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CASE STUDY

Characterization and quantification of solid waste in rural regions

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ABSTRACT

BACKGROUND AND OBJECTIVES: Population growth and economic activity in rural areas are factors driving the waste generation rate. Rural waste management generally still applies conventional patterns and has the potential to damage the environment and threaten human health. Challenges and remedial measures for solid waste management in rural areas differ from urban ones. The first step in planning a waste management system is to identify the generation and characteristics of waste. Unfortunately, data on waste generation and characteristics in rural areas in developing countries are still minimal. The problems are mainly caused by the development of the tourism industry, and it certainly requires waste management as the solution. However, due to the unavailability of waste generation data, this study aims to measure and analyze waste characteristics in the southern zone of Gunungkidul Regency.

METHODS: *Primary* data collection was taken from 16 randomly selected villages in six sub-districts in Gunungkidul Regency. A door-to-door survey was carried to 110 residential and 160 non-residential samples for eight consecutive days using the Indonesian National Standard 19-3964-1994 method. The processed data were analyzed using a quantitative descriptive method.

FINDINGS: The results showed that the average waste generation was 0.29 kilograms per person per day. It shows that the waste generation in the study area is categorized in small-town classification. 75 percent of solid waste generated is food waste and leaves. Meanwhile, paper, plastic, glass, wood, other materials, and fabrics were calculated at 11.8 percent, 10.1 percent, 1.7 percent, 0.5 percent, 0.5 percent, and 0.4 percent respectively. Housing produced less recycled waste as indicated by a high density of 110.6 kilograms per cubic meter. Waste generation and composition are influenced by socioeconomic factors such as economic activity and lifestyle, geographic conditions, and downtown attractiveness.

CONCLUSION: The characteristics of the waste produced by the southern zone of Gunungkidul Regency are not much different from most rural areas in developing countries. Rural waste management needs to see organic waste as the main management material. Organic waste processing through composting can be a future solution, but the active role of residents determines its success. In addition, this method can help extend the life of the landfill capacity because the volume of organic waste will be reduced by half.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
52	8	2

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INTRODUCTION

Population and human activities directly relate to the generation rate and composition of solid waste. The lack of waste services in both urban and rural areas will cause environmental and public health problems. Generally, rural areas in developing countries manage their waste by burning them (de Morais Lima and Paulo, 2018), burying them, or dumping them in backyard pits. Some use the waste from the leftover food as animal feed (Qi *et al*., 2021; Nguyen and Watanabe, 2019). The level of household education, the availability of public waste collection facilities (Liu *et al*., 2020), village spatial planning (Wang *et al*., 2018), social, economic, and natural conditions (Han *et al*., 2018) have influenced these behaviors. Conventional waste management by rural communities can trigger further environmental problems and threaten human health. Small-scale burning of waste in rural China produces emissions of dioxins and dioxin-like pollutants that can be easily exposed to humans through inhalation (Yang *et al*., 2019). Waste incineration increases toxic elements in the air, soil, and water, so it significantly impacts freshwater ecosystems (Lima *et al*., 2021). The decline in environmental quality and public health will ultimately reduce productivity and economic growth (Kubanza and Simatele, 2019). These various risks illustrate that rural areas need waste management. Planning for sustainable waste management can be initiated by understanding the generation and composition of waste. The availability of waste generation and composition data is the basis for appropriate waste management methods and technologies. To date, several studies have quantified the generation and composition of waste. There are differences between rural and urban areas in waste generation rate and composition. Based on some studies, rural waste generation in various developing countries ranges between 0.178-0.9 kilogram per capita per day (kg/capita/day). Romania's rural areas produce an average of 0.4 kilogram per day (kg/day) of waste (Ciuta *et al*., 2015). Villages in Southwest China generated an average of 0.178 kg of waste per day (Han *et al*., 2015). Rural areas in Iran produce waste from 0.293 to 0.588 kg per capita per day (Darban Astane and Hajilo, 2017; Vahidi *et al*., 2017; Taghipour *et al*., 2016). Mae Salong Nok Sub-district in Thailand generates 0.9 kg of waste per day (Suma *et al*., 2019). In contrast to earlier findings, urban areas in 20 countries generated an average of 3.4 kg of solid waste per day (Programme, 2010), which is 70-80 percent (%) greater than rural areas (Hoang *et al*., 2017). Based on the waste composition generated, rural areas in various countries produce 50.5% organic waste on average. Rural areas in Iran such as Khosrowshah District (Taghipour *et al*., 2016), Khodabandeh District (Darban Astane and Hajilo, 2017), Chaharmahal and Bakhtiari Provinces, and Yazd Province (Vahidi *et al*., 2017), on average, produce 49.8% organic waste materials such as food waste, vegetables, fruits, and leaves. The percentage of organic waste produced is quite similar compared to the waste generated in the village of Desoq, Kafr El Sheikh, Egypt, which is 50.1% (Anwar *et al*., 2018). Inorganic waste in the form of plastic is the most commonly found for about 20% of the total waste produced by rural areas (Anwar *et al*., 2018; Darban Astane and Hajilo, 2017). Organic waste is found in all socioeconomic groups, and the proportion will decrease as the family economy increases (Ramachandra *et al*., 2018). Socioeconomic factors such as economic activity and lifestyle influence waste generation and composition (Nguyen *et al*., 2020), rural geographic location (Taghipour *et al*., 2016; Han *et al*., 2015b), downtown attractiveness, and tourism (Medjahed and Brahamia, 2019; Suma *et al*., 2019) influence waste generation and composition. Furthermore, the type of industry in rural areas also greatly influences the characteristics of the waste (Bilgili *et al*., 2019; Han *et al*., 2018). The waste management system implementation in rural areas requires a different approach compared to urban areas (Yukalang *et al*., 2018). However, data on the generation and composition of solid waste in rural areas are still not widely available. It is valuable and prominent to obtain more accurate data on waste characteristics in rural areas (Han *et al*., 2018). Taghipour *et al.* (2016) stated that investigating waste quantity and composition, waste management, and disposal systems in rural areas is still necessary. The lack of accurate information will make the governments difficult to design solid waste management strategies and the right technology (Abdel-Shafy and Mansour, 2018). The Southern Zone of Gunungkidul Regency (SZGR) is a rural area with a coastal area developed as a tourism area and is part of the Gunung Sewu UNESCO Global Geopark. SZGR continues to experience a positive trend of population and economic growth due to the development of tourism and the improvement of accessibility. These conditions cause an increase in waste generation that needs to be managed properly (Masjhoer *et al*., 2020; Masjhoer, 2018). Challenges and remedial measures for solid waste management vary in every country (Al-Dailami *et al*., 2022). One aspect that needs to be considered in waste management system planning is the precise amount and type of waste produced (Quan *et al*., 2022). Empirical data on waste generation and characteristics by residents in SZGR is not yet available. This condition prompts the research question, how much waste is generated, and what is the composition of the waste produced by SZGR? Is the generation and composition of the waste produced by SZGR different from rural areas in other developing countries? Several previous studies (Abdel-Shafy and Mansour, 2018; Han *et al*., 2018; Taghipour *et al*., 2016) have reviewed the importance of waste generation and composition data as a basic foundation in rural waste management planning. The position of this research will add references and support similar research carried out by previous researchers. This research will enrich the data on the generation and composition of rural waste in developing countries. The data obtained from this study will provide an overview of the quantity and composition of the waste generated by residents in rural areas of SZGR. Interested parties can use this valuable information regarding the potential for waste that can be used commercially or non-commercially, processed into energy sources, converted into fertilizers, and designed solid waste management in rural areas. The current study aims is to provide actual data regarding the generation and composition of waste in rural areas in the southern zone of Gunungkidul regency, Indonesia, in 2021.

MATERIAL AND METHODS

Study area

This study is specifically located in the southern coastal area of Gunungkidul Regency. Administratively located in Purwosari sub-districts, Panggang sub-district, Saptosari sub-district, Tanjungsari sub-district, Tepus sub-district, and Girisubo sub-district (Fig. 1). SZGR is a rural area of 530.5 square kilometer (km^2), or 36 percent (%) of the total area of Gunungkidul Regency (Gunungkidul, 2020). The inhabitant is 182,642 people, with an average population density of 344 people per km^2. The population growth rate continues to increase to 1.11% in 2019 (Gunungkidul, 2020). The geographical location of SZGR is in the karst hills area of *Gunung Sewu*, which topography is mostly hillsides with an average height of 299 meters above sea level and a moderate to steep land slope (Gunungkidul, 2020). SZGR is a barren area due to the high porosity surface of the karst hills where surface water flow is hard to find. Typical karst hill soils are red Mediterranean and nutrient-poor latosols. Nevertheless, the locals in this area mostly work as farmers of secondary crops, rice, coconut, rubber, and coffee. SZGR has a coastal area with white sand beaches decorated with steep karst cliffs. The local government has designated this area as a tourism destination. Access to this area is getting easier with the construction of the southern causeway which triggers the development of commercial facilities such as hotels, restaurants, and shops (Masjhoer *et al*., 2020). This condition causes the emergence of waste that must be managed properly.

Material

This study measures the waste generated by residential, called household waste, and non-residential waste called household-related waste. The unit of measurement for waste generation uses the provisions of the Indonesian National Standard (INS) 19-3964-1994, namely, liter per person per day (L/person/day) for volume and kilogram per person per day (kg/person/day) for weight. The waste characteristics measured in this study are limited to physical characteristics, namely composition and density. The composition of waste is divided into organic and inorganic waste. Organic waste is the residue of organic material originating from human or natural activities and will naturally undergo a decomposition process within a certain time. Organic waste consists of food waste and leaves (Or), paper (Pr), and wood (Wd). Inorganic waste is a material that is not easily biodegraded, comes from minerals, and can be recycled. Based on this definition, inorganic waste consists of fiber (Fb), rubber (Rb), plastic (Pl), metal (Mt), and glass (Gs). Other materials are common waste found in residential and non-residential such as batteries, masks, and electronic devices which are considered as residue. The units used to measure the waste composition are in weight % and the density of the waste in kilogram per meter cubic (kg/m^3).

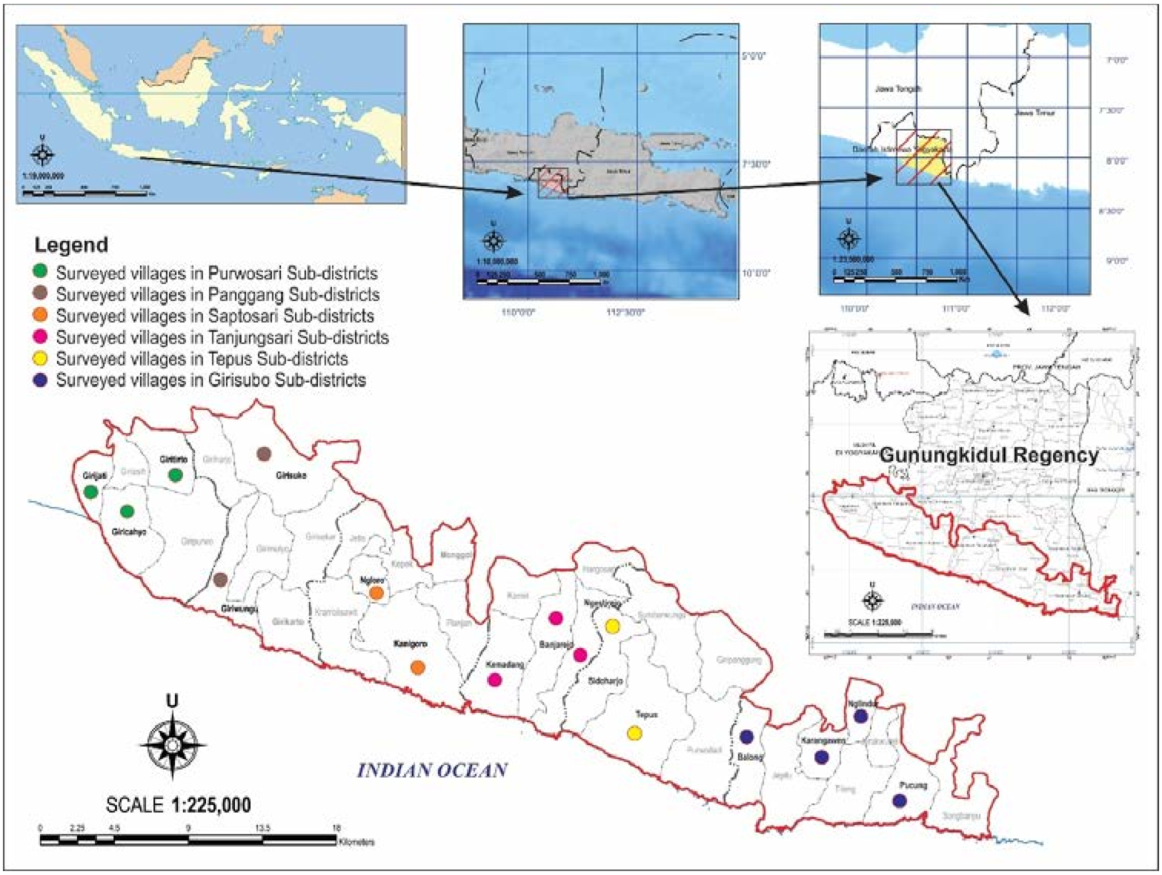

Fig. 1: Geographic location of the study area and surveyed villages in the southern zone of Gunungkidul Regency, in Indonesia

Methods

Primary data collection was held in 16 randomly selected villages, three in the Purwosari sub-district, two in the Panggang sub-district, two in the Saptosari sub-district, three in the Kemadang sub-district, two in the Tepus sub-district, and four in the Girisubo sub-district. These villages were selected from the most populated villages in the sub-district and were willing to be surveyed. Villages that refused due to the Coronavirus Disease 2019 (Covid-19) outbreak were transferred to another village. The village distribution can be seen in Fig. 1. The Secondary data were acquired from the Gunungkidul Regency Central Bureau of Statistics website and the village government. These data are the basis for determining the number of residence and non-residential samples using the stratified random sampling method that INS 19-3964-1994 has specified (Herianto *et al*., 2019; Alfons and Padmi, 2018). Residential is categorized based on the family's economic condition into permanent, semi-permanent, and non-permanent. Non-residential is divided into shops, restaurants, hotels, markets, offices, and public facilities (Table 1). A door-to-door survey was carried out from January to March 2021 to collect data from 270 samples. This process applied strict health procedures regarding the Java-Bali Community Activity Restrictions (JBCAR) policy due to the Covid-19 outbreak. Before the survey, a surveyor team was formed and provided with training and safety equipment such as gloves, hand sanitizer, disinfectant liquid, and masks. Before implementing the measurement, 40-liter garbage bags were given to the residential and non-residential samples. Every day for eight consecutive days, the weight and volume of waste were measured using a 20×20×100 centimeter (cm) measuring box equipped

Table 1: Residential and non-residential samples

Residential	Samples	Non-residential	Samples
Permanent	77	Shops	103
Semi-Permanent	30	Restaurants	21
Non-Permanent	3	Hotels	6
Subtotal	**110**	Markets	8
		Offices	18
		Public facilities	4
		Subtotal	**160**

Table 2: Weight, volume, and waste density in SZGR

No	Samples group	Unit	Weight (kg)	Volume (Liter)	Density (kg/m^3)
I	Residential				
	Permanent	Person/day	0.10	0.51	204.29
	Semi-Permanent	Person/day	0.07	0.46	153.27
	Non-Permanent	Person/day	0.02	0.08	218.04
II	Non-Residential				
	Shops	(m^2/day)	0.02	0.42	54.10
	Restaurants	(m^2/day)	0.06	0.54	105.59
	Hotels	(Room/day)	0.01	0.25	43.70
	Markets	(m^2/day)	0.002	0.03	90.75
	Offices	(m^2/day)	0.0002	0.00	50.27
	Public facilities	(m^2/day)	0.003	0.04	75.64
III	Total residential waste generation		0.19	1.05	
IV	Total non-residential waste generation		0.10	1.29	
V	Total waste generation (III + IV)		0.29	2.34	

with a height scale. After the weighing process, the waste is poured into the ground to sort based on its type. Organic and inorganic waste was weighed separately before each component of the waste type is measured. The survey data was processed and presented in a table using Microsoft Excel 2019 software and graphic using the Origin 2018 software. The processed data were analyzed using a quantitative descriptive method to describe a simple summary of the basic characteristics of the sample in this type of research (Vahidi *et al*., 2017).

RESULTS AND DISCUSSION

Waste generation

The success of developing a rural solid waste management system is determined by the measurement of waste generation as a prerequisite (Taghipour *et al*., 2016). Based on the waste measurements of 16 villages, the total average waste generated by locals in SZGR every day is 0.29 kg/person, or with a population of 182,642, SZGR produces 52.90 tons of solid waste daily (Table 2). It is below the small-town classification according to INS 19-3983-1995, which is 0.625-0.70 kg/person/day. Rural waste generation in SZGR is relatively low compared to rural areas in Romania whose population is 500–15,000 and produces an average of 0.4 kg/person/day (Ciuta *et al*., 2015). It is also lower compared to the rural areas in Iran which generate waste ranging from 0.293 to 0.588 kg/person/day (Darban Astane and Hajilo, 2017; Vahidi *et al*., 2017). However, compared to rural areas in China, especially in the Tibetan Plateau, which generates 0.085 kg of waste per person per day, SZGR generates waste up to triple daily (Han *et al*., 2015a), and it is 38.6% greater compared to Southwest China's rural areas (Han *et al*., 2015b).

Fig. 2 shows that residents in each village produce various amounts of waste. The residents of Banjarejo produce the highest amount of waste at 0.59 kg/day. On the other hand, Giriwungu and Girisuko generate the smallest waste, which is 0.08 kg/person/day. Variations in the amount of waste generated in the SZGR villages show a non-uniformity

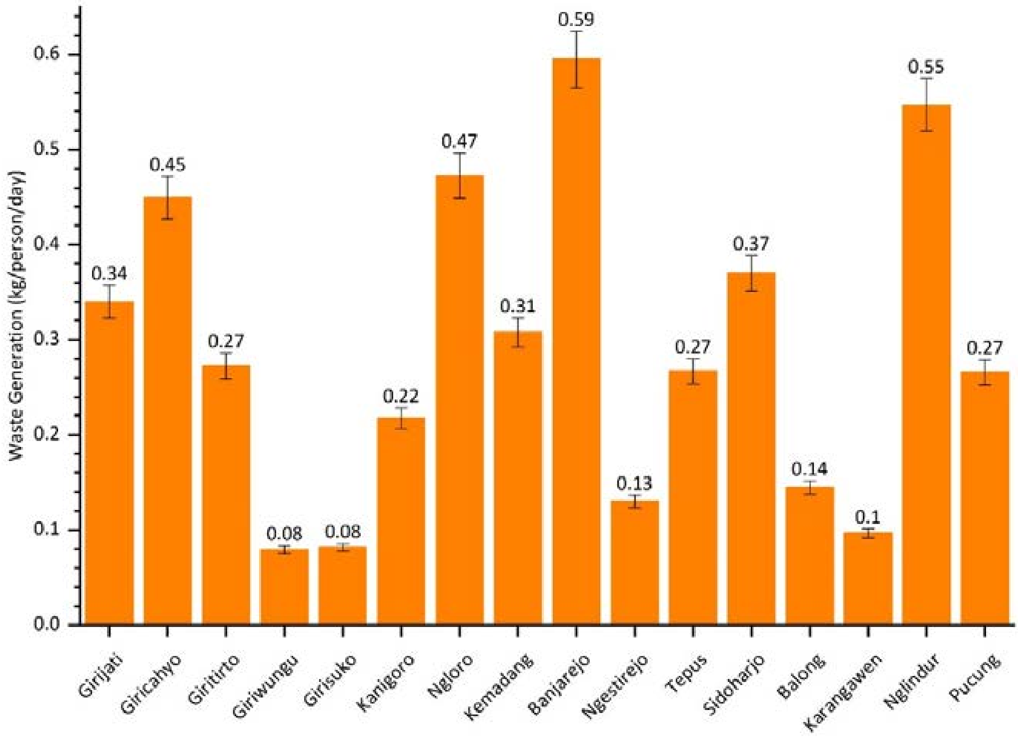

Fig. 2: Waste generation in sample villages

in the community's economic conditions. The change in people's lifestyles is one of the causes of the increasing waste generation. Waste generation and composition are influenced by socioeconomic factors such as economic activity and lifestyle (Nguyen *et al*., 2020), rural geographic location (Han *et al*., 2015b; Taghipour *et al*., 2016), and downtown attractiveness (Medjahed and Brahamia, 2019).

Based on the sample group, the waste generation originating from residential is 0.09 kg/day more than a non-residential waste generation. Permanent residential produce waste 52.63% more than semi-permanent and non-permanent in the residential category, which are only 36.84% and 10.53%, respectively (Fig. 3). The data shows that households with better economic conditions tend to produce more waste. Han *et al.* (2018) stated that an increase in family income in rural areas in developing countries affects food consumption and other necessities of life. This finding was proved by Nguyen *et al.* (2020) who found that household economic conditions and the number of family members correlated with the amount of waste generated. The dominant waste contributors from the non-residential sample are restaurants, shops, and hotels. They produce 93.9% of the total waste generated by non-residential (Fig. 2). The development of the tourism sector in SZGR also triggers the growth of commercial trade along the road to the tourism sites. During the Covid outbreak, the trading activity in SZGR continues to function despite the JBCAR implementation because they provide the essential need of locals. This traditional market in SZGR contributes 2.8% of the total non-residential waste generation. The market operates only twice a week, and the market area becomes a divider that reduces the amount of waste generated. Due to JBCAR implementation to suppress the Covid-19 outbreak, offices and other public facilities operate with a limited number of employees, which causes waste generation to be considerably small. Therefore, it can be clearly stated that local activities and the type of economy in the village determined the waste generation rate. The Mae Salong Nok countryside has waste generation up to 3 times more than SZGR. The tourist who comes to Mae Salong Nok contributes to the amount of waste other than that

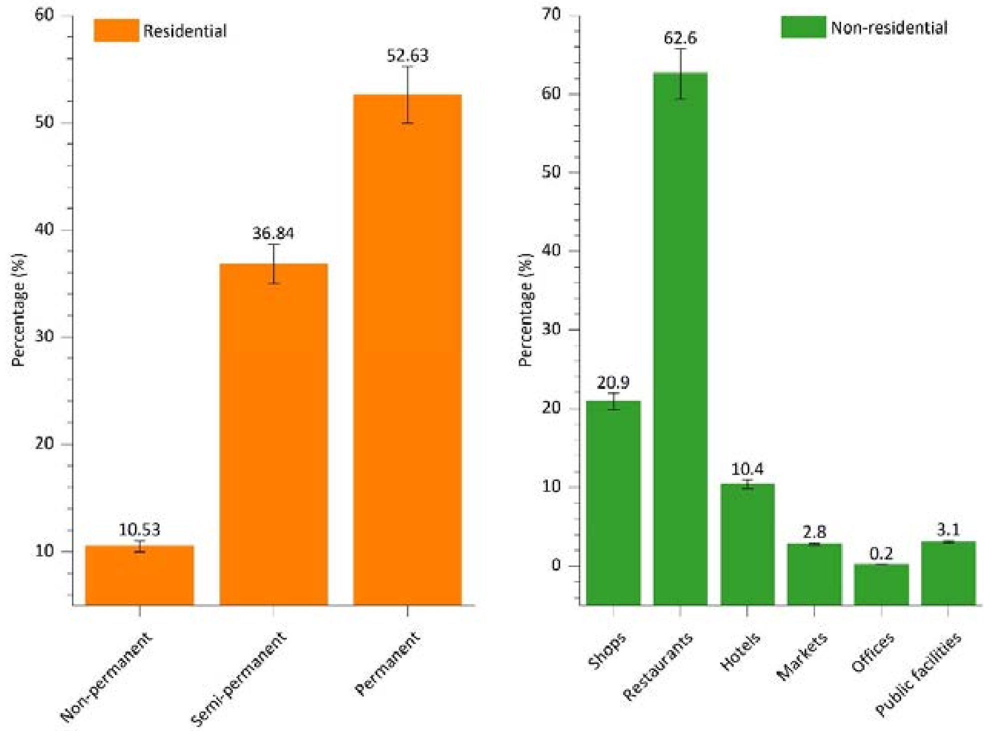

Fig. 3: Waste generation based on samples group

produced by the local community (Suma *et al*., 2019). Han *et al.* (2018) and Bilgili *et al.* (2019) agreed that economic drivers or the type of industry in rural areas affect the waste generation rate.

Waste composition and density

Understanding the composition of rural solid waste will determine the appropriate method and technology in each stage of solid waste management, starting from the storage, collection, transportation, and final processing stages. SZGR produces waste with an average composition of 87.3% organic material and 12.7% inorganic material. This proportion is similar to rural areas in developing countries. Rural areas in various developing countries such as Iran (Darban Astane and Hajilo, 2017; Vahidi *et al*., 2017; Taghipour *et al*., 2016), Egypt (Anwar *et al*., 2018), China (Han *et al*., 2015b), and Ghana (Boateng *et al*., 2016), produce more organic waste materials such as food waste, vegetables, fruits, and leaves than inorganic waste types. The most inorganic waste produced by rural areas in SZGR is plastic, with a proportion of 10.1%, followed by glass waste (1.7%), other materials (0.5%), and fabrics (0.4%). Plastic is the most common inorganic waste type, with less than 20% of the total waste produced by rural areas (Anwar *et al*., 2018; Darban Astane and Hajilo, 2017; Vahidi *et al*., 2017).

All sample villages generally produce waste with a composition of more organic waste than inorganic waste. Organic materials in the form of food waste, leaves, and paper were found in all villages, while inorganic materials produced by all villages were in the form of plastic (Fig. 4). Sidoharjo became the village with the largest organic material whereas the most inorganic material was found in Girijati village. The types of food waste and leaves in Pucung and Girijati villages have a small portion compared to other types of waste. The non-residential sample, which is larger than the residential sample, could be the reason. Various economic activities in an area will affect the waste composition. According to Boateng

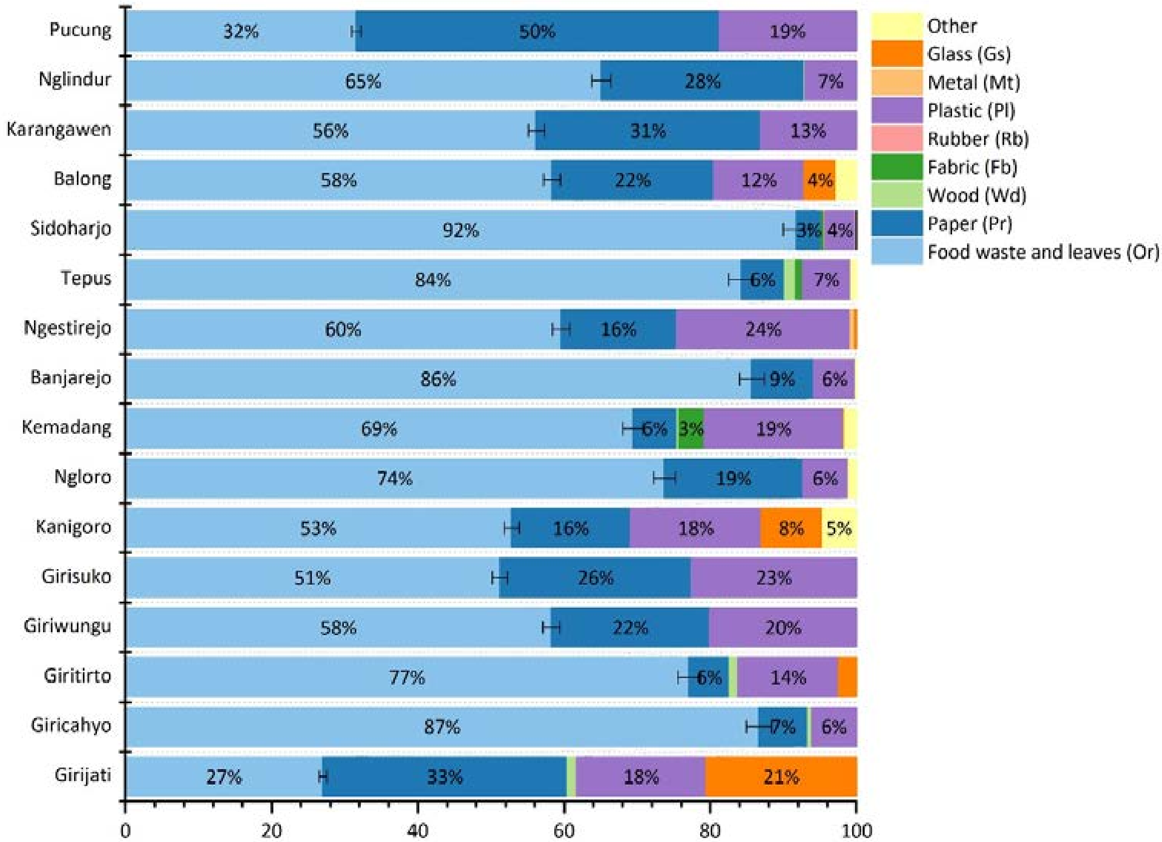

Fig. 4: Waste composition based on sample villages

et al. (2016), rural residents still buy raw materials for fresh food in large portions, thus producing the largest amount of organic waste. Furthermore, different types of industries in rural areas significantly influence the characteristics of waste (Han *et al*., 2018; Bilgili *et al*., 2019). Based on the sample group, the residential sample produces an average of 92.84% organic waste, while the rest is inorganic waste. Plastic, fabric, and other materials are 6.7%, 0.39%, and 0.02%, respectively. Glass, metal, and rubber wastes were not found in the residential samples (Fig. 5). The non-permanent residential produces more organic waste compared to semi-permanent and permanent. It shows that the family's economic condition also encourages the diversity of waste produced. Organic waste is discovered in all social strata, but as the family economy increases, the proportion of inorganic waste types increases (Ramachandra *et al*., 2018). The composition of recycled waste originating from residential in SZGR tends not to vary. The locals have a low level of consumption, and they tend to cook their daily meals using raw materials from around their yards.

The non-residential sample produced an average of 86.33% organic waste; the rest was inorganic waste (Fig. 6). Markets and restaurants generate the most organic waste, while the most inorganic waste comes from shops, hotels, offices, and public facilities. The local markets generate organic waste such as leftover vegetables, fruits, fish, poultry, and other easily rotten or unsold products. Meanwhile, restaurants generally produce raw leftovers and food scraps. Meanwhile, paper is mostly disposed of by offices and shops, while plastic waste is collected from shops, hotels, and other public facilities.

On average, the solid waste density produced by SZGR is 110.6 kg/m^3. The residential area has a higher density value than the non-residential (Fig. 7). High

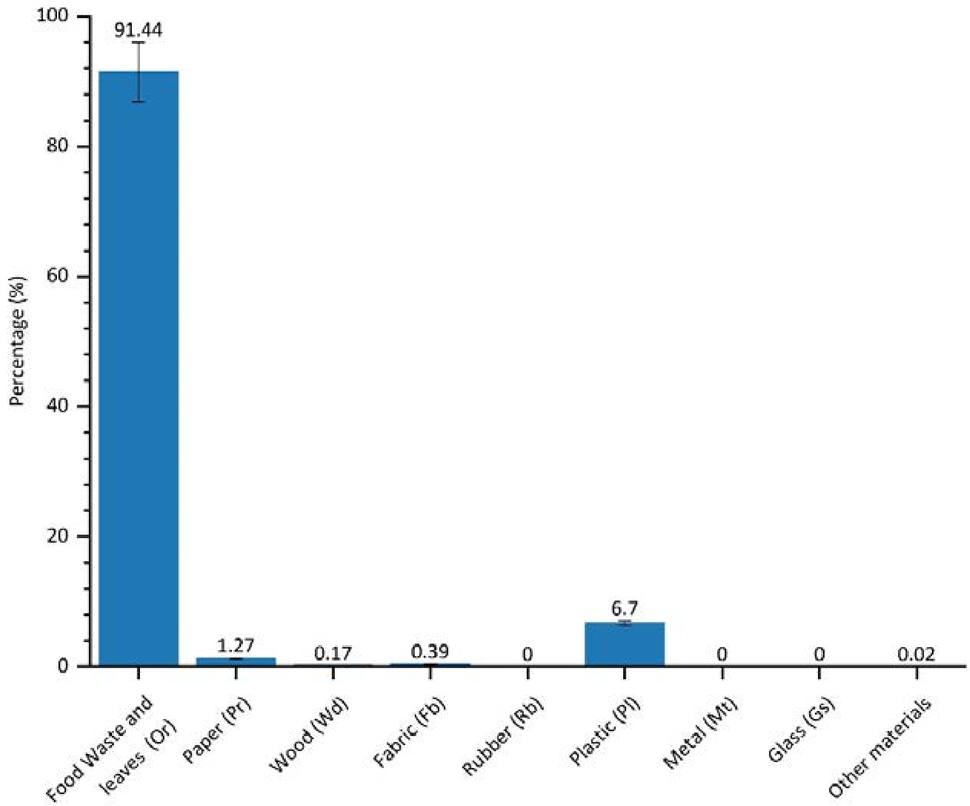

Fig. 5: Residential waste composition

solid waste density indicates that the residential sample produces less recyclable waste. These results align with the variety of inorganic waste discovered in non-residential premises. In a different case, rural areas in Western China, for example, have low solid waste density because they contain large amounts of paper/cardboard and plastic or rubber (Han *et al*., 2019). The solid waste density will determine the type of transportation ideal for transporting waste.

According to the sample villages, the waste density shows that Giricahyo has the highest average waste density, and Giriwungu has the smallest (Fig. 8). The waste density shows differences in organic and inorganic compositions portion in each village. A high-density value indicates that the village produces more waste with high moisture and low calories. The three villages with the highest solid waste density, namely Giricahyo (93.9%), Ngloro (92.7%), and Banjarejo (94.2%), produced a higher portion of organic material than inorganic (Fig. 8). However, there is a compelling finding in Sidoharjo Village. This village has an organic composition of (95.3%), with a solid waste density of 151.16 kg/m^3. Allegedly, the inorganic waste in that village has a larger dimension, thus reducing the waste density. The waste density determines the appropriate treatment, especially for organic waste, which is ideal as a raw material for composting and biogas. According to Syafrudin *et al*. (2018), waste density affects the decomposition rate and the content of methane gas used for biogas.

The generation, composition, and density of waste in SZGR are well known and have similarities with rural areas in other developing countries, including applied waste management. SZGR's rural waste management practices are still conventional. The residents burn and stockpile their generated waste (Masjhoer *et al*., 2022). In Brazil, rural waste is commonly burned or buried without any safeguards (Caiado Couto *et al*., 2021). In rural China, most waste is burned and dumped on roads, rivers, and open dumps (Cao *et al*., 2018). The processing of organic waste requires additional attention compared to inorganic waste.

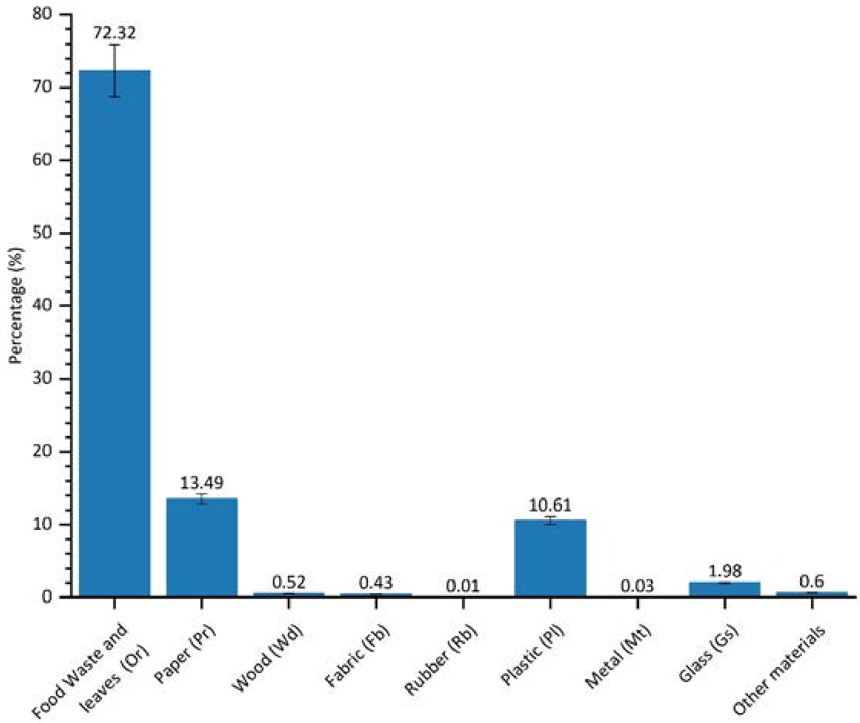

Fig. 6: Non-residential waste composition

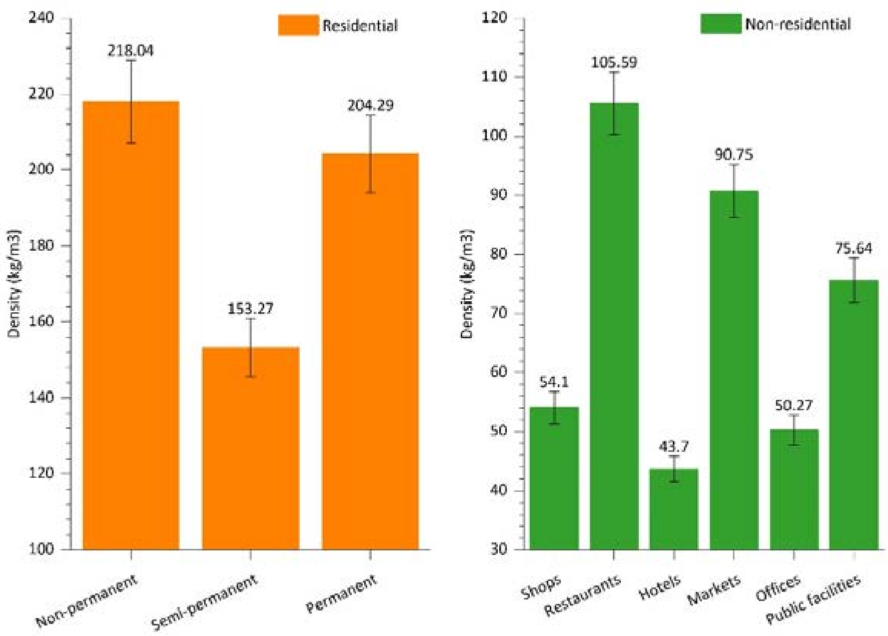

Fig. 7: Waste density in the Southern Zone of Gunungkidul Regency

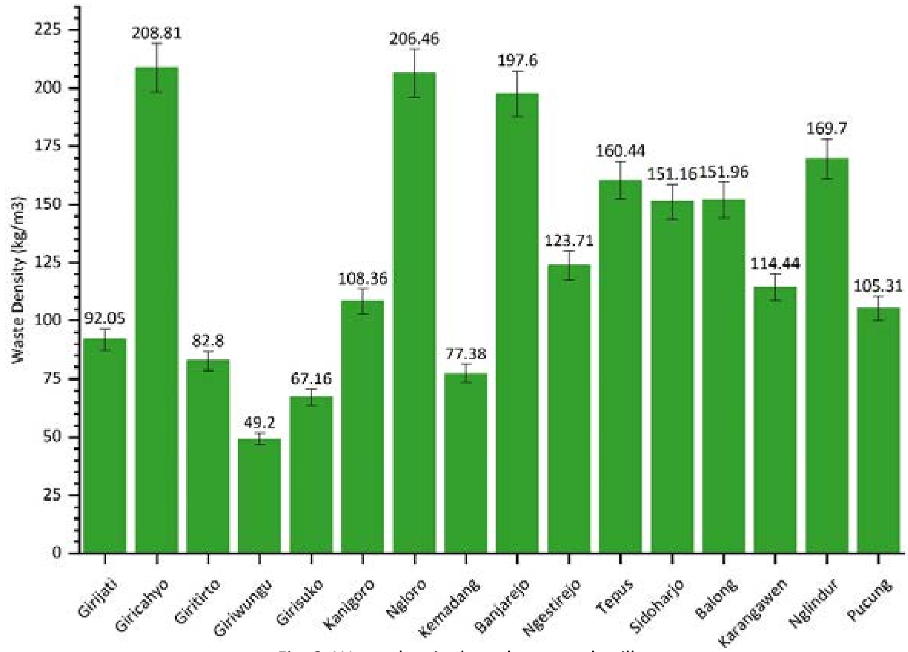

Fig. 8. Waste density based on sample villages

The combustion of organic matter produces harmful and toxic gases because it has a low calorific value (Kim and Kim, 2010). Research by Lima *et al*. (2021) shows that open waste burning threatens the health of rural communities and aquatic ecosystems. The smoke produced from burning waste contains Particulate Matter (PM), carcinogenic dioxins, and various other harmful pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs) (Das *et al*., 2018). Open burning can trigger a variety of health impacts, such as acute and chronic respiratory disease, cardiovascular disease, and cancer, in addition to impacts on the local climate. Therefore, the burning of organic waste potentially causes environmental hazards. On the other hand, landfilling methods for waste give rise to leachate, groundwater pollution, and toxic emissions (Shahnazari *et al*., 2021). The risks that can arise from improperly-managed landfill include groundwater contamination caused by leachate, methane gas emissions, and combustion fumes containing harmful gases. Unsustainable waste management can impact human health, such as the emergence of cholera, skin infections, and chronic diseases caused by hazardous chemical waste (Al-Dailami *et al*., 2022). In line with the increasing volume of waste generation, waste management that is not environmentally friendly can harm health and disrupt the preservation of environmental functions. The environmental quality needs to be improved to ensure future welfare and quality of life. Human behavior can affect the life and well-being of humans and other living creatures (Abdul and Syafrudin, 2018). Waste management in rural areas is more dependent on citizen participation because of several characteristics, such as a relatively large area, scattered sources of waste, and difficult transportation (Shi *et al*., 2021). Waste generated by the community should be managed at the waste source by sorting it based on the waste composition. Waste sorting will facilitate the handling of waste in the next stage. Segregated waste will facilitate handling in landfills and thermal incinerators (Quan *et al*., 2022). Meanwhile, mixed organic and inorganic waste will be difficult to use as raw materials in composting, biogas, or recycling (Syafrudin *et al*., 2018). Reducing waste at the source of waste is the most effective strategy and solution to overcoming the problem of waste accumulation in rural areas (Shen *et al*., 2020; Mihai and Grozavu, 2019). Al-Dailami *et al*. (2022) stated that the application of Reduce Reuse and Recycle (3R) is considered the best strategy in solid waste management. The best and most practical method of processing organic waste is by recycling organic waste into fertilizer (Shahnazari *et al*., 2021). Organic waste will go through decomposition by nature into nutrients. However, uncontrolled quantities and conditions in the decomposition process can cause environmental problems. SZGR produces 87.3% of organic waste that needs to be handled by a raw material-oriented method. Chen, Zhang, and Yuan (2020) argue that organic materials must be viewed as raw materials and have value. Organic materials can be used as raw materials to manufacture fertilizers through the composting process. Composting organic waste into fertilizer is a superior technology in rural waste management (Patwa *et al*., 2020; de Morais Lima and Paulo, 2018). This process decomposes organic waste in a faster time and reduces volume significantly, and reduces the amount of waste disposed of in the landfill. The reduction in organic waste volume results from an overhaul of microbial activity (Sayara *et al*., 2022). Composting technique is a method that can reduce the volume of organic waste by half (Ma *et al*., 2017). The waste bank program promoted by the Gunungkidul government to reduce waste at the source (Faradina *et al*., 2020) needs to consider organic waste as a potential raw material that can be transformed into a valuable main product. Organic fertilizers produced from the composting process are considered more effective in reducing waste and do not require expensive technology in processing; thus, people can do it at the household level. Rural organic waste is more biodegradable compared to that of urban areas, and the practice of composting is an alternative that households can do (Báreková *et al*., 2020). The organic waste composting practice is a form of good waste management based on reduction, reuse, and recycling principles (Han *et al*., 2015a). SZGR is a karst area with nutrient-poor soil that can be improved by adding nutrient-rich organic fertilizer. The farmers will also have economic benefits from using organic fertilizers. They can produce and use organic fertilizers to replace chemical ones. However, efforts to apply organic fertilizers to the community in SZGR need to be accompanied by the socialization of the nutrient content and economic value of organic fertilizers (Chen *et al*., 2020).

CONCLUSIONS

Population and economic growth in rural areas lead to waste generation, even at a different level from the urban. Unfortunately, local governments in developing countries do not give more attention to waste services in rural areas. This condition leads rural communities to manage their waste conventionally, such as by piling them up or burning them in the open air. However, this conventional waste management can trigger environmental problems and threaten human health. The initial data on waste generation and composition produced by rural areas will determine the ideal method and technology for designing the solid waste management system. The results showed that the generation and composition of rural waste in SZGR were categorized into the small-town classification. Although the generation of rural waste is not as large as in urban areas, it still requires proper waste management. In SZGR, the composition of organic waste is greater than inorganic waste. Commercial activities generate a more diverse waste composition than residential. The calculation of waste density also supports the domination of organic waste. The waste characteristics produced in the Southern Zone of Gunungkidul are not much different from most rural areas in developing countries. The results of this study certainly add information and serve as a comparison for formulating rural waste management strategies in a wider context. Based on the research result, local governments need to consider the generation and composition of waste as a milestone to improve the waste management system quality. Rural waste management needs to see organic waste as the primary management material. Abundant organic waste should be the primary focus to be handled and seen as raw materials for other valuable products. Composting organic waste will provide many benefits for the residents who work as farmers. In addition, this method can help extend the life of the landfill capacity because the volume of organic waste will be reduced by half. Composting requires the local community's participation in adopting composting as a rational and profitable method. Therefore, further research is needed to provide information on the community's willingness to participate in composting. Moreover, a feasibility study of the fertilizer content and the economic feasibility of its application may also be required for further research.

AUTHOR CONTRIBUTIONS

J.M. Masjhoer, the corresponding author and second author has contributed in the data analysis, interpreted the results, and preparing the manuscript. S. Syafrudin as the first author supervising the second author, conceptualization, and methodology for the research. M. Maryono participated in supervision-design and revision the manuscript.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

%	Percent
3R	Reduce Reuse and Recycle
CO	Carbon monoxide
Covid-19	Coronavirus Disease 2019
cm	Centimeter
Fig.	Figure
INS	Indonesian National Standard
JBCAR	The Java-Bali Community Activity Restrictions
kg/day	Kilogram per day
kg/capita/day	Kilogram per capita per day
kg/m^3	Kilogram per meter cubic
kg/person/day	Kilogram per person per day
km^2	Square kilometer
L/person/day	Liter per person per day
m^2/day	Square meter per day
NMVOCs	Non-methane volatile organic compounds
NOx	Nitrogen oxides
PM	Particulate matter
SO_2	Sulfur dioxide
SZGR	Southern Zone of Gunungkidul Regency
UNESCO	The United Nations Educational, Scientific and Cultural Organization

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