doing so, the study sought to contribute to the larger understanding of household waste generation by using the municipality as a case example of the state of solid waste management on the municipal level. In addition, since WACS follows a standard methodology, it may also serve as a reference for longitudinal studies or WACS that the local government of Irosin will conduct in the future. Figure 1 illustrates the relationship between different variables in this study.

Overall, the core aim of this study was to help enhance the municipal solid waste management policies of Irosin by equipping local policymakers with foundational data that may be used for evidence-based interventions. Specifically, this study sought to:

- determine the per capita waste generation rate of the household population of the Poblacion area in Irosin, Sorsogon;
- derive the percent (%) composition of waste generated in terms of four distinct waste categories (biodegradable, residual, recyclables, and special waste);
- calculate the percentage of waste collected that may be divertible and suggest options for waste diversion; and
- project the 10-year per capita waste generation rate relative to the population growth rate.

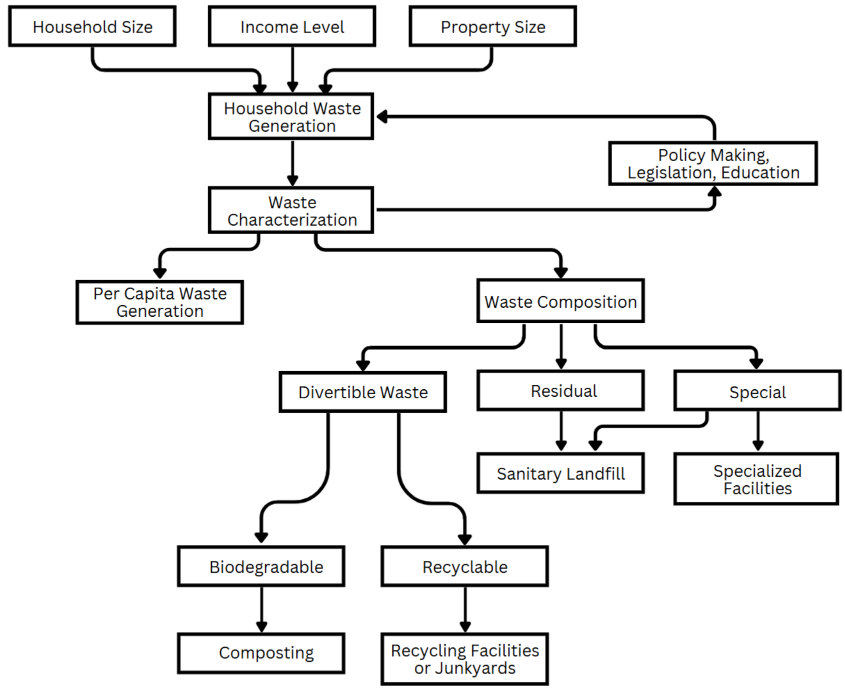

Figure 1.
Conceptual Framework of the Study

2 Methodology

2.1 Research Design

The Waste Analysis and Characterization Study (WACS) manual [11] of the Department of Environment and Natural Resources was used as the primary guide for conducting this study. The methodology of the studies conducted by Lunag et al. [12] and Breva [13] were also used as a reference, particularly with how they chose to get their samples only from barangays that the waste collection system of their respective study areas cover, and the formula for determining the average per capita waste of households. The study uses a quantitative data collection method by retrieving waste from sample households for measurement purposes.

The researcher collaborated closely with the Local Government Unit (LGU) of Irosin, notably the Municipal Environment and Natural Resources Office (MENRO). Helpers, equipment, facilities, and a vehicle for transporting waste were provided for the study.

2.2 Study Area

Irosin is a 2nd class valley-town municipality in the province of Sorsogon with a population of 59,267 as of the 2020 census [14], projected to reach around 60,398 by 2023. It is the only landlocked municipality in the province, surrounded by mountains on all sides. It has a total land area of 15,880 hectares (158.8 km) divided into 28 barangays. Alienable & disposable land comprise 93% of the total land area, with forests comprising 7%. The local economy is predominantly driven by agriculture, benefiting from fertile volcanic soil due to its proximity to Mt. Bulusan and its inland location, which lacks direct access to the sea compared to its neighbors. For this reason, it is usually dubbed the Rice Granary of Sorsogon. Furthermore, its ideal location at the center of a network of towns in the southern tip of the province has also contributed to its economic growth, attracting large franchise retail and wholesale establishments.

For this study, the term "Poblacion" will refer to the town center of Irosin, consisting (but not the entire extent) of five barangays, namely San Pedro, San Julian, San Juan, Bacolod, and San Agustin (Figure 2). This area was chosen for the study because it is the most densely populated in the municipality and is regularly serviced by waste collection – both of which will be relevant in further discussions in this paper. It is also where most of the economic activity in the municipality occurs. The projected population of these five barangays from 2021 to 2023 is also presented in Table 1

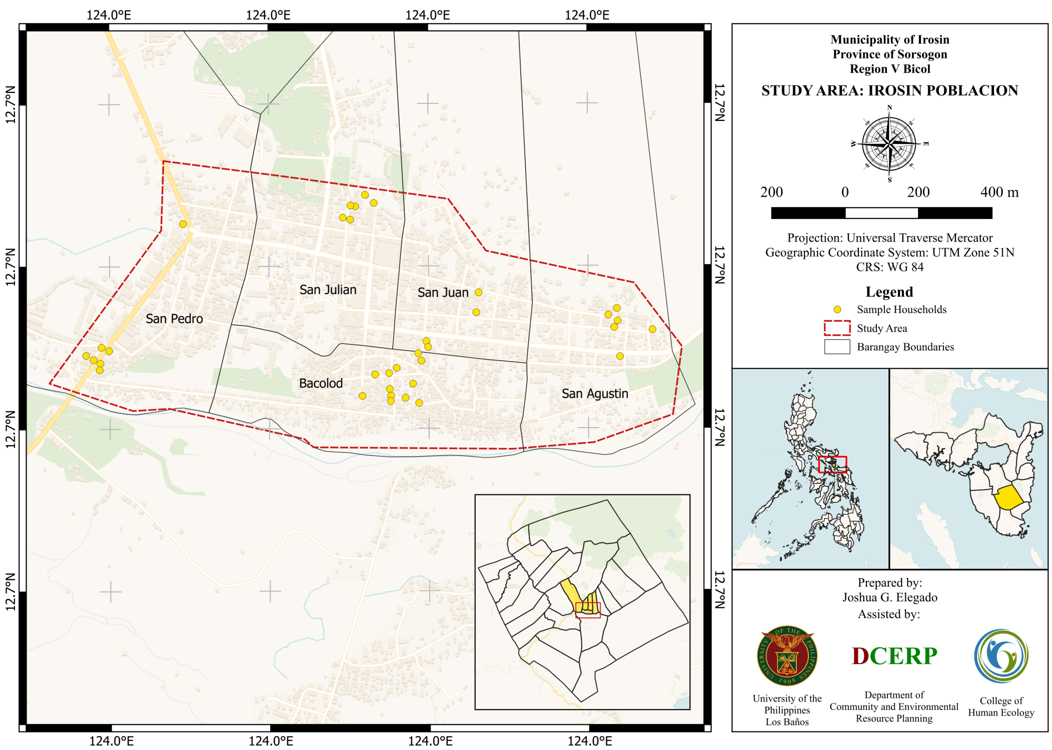

Figure 2.
The combined portions of the five barangays that make up the Irosin Poblacion (red)

Table 1. Projected Population of the Poblacion

Irosin Poblacion	Base Pop. (PSA, 2020)	Participation Rate	Projected Population		
			2021	2022	2023
TOTAL	14620	1	14670	14719	14770
Bacolod	4645	0.318	4661	4676	4693
San Agustin	2334	0.160	2342	2350	2358
San Juan	2101	0.144	2108	2115	2123
San Julian	2273	0.155	2281	2288	2296
San Pedro	3267	0.223	3278	3289	3301

The municipality has experienced growth over the years with an increase in the number and diversity of commercial activities in the Poblacion and an increase in population from both its native population and migrants from nearby towns. However, local solid waste management services have struggled to keep up with the output of rapid urbanization. As a result, many of the guidelines set by RA 9003 for municipalities have not been met. Particularly, the municipality lacks access to a local sanitary landfill – its local controlled dumpsite shut down in 2022 due to overcapacity – and instead relies on transporting collected waste to a contracted accredited sanitary landfill operated by the IWA BESU Corporation in Daraga, Albay – around three (3) hours away from the municipality. According to the then chairperson of the Municipal Environment and Natural Resources Office, this costs the local government around P6,535,491.30 annually, not including oil and lubricants, personnel wages, and vehicle maintenance. Other issues that were mentioned in the draft Municipal Solid Waste Management Plan (MSWMP) from 2020 to 2030 were the continued use of single-use plastics, reduction in backyard composting practices, and solid waste management programs heavily focused on the LGU and having little involvement with the barangay level [15].

The issues cited above are not exclusive to Irosin. Since the law's enactment, studies have been conducted to evaluate the number of municipalities that comply with RA 9003 [10, 16]. These studies identified recurring issues, such as the absence of sanitary landfills, underutilization of MRFs, and lack of source separation, all linked to limited financial and technical resources. Furthermore, national policies on solid waste management varied even in complying municipalities, implying that distinct limiting factors in each municipality influenced policy implementation strategies [9]. Effective enforcement of SWM strategies that comply with RA 9003 remains difficult for most municipalities because it extends far beyond collection and disposal. Coupled with the public not being sufficiently informed about the adverse effects of careless disposal practices, it quickly weakens efforts to enforce policies [17].

2.3 Sampling Method

The study referred to the WACS manual by the DENR on Household sampling and selection [11]. According to the manual, the recommended total sample size for small to medium-sized LGUs was 30 at the very least. Though there was the option to opt for a stratified sampling method, it was ultimately decided to go for the manual's suggestion given the limited number of helpers (collectors, sorters, etc.) and resources available to the researcher and the urgency of sorting and weighing the waste as soon as they are collected.

Several criteria were stated in the manual for choosing the participants. This was to limit the variability of the waste collected from the sample. These include:

1. The household may only have 4-6 regular members. Household membership is an important criterion in the WACS as it connotes the expected per person average waste accumulation and, at the same time, the household waste volume. If members of the family are more than the usual average, then results may be skewed and may not reflect the reality in the locality
2. The household may not be engaged in home-based businesses that increase waste generation. As the study focuses on household wastes, carefully selecting participants will be necessary to analyze waste production at the household level properly.
3. The household was willing to cooperate with the study; and
4. There were no significant events in the household (birthdays, weddings, fiesta) at the time of the actual WACS.

A total of 35 households fit the criteria above and agreed to participate in the study. This clears the minimum requirement stated in the WACS manual utilized by a Breva [13] for a medium-sized LGU like Irosin. The total was subdivided into different income ranges and barangays based on their participation rate in the total population of the Poblacion; seven (7) participants were from Brgy. San Pedro, six (6) from Brgy. San Julian, twelve (12) from Brgy. Bacolod, four (4) from Brgy. San Juan, and six (6) from Brgy. San Agustin. This is presented in Table 2. Considering these criteria and quotas, the researcher used quota sampling when looking for participating households.

Table 2. Number of Households per Barangay

Barangay	Income Level			TOTAL
	Low	Middle	High	
San Pedro	3	4	0	7
San Julian	3	3	0	6
San Juan	1	2	1	4
Bacolod	7	5	0	12
San Agustin	4	2	0	6
TOTAL	**18**	**16**	**1**	**35**

2.4 Technical Working Group

A technical working group (TWG) consisting of four select staff members under the Municipal Environment and Natural Resources Office (MENRO) of Irosin was created to assist the researcher in conducting the study, particularly in approaching candidate households to request their participation and all activities under the data collection period. Two were tasked to accompany the researcher in locating, approaching, and orienting prospective respondents throughout the study area. Meanwhile, the other two members of the TWG assisted the researcher in collecting the waste bags from each household daily during the Actual WACS period. One drove the utility vehicle carrying the waste bags to the sorting facility, while the other joined the researcher in going house to house to collect the waste bags.

2.5 Participant Orientation and Profiling

Qualified households were determined and approached by the TWG with assistance from a representative from the respective barangay. These households were briefed regarding the study's purpose and their role should they agree to participate. Socio-demographic data such as household size and income level were obtained to verify their qualifications and contact information for the communication of data-gathering plans. They were also asked if they had the time to attend an in-depth orientation in the Irosin municipal building conference hall. It was imperative to let the participants know there was no need to change their daily habits during the study period to yield the most accurate results.

Orientations in the Irosin municipal building were held twice before the actual WACS. They were given instructions on how to segregate their waste and have it ready by the morning following the start of actual WACS. They were also advised not to do general cleaning over the period and to place the waste bags provided to them in a dry area as it was rainy at the time. Before the WACS date, they were given six waste bags to use specifically for the study period, two for each day to segregate the waste between biodegradable and non-biodegradable. Those who were unable to attend the orientation were given the waste bags in their homes the day before the Actual WACS instead. This was done in sync with a trial of the waste collection route with TWG Group B, which was planned for the activity.

2.6 Actual WACS

WACS aims to determine the waste generation characteristics of a target population in an average time. Therefore, it was imperative to schedule the date for the actual WACS outside of any holidays or significant events that may influence the amount of household waste. According to the WACS manual [11], there may only be three days of WACS necessary, as long as it includes one regular weekday, a weekend, and a market day. As the weekends are also when the households of Irosin would buy their groceries from the market, it was decided that the weekend day and the market day would be the same, and an additional weekday was added instead. After confirming with the MENRO, the dates of the 16th (Thursday), 17th (Friday), and 19th (Sunday) of November 2023 were selected as the actual WACS date.

The wastes from each WACS day were collected by TWG Group B, and the researcher only collected them after 24 hours had elapsed so as to represent the waste generated by the household in an entire day. Therefore, waste generated on the 16th would be collected on the morning of the 17th until all wastes from the three Actual WACS dates were collected. Since members of the TWG were government employees, a special agreement had to be made between them and the researcher to work on Saturday to collect the waste from the previous WACS day (Friday the 17th) in exchange for monetary compensation. However, this agreement could not be made for the following day, which is why there is a gap of one day (Saturday the 18th) in the Actual WACS period.

A small transport vehicle was utilized and driven by one of the members of TWG Group B to collect the wastes from all sample households in one trip. Each pair of waste bags was tagged by the researcher and the other member of TWG Group B upon collection for identification, and then all were sent to the disposal facility in the Eco-Zoo Park for sorting and weighing. Four classifications of waste from the WACS manual were utilized in this study. Biodegradables refer to those that will decompose naturally, such as food waste, yard trimmings, and wet paper. Recyclables are uncontaminated wastes that can be repurposed, including polyethylene terephthalate (PET), glass bottles, tin cans, and dry paper. Residuals are difficult or impossible to reuse wastes and would most likely end up in landfills such as plastic wrappers, sando bags, and styrofoam. Lastly, special wastes refer to household toxic wastes (insecticides, disinfectants, spent cell batteries), white goods (appliances and electronics), and bulky waste (furniture and miscellaneous debris).

2.7 Measurement of Collected Waste Samples

A sorting site was prepared before the WACS period to receive the waste collected from the samples. At the end of each day of data collection, each tagged bag was emptied and weighed by the two TWG Group B members and recorded by the researcher utilizing a sample-by-sample characterization approach. The calibrated pails were used to expedite measuring the weight of collected samples by serving as receptacles. The researcher used a WACS field data entry form to standardize the data documentation. Every pair of waste bags from each sample household was weighed together to get their total weight, then their contents were scattered and sorted into separate piles according to their waste type on a tarpaulin mat. Then, each pile was weighed before being put into segregated sacks for final disposal.

The average per capita generation and the percent composition of waste generation are calculated using Equations 1 and 2

$$PerCapitaGeneration = \frac{AverageWasteGeneratedperHousehold}{AverageHouseholdSize} \tag{1}$$

$$PercentComposition = \frac{y}{x} * 100 \tag{2}$$

where y is the total amount in kgs of waste for a specific waste type, and x is the total amount in kilograms of all waste types [13].

The per capita waste generation was then multiplied by the projected population of the *Poblacion* and the municipality for the year 2023 to find the estimated waste generation rate per day of the entire population. A brief report summarizing the results of a WACS conducted in 2017 was obtained from the MENRO and was used as a reference for comparing the results of this study [18].

3 Results and Discussion

3.1 Per Capita Waste Generation

The results of the 3-day WACS are presented in Table 3, which features a breakdown of all waste collected from source households in the Poblacion. With an average sample household size of 5 residents per household, it was found that the per capita waste generation per day was 0.331 kgs at source. Compared to the per capita waste generation rate from the 2017 WACS (0.335 kgs), a decrease of 0.04 kgs (4 grams) can be observed. It is also lower than the national average of 0.4 kgs/day derived from a report by the Commission of Audit [1] in 2023.

A point of comparison can also be drawn from the two WACS examples from other municipalities in the Philippines presented in the earlier chapters. As with the case of Lunag et al. [12], their study found that the residential population of the highly urbanized Baguio City had a per capita waste generation rate of 0.4193 kg/day. In contrast, Breva observed a lower per capita waste generation rate of 0.21 kg/day in Magsaysay, Misamis Oriental, a fourth-class municipality. Irosin's 0.331 kgs/day would then fall between these two findings. This suggests a potential correlation between a municipality's income class and its average waste per capita waste generation rate.

Table 3. Per Capita Waste Generation Rate of Sample Households

	Weight per Category (in kg)				Total (in kg)
WACS DAY	**Biodegradable**	**Recyclable**	**Residual**	**Special**	
Mid-Week	43.780	8.400	15.100	2.890	70.170
End-of-Weekday	16.950	3.900	8.200	4.560	33.610
Weekend	47.800	4.300	17.500	0.200	69.800
Total	108.530	16.600	40.800	7.650	173.580
Mean/day (All sample HH)	36.177	5.533	13.600	2.550	57.860
Mean/day (One HH)	1.034	0.158	0.389	0.073	1.653
Mean/day (Per Capita)	0.207	0.032	0.078	0.015	**0.331**

San Agustin is the barangay with the most significant contribution to the total waste generated over the entire WACS period in terms of total weight in kgs. Even though it has half the sample household representation of the second greatest contributor, Bacolod – six to twelve, respectively. The third largest contributor is Barangay San Pedro. Meanwhile, San Juan generated the least waste out of the five. This is presented in Table 4, which features the breakdown of the total waste generated per barangay. The large amount of waste generated by Barangay San Agustin could be attributed to the larger lot sizes of the sample households. Properties with yards and open spaces typically feature gardens, trees, and other vegetation, leading to increased biodegradable waste generation. This is reflected in the same table wherein biodegradable waste contributed the most to the waste generation from San Agustin. This may also explain why Bacolod wasn't the greatest contributor, as properties in this Barangay are smaller and tightly packed. San Juan has the least could be attributed to the smaller number of samples and property size from that barangay.

The slight decrease in the per capita waste generation rate implies that there has been no noticeable difference in the waste generation patterns of the population of Poblacion over the years between the two WACS. However, there are some nuances to this comparison. First is that

Table 4. Waste Collected from Each Barangay Over the Entire WACS Period

Barangay	Biodegradable	Recyclable	Residual	Special	TOTAL
San Pedro	21.47	3.77	7.59	0.8	33.63
San Julian	13.84	2.36	4.59	0.2	20.99
Bacolod	26.96	3.05	11.97	5.39	47.37
San Juan	8.24	1.7	2.78	0.05	12.77
San Agustin	38.02	5.72	13.87	1.2	58.81
TOTAL	108.53	16.6	40.8	7.64	173.57

there is a significant difference in the number of cooperators between the two studies (133 to 35, respectively). The study area for the 2017 WACS includes all of the places that the waste collection service covers, which provides for more rural areas, whereas the present study focused more on the Poblacion. Nevertheless, the close similarity between the findings of both studies regarding the daily per capita amount of waste generated lays credence to the recommendations of the WACS manual regarding the number of cooperators required for the study.

By taking the daily per capita waste generation rate above and multiplying it with the projected population of the five barangays of the *Poblacion* in the year 2023, the amount of waste generated per day by the total population of the *Poblacion* was derived. It was found that with a population of 14,770, the total waste generated was estimated to be around 4,883.38 kgs/day. When the exact computation is applied to the population projection of the entire municipality of Irosin in 2023 – which is 60,398 – the total is around 19,969.270 kgs (Table 5). This is an increase of 315.27 kgs per day compared to the findings of the 2017 WACS. When computed, the Poblacion accounts for 24.45% of the waste generated by the municipality. These estimations bear nuance, however, as the current study's focus on the Poblacion does not adequately consider the variability in waste generation between urban and rural barangays.

Table 5. Percent Composition to Total Per Capita Waste Generation by Waste Type

	Poblacion	Municipality
Population at Year 2023	**14770**	**60398**
Waste Type	**Amount (in kgs)**	
Biodegradable	3,053.31	12487.716
Recyclable	467.01	1909.724
Residual	1,147.84	4693.770
Special	215.22	880.059
Total	**4,883.38**	**19969.270**

3.2 Composition of Waste Generated

The waste collected from the households was classified into four different categories, as stated in the WACS manual [11]. **Biodegradables** refer to wastes that can decompose naturally in a relatively short time. These include food waste, yard trimmings, and wet paper. **Recyclables** are wastes free from contamination and can be repurposed into other materials such as polyethylene terephthalate (PET) bottles, dry paper, cartons, etc. **Residuals**, on the other hand, are wastes that take a considerably long time, from hundreds to thousands of years, to decompose naturally. These include tattered textile, paper and other packaging materials; laminates and composite materials like tetra packs; thin film single-use plastics like sando bags; food and candy wrappers; broken or contaminated ceramics; and used sanitary napkins or diapers. The last classification is **special waste**, which refers to either bulky or hazardous wastes. Household chemicals, appliances, and broken electronics fall into this category.

The distribution of daily waste generated in percentage (%) among different waste types per capita is presented in Table 6. Biodegradable waste was the major waste type collected, accounting for 62.52% of the total waste generated. It is followed by residual waste at 23.51%. Recyclable waste, on the other hand, constituted only 9.56%. Lastly, special waste comprised the least of the total waste collected at just 4.41%. The table also shows the estimated proportion of kgs of waste produced per waste type. This was done by multiplying the total estimated waste generated by the projected total population of the Municipality by the year 2023.

Comparing these results with those of Lunag et al. [12] and Breva [13], some similarities can be observed. In all three WACS, biodegradable waste consistently accounts for the most significant proportion of all waste types. However, the same does not hold for the second largest contributor, as both reference studies identified recyclables, rather than residuals, as the predominant category. Special waste, meanwhile, was the lowest contributor in all studies. These similarities suggest a common trend of biodegradable waste being a dominant contributor to the waste stream across different contexts.

Table 6. Percent Composition to Total Per Capita Waste Generation by Waste Type

Waste Type	Amount in kgs	% Composition	Projected Amount in kgs produced by Mun. Pop.
Biodegradable	0.207	62.53	12486.40
Recyclable	0.032	9.56	1909.83
Residual	0.078	23.51	4694.05
Special	0.015	4.40	878.98
Total	0.331	100	19969.27

The large percentage of biodegradable and residual wastes in the total waste generated indicates which category of waste the LGU of Irosin should pay attention to when designing its solid waste management strategies. As these types of waste take up most of the total waste generated by the average individual, the LGU should consider ways to either reduce the amount of waste generated or divert it from landfills or the waste stream altogether. Two common ways of diverting biodegradable waste from landfills are incineration and composting. The first option does not apply to Irosin because of Republic Act No. 8749 or the "Philippine Clean Air Act of 1999" which prohibits the act of incineration for treating municipal waste [19]. Therefore, Irosin only utilizes composting through a dedicated facility in its disposal site. There are Materials Recycling Facilities (MRFs) in almost every barangay in the municipality, but they are mostly utilized for storage. There are no recycling facilities in Irosin and collected recyclable wastes are sold to private companies that operate in the municipality.

Comparing these results to the previous WACS conducted in Irosin in 2017 shows a considerable difference in the percent shares of the different waste types to the total amount generated per day, except residual wastes, which appears to have remained mostly the same in both studies. This is presented in Table 7. The side-by-side comparison shows that in both WACS, biodegradable wastes come out on top as a major contributor to the total amount of waste generated by the population in terms of weight in kgs, and the trend suggests that it is likely to increase in the future. Another notable point is that recyclable wastes have decreased significantly while special wastes have increased. On the other hand, residual wastes had nearly the same percentage share as they did in the past.

3.3 Waste for Diversion

The sum of all biodegradable and recyclable wastes generated per day by the population of the Poblacion provides the total amount of waste that has the potential to be diverted from the landfill or the waste stream. Table 7 shows that as much as 72.09% or approximately 3,520.32 kgs of waste generated can be diverted. That figure may also represent the amount of excess waste that ends up in the landfill, assuming there is no proper separation of wastes at source (households) and upon collection. Ergo, the lack of proper waste separation conflates the amount of waste that the waste collection and disposal system has to accommodate, increasing the demand for resources in the sector. With this in mind, the LGU should consider ways to promote waste separation and strategies to repurpose the divertible wastes generated by the population.

Table 7. Potential for waste diversion

Waste Type	Amount (in kgs/day)	Percentage (%)
All Types	4,883.38	100.00
Biodegradable	3,053.31	62.52
Recyclable	467.01	9.56
Total (For Diversion)	3,520.32	72.09

There were attempts by several developed countries to bring waste-to-energy technologies to the Philippines [17, 20]. Still, since many of these involved incineration, these projects would have conflicted with RA 8749 [21], which left municipalities like Irosin with limited options besides composting for diverting biodegradable waste. One promising alternative waste diversion strategy the local government could explore that complies with existing laws is the production of Refuse-derived Fuels (RDF). This process converts waste into fuel alternatives in the form of pellets or gasses [22, 23, 24]. Though this would require specialized technologies, there is potential for promoting a circular economy through this method [25], as there have been successes with the use of RDF in other industries such as cement production [26].

As for recyclable wastes, one of the interventions for diverting waste proposed in the draft MSWMP was the Eco-Savers Program, a program in which students from public schools within the municipality will be encouraged to bring recyclable waste from their households and exchange them for points which can then be used to redeem school supplies at a later date [18]. The waste collected will be sold to recycling facilities or junk shops to generate funds for the program. This was based on a project of a similar name implemented in some parts of Marikina, Metro Manila, in the past, but there is little information on how effective it was. Nevertheless, school-based SWM strategies remain common because these institutions generate significant waste (paper, cardboard, etc) [10]. A similar program was implemented in Sta. Cruz, Laguna, but instead of redeemable rewards, funds were used to provide financial assistance to select beneficiaries – typically those in senior high school or college with good standing but limited financial resources [27]. A study conducted by Velasco et al. [27] found that the program encountered a few challenges, particularly some grievances by beneficiaries, difficulty in applying, and low engagement by the population. However, the study also emphasized several positive social, economic, and environmental benefits, indicating that similar SWM strategies could yield success with close participation of stakeholders and efficient information dissemination.

Eco-bricks may also be a viable waste diversion strategy that the local government could explore. There are two common approaches to this process: one involves filling Polyethylene Terephthalate (PET) containers with shredded plastics [28], while the other incorporates shredded plastics as additives in cement bricks [29]. Both variations may be used for non-load-bearing structures like pavements or partition walls. The sale of these eco-bricks has the potential to be an additional source of income for the municipality that could help subsidize the costs of SWM in addition to diverting waste from landfills.

To minimize the costs associated with proper SWM and to create opportunities for income generation and job creation, it is highly suggested that the local government adopt an integrated solid waste management program that assigns roles and responsibilities to various stakeholders beyond just the agencies involved in collecting and disposing of solid waste. SWM is a complex, multi-dimensional issue shaped by social, political, economic, and environmental factors [30]. Policymakers may look towards investing in integrated waste management technologies, the feasibility of which may be studied as with the case of Bay, Laguna, in a study conducted by Langit et al. [31]. A good start could be improving current MRFs to be more functional and marketable to attract businesses or entrepreneurs that specialize in recycling [32]. They may also try waste valorization as a supplementary strategy, which involves more complex means of converting waste into valuable products [10].

3.4 10-Year Waste Projection

A waste projection helps determine the estimated amount of waste that will be generated in the future [33]. The WACS process is used to compare different future scenarios considering the growth of the population and planned interventions or lack thereof. This was done by taking a population projection in the next five years (2024-2028) and exactly 10 years from the year the study was conducted (2033) and then multiplying it with the current per capita waste generation rate.

Table 8. 10-year Projection of Daily Waste Generation Rate of Poblacion Households (No Intervention)

	Daily Waste Generation Per Capita By Waste Composition (kgs)					
	2024	**2025**	**2026**	**2027**	**2028**	**2033**
Projected Pop.	14820	14870	14921	14972	15023	15281
Biodegradable	3063.65	3073.99	3084.53	3095.07	3105.61	3158.95
Recyclable	468.59	470.17	471.79	473.40	475.01	483.17
Residual	1151.72	1155.61	1159.57	1163.53	1167.50	1187.55
Special Waste	215.94	216.67	217.41	218.16	218.90	222.66
Total	4899.91	4916.44	4933.30	4950.16	4967.02	5052.33

Considering a consistent population growth rate and assuming a scenario where no interventions are made to improve the solid waste management system of Irosin, it is projected that by the year 2033, the daily waste generation rate of the population of the Poblacion will reach 5,052.33 kgs - an increase of 139.95 kgs/day or 2.87%. This is presented in Table 8, along with the composition of waste per category.

In contrast, Table 9 presents a scenario wherein the 72.09% full waste diversion potential is achieved. It shows that by 2033, only 1,410.10 kgs of household waste per day would have to be collected and sent to the disposal facility.

Table 9. 10-year Projection of Daily Waste Generation Rate of Poblacion Households (With Intervention)

	Amount (in kgs)					
Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2033**
Projected Total Waste Generation	4899.91	4916.44	4933.30	4950.16	4967.02	5052.33
Potential Total Waste Diversion	3532.34	3544.260	3556.416	3568.572	3580.728	3642.222
Potential for Collection (After Diversion)	1367.56	1372.18	1376.88	1381.59	1386.30	1410.10

The study highlighted the considerable potential reduction of waste generated by households in the Poblacion that the LGU would have to accommodate daily, thereby contributing to a more efficient allocation of its limited resources. For instance, higher waste diversion rates in the future mean less waste ends up in landfills, significantly extending their operational lifespan. This means there would be no need to establish a new landfill anytime soon after the one that is planned to be built. Furthermore, recyclable and biodegradable waste in landfills due to a lack of diversion strategies represents missed income opportunities for the municipality. Without proper waste separation at source, the LGU would have to increase the workforce further down the waste stream to manage the waste produced by a growing population.

4 Conclusion and Recommendations

Conducting a waste characterization is one of the initial steps in creating a municipal solid waste management plan, as it establishes a quantifiable basis for developing action plans and strategies in dealing with municipal waste. Recognizing the lack thereof in the town of Irosin, the study was conducted with a specific focus on household waste in the town's Poblacion area. The study found that the daily per capita waste generation rate of the population of the Poblacion had not significantly changed since the last WACS in 2017, from 0.335 kgs/day to 0.331 kgs/day. In order of the highest percent contribution to the total waste generated by sample households, biodegradables took up the largest share, followed by residuals, recyclables, and special waste. A substantial portion (72%) of the total waste generated was found to be divertible, suggesting that the amount of waste in landfills can be greatly reduced by investing in technologies to reuse or repurpose the diverted materials. The study also presented an estimated 2.87% increase in the waste generation rate of the population of Irosin after 10 years with the use of a standard population projection.

It was made apparent by the results of the study that despite having a per capita waste generation rate that is lower than the national average, which has not increased over the past five years, and composed mostly of divertible waste, the town of Irosin continues to struggle with managing their waste because of the apparent lack of effective management strategies such as waste separation by type and waste diversion. This presents a clear direction for the local government to approach the issues with waste management in the municipality.

Given the limited capacity of the municipality to accommodate centralized sorting, it is recommended that the local government promote and educate the population to separate their wastes at home. Source separation can help divert recyclable and reusable materials from the waste stream before collection, reducing the overall cost of waste management as the local government would not need to allocate funds for sorting in disposal sites. This also prevents organic matter from biodegradables from contaminating other types of waste, which may render them unsalvageable. Lastly, developing a habit of separating waste at home may indirectly lead households to become more conscious about their consumption and waste generation habits.

As for waste diversion strategies, the local government may consider decentralized composting. This can be done by setting up smaller-scale composting facilities in every barangay or cluster. The advantages of opting for this method instead of centralized composting are that it eases the burden on municipal waste collectors and promotes public participation in composting. The composting product may also be sold for a profit or donated to local farmers.

The local government can also coordinate with local private companies or junk shops that specialize in finding markets for recyclable materials. Rehabilitation of the materials recovery facilities in each barangay is essential in this pursuit, as proper storage of recyclable materials ensures their quality and marketability.

This study primarily aimed to characterize the solid waste generated by households in the Irosin Poblacion. However, a gap remains for future researchers to address by expanding the scope to cover waste characterization in non-household settings, including markets, institutions, and other sources of waste generation within the municipality. For researchers intending to conduct similar studies in different municipalities, it is strongly recommended to increase the sample size and diversify the population studied – particularly in terms of income ranges. This approach would provide deeper insights into the effects of varying socio-economic factors on solid waste generation.

Statements and Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Ethical Considerations

In compliance with the Data Privacy Act of 2012 (Republic Act No. 10173), the information collected and the personal information of the sample households were used primarily in the study and remains confidential. The study ensured responsible and respectful conduct of the research applying basic ethical considerations including informed consent, voluntary participation, confidentiality, anonymity, minimizing harm, and accurate reporting of the results.

This article is the full version of the research paper presented at the 2024 DCERP Research Day, CHE-UPLB [34, 35] and the International Conference on Human Settlements Planning and Development (ICHSPD) 2024, SM Aura, BGC, Manila [36].

Data Availability

The data in this study are available upon request from the authors.

Author Contributions

J.G.E.: conceptualization, methodology, formal analysis, writing – original draft preparation, visualization. **E.M.R.Jr.**: conceptualization, supervision, writing – original draft preparation, writing – review and editing. **K.S.A.C.B.**: conceptualization, validation, writing – original draft preparation, writing – review and editing. **A.B.T.**: conceptualization, validation, writing – original draft preparation, writing – review and editing.

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