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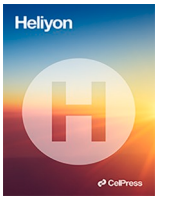

Assessing the impact of COVID-19 on waste generation: Focus on plastic, food, and medical wastes in South Korea

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ABSTRACT

The COVID-19 pandemic may have considerably increased household and medical waste generation. However, waste generation patterns are not consistent and may vary globally. Therefore, using data (2018–2021) from 25 autonomous local governments under the Seoul Metropolitan Government, this study investigated whether plastic, food, and medical waste generation increased in South Korea during the pandemic. Descriptive statistics, spatial distribution patterns, and cluster analyses were used to examine the impact of COVID-19 on the jurisdictions. Results revealed that the fluctuations in plastic, food, and medical wastes generation had little impact on the waste management system in Seoul. Patterns varied little compared to the pre-COVID-19 period. This study raises the possibility that, while it may appear that there were waste management issues and waste accumulation during COVID-19, there is much variation in the results at the jurisdictional level. This showed that not all regions experienced problems in waste management during the pandemic.

1. Introduction

Globally, COVID-19 has had a substantial impact on the generation of municipal solid waste (MSW) and medical waste, and it has also revealed problems with waste collection and treatment systems [1]. The pandemic caused a considerable increase in household (such as plastic and food) and medical waste generation, which may have had a negative impact on the environment and recycling [2–6]. Further, challenges in waste collection, transportation, disinfection, sorting, and dumping have been identified globally [7]. In many countries, the substantial increase in MSW exceeded disposal capacity, necessitating the implementation of emergency MSW disposal and management [8].

However, waste generation patterns are not consistent globally and may change based on regions, socioeconomic conditions, and government policies [9]. The impact of COVID-19 on plastic output, for example, may be unclear. While food packaging waste decreased in shops and restaurants, additional plastic usage in e-commerce and food delivery services offset this decline [10]. Total lockdowns and temporary restaurant closures increased the demand for home delivery of food and groceries and the usage of single-use plastics, which resulted in an increase in plastic waste [2,6]. In addition, the pandemic altered food consumer habits, resulting in food and grocery stockpiling as well as panic buying [4]. As COVID-19 spread globally, the amount of medical waste generated from hospitals and healthcare institutions rapidly increased [3]. Shams et al. [5] reported a considerable increase in medical waste generation in more than 10 countries during the COVID-19 pandemic.

There have been contradictory reports regarding the increase or decrease of plastic, food, and biomedical waste generation during

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COVID-19 [7,9,11,12]. Mahyari et al. [7] reviewed 299 articles containing the keywords "COVID-19" and "waste" and showed that the lockdown, staying at home, and remote working increased the amount of residential and household waste. Moreover, online shopping, product and pharmaceutical packaging, personal protective equipment, and single-use plastics all increased plastic waste. Notably, data regarding food waste have been contradictory. Initially, research supporting increased generation stated that takeout food consumption, breakage in food chains due to lockdowns, and excessive food procurement and stockpiling resulted in more food waste. However, other research indicated that the shutdown or closure of restaurants, home cooking, efficient use of leftover food, and careful food purchase during COVID-19 resulted in less food waste than before COVID-19.

Ali and Parvin [11] analyzed 58 studies on waste management during COVID-19. Their key findings were: First, food waste generation decreased during the pandemic because of changes in consumption behavior (avoidance of supermarkets and hygiene concerns). Second, the sudden excessive plastic waste generation during the pandemic presented a challenge to waste management. Third, medical or hospital waste increased sharply, necessitating improved medical waste management. A recent study by Urbańska et al. [12] found that, at the national level, MSW amounts did not differ much from those of the pre-COVID-19 era. Requena-Sanchez et al. [13] investigated household behaviors in six Latin American countries and found that participants in the study did not report major waste composition changes before or during the pandemic. In summary, numerous studies found that there was more plastic, food, and medical waste generated during the pandemic than there had been before COVID-19. However, due to the contradictory results, the impact of COVID-19 on waste generation remains unclear.

Although research on the effect of COVID-19 on plastic, food, and medical waste generation exists, there are several limitations that need to be addressed. First, waste generation has been studied at the national level without considering the possibility of regional differences in waste generation patterns. Second, given that COVID-19 affected every region, pattern changes should be comparable across regions if COVID-19 is the primary driver of changes in waste generation patterns. This assumption has not yet been investigated. Third, to compare the impact of COVID-19 on waste generation among jurisdictions, waste management policies of target jurisdictions should be equivalent. This condition has often been overlooked by studies that compare waste generation among nations and regions. Finally, although COVID-19 cases are considered responsible for increased waste generation, the relationship between the number of confirmed cases and waste generation patterns has rarely been examined.

To address these limitations, this study investigated the effect of COVID-19 on plastic, food, and medical waste generation in South Korea. Using data from 2018 to 2021, we compared the waste generation trends of 25 autonomous local governments governed by the Seoul Metropolitan Government using the same waste management policy. The number of COVID-19 cases and employment in the food service industry within these regions were taken into account. Descriptive statistics, spatial distribution patterns, and cluster analyses were used to examine the effect of COVID-19 on the jurisdictions. The remaining information is divided as follows: Section 2 briefly explains the context of MSW management in South Korea. Section 3 explains the data and methods. Section 4 summarizes the results of the pre-COVID-19 and COVID-19 period waste generation analyses. Lastly, Section 5 discusses the study's findings and the implications for future research.

2. MSW management in South Korea

2.1. Policy background

In South Korea, a volume-based waste fee (VWF) system is used in all jurisdictions. The Ministry of Environment (MOE) manages waste at the national level in accordance with the Wastes Control Act (WCA). Based on the WCA, the MOE provides standards, guidelines, and support for waste management policies to local governments [14]. Waste management policies are implemented at the lowest level of the government. The districts (gus) under the Seoul Metropolitan Government are the lowest level governments. Although these gus are part of the Seoul Metropolitan Government, they have their own waste management legislation, waste management facilities and equipment, waste management budgets, and the authority to collect VWF fees [15]. Furthermore, many waste management decisions are made at the local government (gus) level. Therefore, the gus was used as the unit of analysis in this study.

In South Korea, MSW is disposed of in two ways: (1) by individuals using designated VWF plastic bags, and (2) by recycling MSW. Recyclables are left in designated receptacles or at sites near households or multi-unit residential buildings [15]. Plastics recovered from local government recycling bins are considered recycled MSW. South Korea has five types of plastic waste: (1) polyethylene terephthalate; (2) polyvinyl chloride; (3) polypropylene; (4) polystyrene; and (5) polyethylene. Food waste is also classified as recyclable MSW. Depending on the residential type, food waste can be disposed of using VWF food waste plastic bags, radio-frequency identification-based food waste receptacles, and designated chips or stickers [16]. Local governments are responsible for collecting food waste and recycling organic substances and nutrients, which is then converted into animal feeds or fertilizers [17].

Medical waste is generated by public health, medical, testing, and inspection institutions, as well as veterinary clinics, according to Article 2 of the WCA. Depending on the institution's size or function, the local environmental offices of the basin under the MOE or the local government must receive reports from medical waste dischargers under the WCA. According to Oh et al. [18] and Yoon et al. [19], South Korea has eight different types of medical waste: infectious medical waste, hazardous medical waste (body parts, fluids, placenta, sharps, and pathological tests, biological/chemical, and blood-contaminated samples), and general medical waste.

2.2. Waste generation trend in Seoul during COVID-19

This study makes several assumptions when examining the waste generation trend in Seoul during COVID-19: First, as the COVID-

19 infection rate increased or decreased, so did the generation of plastic, food, and medical waste, which affected all regions. Second, there was an overall increase in the amounts of plastic, food, and medical waste during the COVID-19 period. Third, the COVID-19 infection rate affected waste generation patterns differently in different jurisdictional areas. Jurisdictions with more infected citizens exhibited considerable changes in plastic, food, and medical waste generation. Finally, restaurant lockdowns and shutdowns affected citizen food consumption behavior, leading to an increase in food waste.

3. Materials and methods

3.1. Data

This study used official government data from the MOE and Seoul Metropolitan Government Data Archive of South Korea [20,21,22]. Each year, the MOE collects data on waste from each local government and uploads it to the Korea Resource Recirculation Information System and the MOE Statistics Portal website in collaboration with the Korea Environment Corporation. The most recent data at the time of the study were for the calendar year 2021 [20]. This study extracted data on plastic, food, and medical waste from the raw MOE data for analysis. In South Korea, plastic and food waste are legally classified as residential waste [17]. Medical waste is classified as "designated waste," which is a subcategory of "business waste" and is defined as "waste feared to be contagious and discharged from medical, research, and inspection institutions" [17]. Population and regional surface area (square km) were included in the MOE data. The Seoul Metropolitan Government Data Archive is a web-based platform that collects government data on the city of Seoul.

In addition to waste management data, spatial data (shape file) of the Seoul Metropolitan Government Region were extracted from the National Spatial Data Infrastructure Portal of South Korea to depict the spatial distribution of the study variables [23]. The R was used to graphically display the regional distribution patterns of the study variables. A hierarchical cluster analysis was performed to identify possible groups (clusters) within the 25 gus of the Seoul Metropolitan Government using Ward's minimum variance method. The number of clusters was identified using the Hubert and D indices.

3.1.1. Plastic waste

Although the MOE defines five types of plastic, all plastic waste from households is collected as recyclables, and the amount of each type of plastic is not recorded. Therefore, because the MOE data did not distinguish between plastic categories, the total volume as recorded was used in this study. For comparison among different jurisdictions, the amount of plastic waste generated was divided by the population in each gus.

3.1.2. Food waste

Food waste amounts were extracted from the MOE data. As food is consumed by individuals, the total amount of food waste was divided by the population to generate a per capita scale.

3.1.3. Medical waste

Medical waste data were extracted from the MOE data. The amount of medical waste was divided by the population to calculate the per capita waste amount.

3.1.4. COVID-19 infection

The number of confirmed COVID-19 cases were obtained from the Seoul Metropolitan Government COVID-19 Data Archive [21]. In the dataset, the number of COVID-19 infections was tallied at the local government level. As the waste data used were only available on an annual basis, the number of COVID-19 cases were totaled per year to match the period. The percentage of the infected population was calculated by dividing the number of COVID-19 cases by the population size.

Table 1
Descriptive statistics of study variables.

Variable	2018		2019		2020		2021	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total municipal solid waste (MSW)	380.4	199.1	392.0	182.9	382.4	146.1	407.1	223.1
Plastic waste	9.5	7.4	10.4	7.8	17.5	9.0	15.3	4.9
Food waste	101.8	47.0	97.0	40.7	90.6	30.5	89.6	29.9
Medical waste	6.2	6.0	6.2	6.2	6.2	5.9	7.2	6.8
COVID-19 infection	N/A		N/A		1.7	0.3	21.8	2.8
Food and lodging industry employment (square km)	883.5	580.4	885.9	606.7	764.2	474.3	753.3	464.9
Population (square km)	17486.2	4838.5	17386.4	4811.4	17230.2	4750.2	16921.6	4702.0

*Note: Total MSW, and plastic, medical, and food wastes are in kg per capita scale. COVID-19 infection scale comprises the number of individuals infected per 1000 citizens.

3.1.5. Food and lodging industry employment

The Korean Standard Industrial Classification established by Statistics Korea (the Official Statistics Agency of Korea) was used to extract data on food and lodging industry employees within a region or jurisdiction. The data for these variables were downloaded from the Industrial Classification Data Archive of the Seoul Metropolitan Government [22]. The variables were divided by the regional surface area (square km) to investigate the changes in the food and lodging industry employment at the regional level.

4. Results

4.1. Descriptive analysis

Descriptive statistics of the study variables are shown in Table 1.

During the pandemic, the total amount of MSW generated showed little variation. MSW per capita decreased by 2.4% between 2019 and 2020, but increased by 6.5% between 2020 and 2021. Therefore, MSW did not increase rapidly during COVID-19.

Plastic waste disposal increased by 67.8% in 2020. Despite an increase in the number of COVID-19 cases in 2021, the volume of plastic waste decreased by 12.4% compared with the previous year. Furthermore, the increased amount of plastic waste accounted for less than 2% of the total generated MSW during the pandemic.

Food waste generation decreased in both 2020 and 2021. Therefore, less food waste was generated during the COVID-19 period than in the pre-COVID-19 period.

Medical waste generation showed no notable increase in 2020 but increased by approximately 16.8% in 2021. This increase could be attributed to the rapid increase in COVID-19 cases in 2021. Medical waste increased by approximately 1 kg per capita in 2021, accounting for approximately 0.25% of total generated MSW.

The average number of COVID-19 cases (per thousand; only available from 2020) was only 1.7 in 2020 but rose to 21.8 in 2021, with an increase of more than 1175%. Employment in the food and lodging industry decreased by 13.7% and 1.4% in 2020 and 2021, respectively. The population showed minor changes during the study period.

The changes in waste generation by each waste category are shown as annual changes in Table 2. The following are the results for the first (2020) and second (2021) years of the pandemics: First, approximately 72% of the jurisdictions showed an increase in plastic waste during the first year of the pandemic, whereas 48% experienced an increase in plastic waste during the second year. Although the overall amount of plastic waste increased, the pandemic did not positively affect its generation in most jurisdictions. Second, in the first year of COVID-19, 72% of gus had less food waste, whereas 68% of jurisdictions had less food waste in the second year. Therefore, COVID-19 had a negative effect on food waste. Third, approximately 48% of the gus showed an increase in medical waste generation in the first year, whereas 88% of the gus showed an increase in medical waste in the second year. This suggests that the amount of medical

Table 2
Percent changes in waste generation by each waste category.

Year/Jurisdiction	2020	2021	2020	2021	2020	2021	2020	2021
	Plastic waste		Food waste		Medical waste		Food and lodging industry employment	
Dobong-Gu	−11.4	10.0	−5.7	1.1	0.03	0.4	−56.8	0.2
Dongdaemun-Gu	5.5	−21.0	0.2	4.7	−0.2	1.0	−173.8	−2.5
Dongjak-Gu	12.4	−8.2	−4.7	−2.5	−0.7	0.1	−138.1	−26.9
Eunpyeong-Gu	−2.4	5.0	5.0	−0.5	0.8	1.2	−48.9	3.1
Gangbuk-Gu	1.5	1.3	−3.7	−3.1	0.1	0.5	−69.0	0.0
Gangdong-Gu	13.5	2.0	−9.4	5.0	−1.5	1.7	−90.5	10.8
Gangnam-Gu	4.4	−2.4	85.6	−5.3	−0.4	1.3	−145.0	−76.5
Gangseo-Gu	9.8	−6.1	−9.3	−5.6	0.6	0.5	−67.6	11.3
Geumcheon-Gu	−4.4	−4.6	−6.4	1.3	0.4	−0.2	−97.8	−7.8
Guro-Gu	8.3	0.3	−6.8	0.6	−0.4	0.7	−78.2	−30.6
Gwanak-Gu	4.5	6.1	0.5	−0.3	−0.1	0.7	−79.7	−1.2
Gwangjin-Gu	34.1	−28.4	−5.7	−2.6	−0.2	0.9	−103.3	−50.4
Jongno-Gu	−1.9	−11.9	−46.2	−5.7	−0.7	4.9	−180.8	−13.1
Jung-Gu	−2.3	9.6	14.4	2.6	1.0	4.8	−775.2	−20.2
Jungnang-Gu	−2.8	7.3	46.7	−0.9	−0.2	0.8	−80.1	9.0
Mapo-Gu	7.9	1.4	−35.5	−5.8	0.0	0.2	−154.2	−12.7
Nowon-Gu	12.3	−0.1	−3.1	−0.1	0.1	1.1	−52.9	13.5
Seocho-Gu	12.4	−4.0	−18.2	−1.9	−0.6	1.5	−73.8	−40.4
Seodaemun-Gu	7.7	−3.7	−9.1	0.4	−1.2	1.7	−120.2	−8.6
Seongbuk-Gu	23.9	5.0	−3.9	−0.5	−0.3	0.3	−77.3	10.7
Seongdong-Gu	10.1	−3.2	7.5	−0.1	0.1	2.1	−67.6	30.2
Songpa-Gu	15.5	−7.6	−100.2	−2.4	0.4	1.5	−6.4	−100.8
Yangcheon-Gu	9.8	5.5	−20.3	0.8	−0.4	0.7	−87.8	29.9
Yeongdeungpo-Gu	−5.1	1.0	−13.9	−3.7	0.5	−2.0	−124.6	10.9
Yongsan-Gu	13.3	−7.4	−16.1	−0.7	3.1	−0.2	−93.8	−10.1
Increased (n)	18	12	7	8	12	22	0	10
Decreased (n)	7	13	18	17	13	3	25	15

*Note: Plastic, food, and medical wastes are in kg per capita scale.

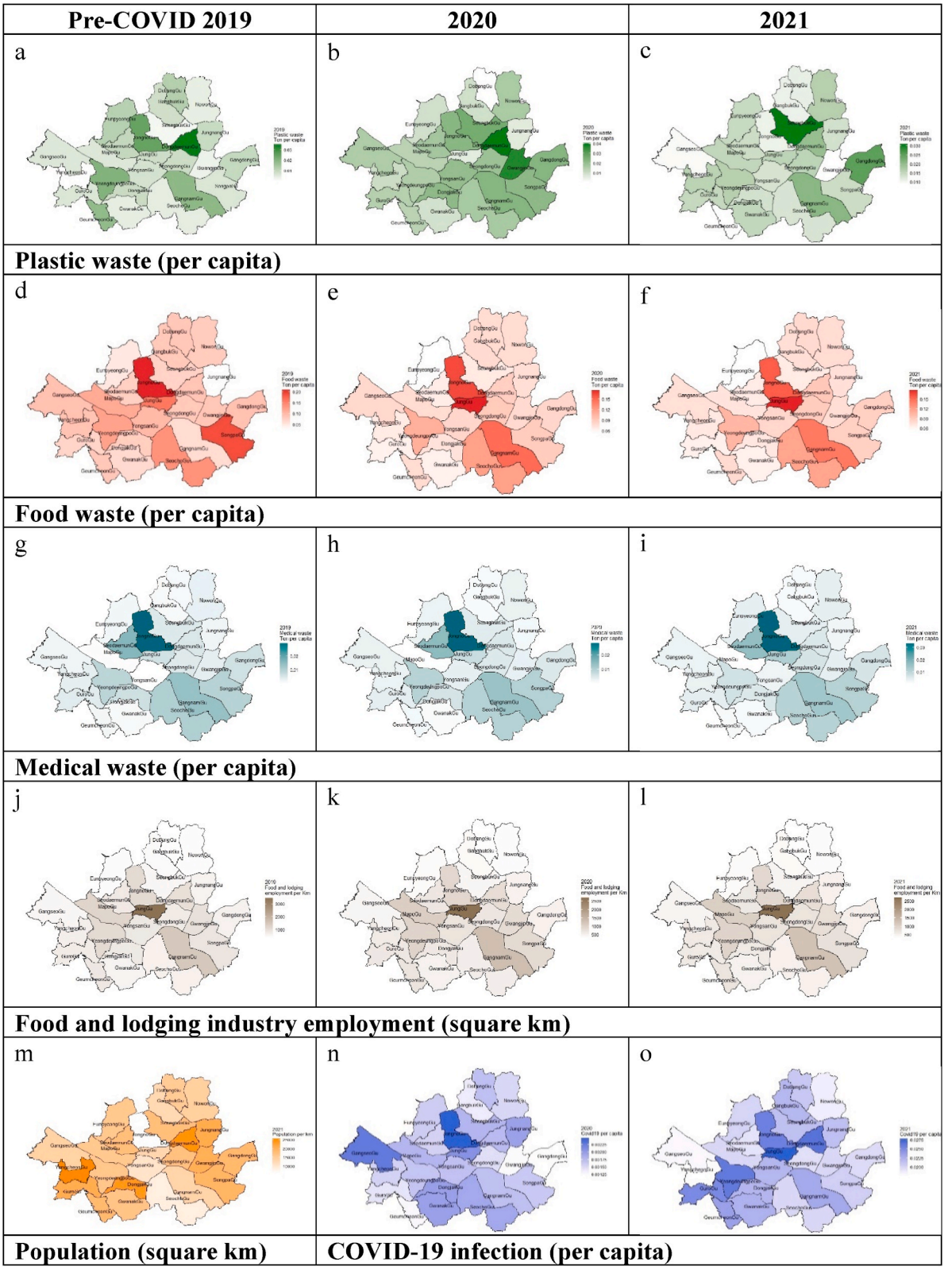

Fig. 1. Spatial distribution pattern analysis of plastic waste(a-c), food waste(d-f), medical waste(g-i), food and lodging industry employment(j-l), population(m), and COVID-19 infection(n,o).

care increased with the increasing number of COVID-19 cases. Finally, all 25 gus showed a decline in employment in the food and lodging service industry in the first year, whereas 60% of the gus showed a decrease in employment in the second year. Therefore, employment in the food and lodging industry was negatively impacted by the COVID-19 pandemic.

4.2. Spatial distribution pattern analysis

A spatial distribution pattern analysis was performed to investigate whether there were any consistent density changes in the waste generation-related variables of the 25 gus between the pre-COVID-19 and COVID-19 periods. Fig. 1 depicts the spatial distribution patterns from 2019 to 2021. Although the density pattern may alter, it does not affect the waste generation rankings of each region. If COVID-19 had a universal impact in all areas, the rankings of the study variables would change little regardless of the amount of waste generated. Therefore, the rankings of each study variable were coded from highest to lowest (a higher generation equals a higher rank). Fig. 2 shows the fluctuations in waste generation, food and lodging industry employment, and COVID-19 infection rankings.

Figs. 1 and 2 illustrate the following: Plastic waste density patterns did not match for the pre-COVID-19 and COVID-19 periods. The majority of the jurisdictions showed changes in their rankings during the study period. Therefore, although the overall amount of plastic waste increased during COVID-19, the increase rates among jurisdictions showed little similarity. Notably, food waste density patterns remained consistent over both years, with a minor decrease in the amount. Prior to COVID-19, the food waste disposal rankings were relatively erratic, whereas they had a more consistent trend during the COVID-19 period. This suggests that food waste generation decreased during the pandemic in most jurisdictions. Medical waste generation density patterns were stable from 2019 to 2021. During the study period, the medical waste disposal rankings of most regions showed minimal changes. This indicates that the

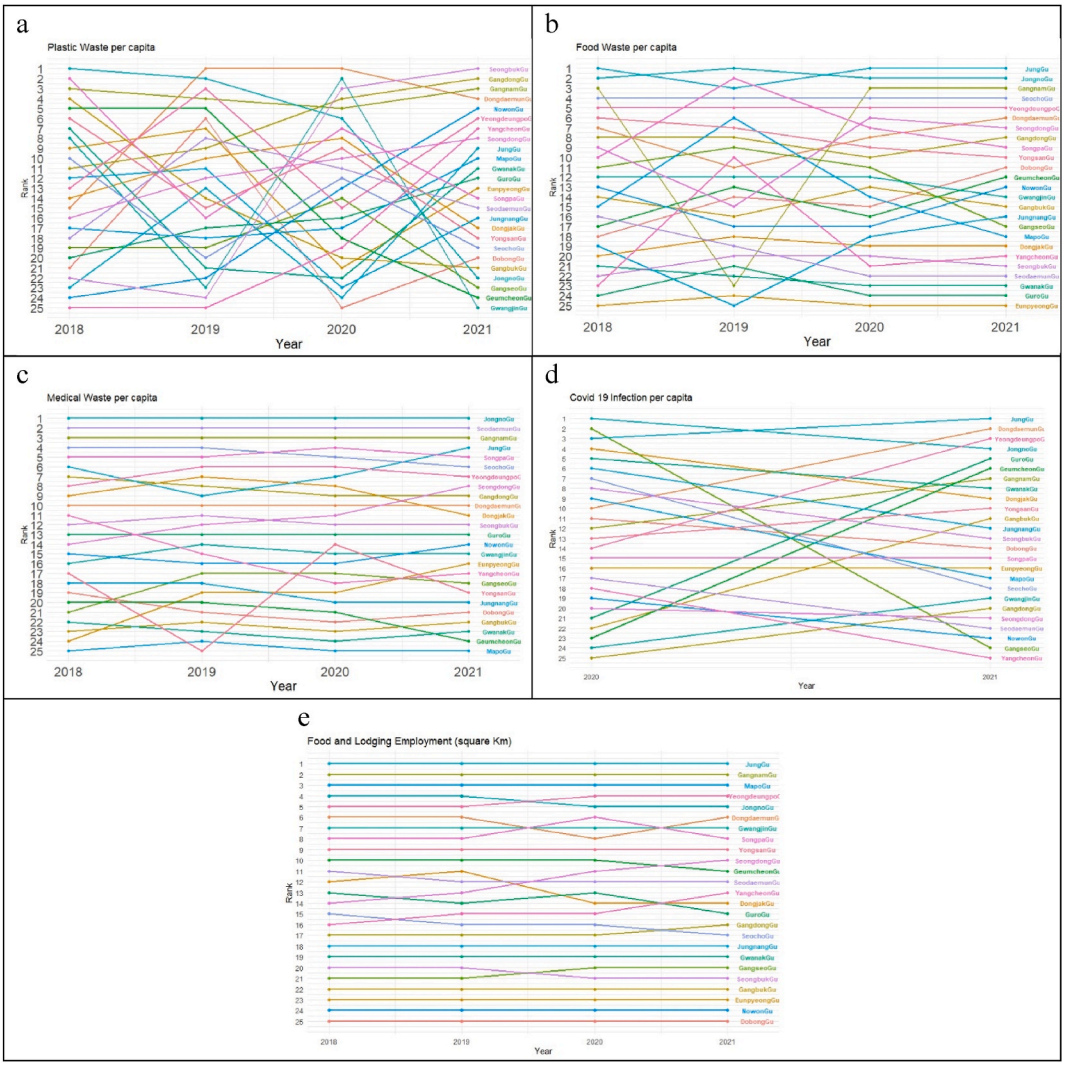

Fig. 2. Ranking of each gu for plastic waste (a), food waste (b), medical waste(c), COVID-19 infection(d), food and lodging employment(e).

amount of medical waste increased during the pandemic, but the waste generation rank remained relatively stable. The COVID-19 infection rate rankings changed in most jurisdictions during 2020–2021. Compared to 2020, there was little similarity in density and ranking in 2021, when COVID-19 cases surged. Food and lodging employment density patterns were consistent across all years,

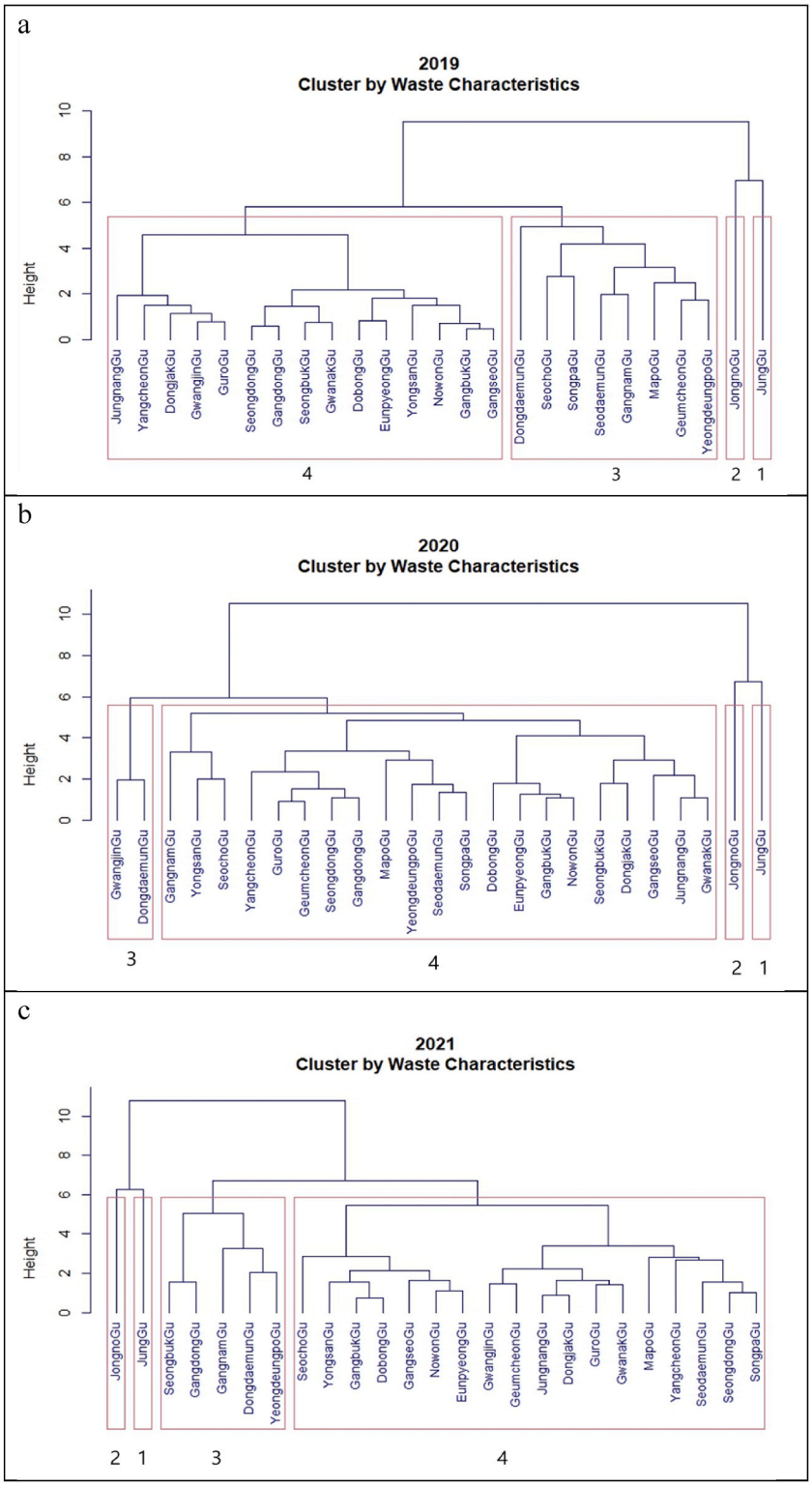

Fig. 3. Cluster analysis of gus by waste characteristics in year 2019(a), 2020(b), 2021(c).

with relatively minor changes in employee number rankings. However, the number of jobs decreased, implying a simultaneous decrease in employment in multiple jurisdictions.

4.3. Cluster analysis results

A cluster dendrogram is shown in Fig. 3. Table 3 presents the mean values of the study variables to reiterate the hierarchical cluster analysis and identify the differences in waste characteristics among the clusters.

Four clusters were identified within the 25 jurisdictions in all periods. Jung-Gu (Cluster 1) remained a distinct cluster for the entire period, whereas members of the other clusters changed over time. Clusters 1 and 2 had similar members throughout the study period, whereas Clusters 3 and 4 did not show a clear pattern of overlapping members. Cluster 1 had the highest employment in the food and lodging industry across all years. During the pandemic, Cluster 1 also had the highest generation of food waste and number of COVID-19 cases. Cluster 2 generated the most medical waste for all years. Furthermore, Cluster 2 had the lowest population density for all years. Clusters 3 and 4 exhibited low study variable levels during the study period, except for a few instances. For example, in 2020, Cluster 4 had the highest level of plastic waste generation and population density. Similarly, in 2021, Cluster 3 had the highest population density and plastic waste generation. In summary, the clusters showed several recurrent patterns. Clusters 1 and 2 had high levels of food and medical wastes, COVID-19 cases, and food and lodging employment during the pandemic, despite having low population densities. Except for high population densities and plastic waste generation, most study variables remained low in Clusters 3 and 4.

5. Discussion

In this study, the impact of COVID-19 on variations in waste generation patterns during the pandemic was investigated. The results of the descriptive and spatial distribution pattern studies were inconclusive, indicating that the relationship between COVID-19 and waste generation patterns is yet unknown. The results suggest that the jurisdictions (gus) can be divided into several groups depending on the waste generation characteristics of the study variables. The overall amount of plastic waste increased during the pandemic. However, the effect of COVID-19 was ambiguous at the regional level because the relationship between the number of COVID-19 cases and amount of plastic waste was neither positive nor linear. Furthermore, most jurisdictions revealed a decrease in plastic waste in 2021. Cluster analysis revealed that gus with high population densities generated the highest levels of plastic waste during the pandemic. Therefore, pandemics such as COVID-19 may not necessarily lead to more plastic waste generation at the regional level. Further research is needed to determine why some jurisdictions generated more waste than others during the pandemic, which will aid in identifying the characteristics of regions that generate more plastic waste. Further, it will also help in establishing tailored regional policies rather than policies that presume a rapid increase in plastic waste in all jurisdictions during the pandemic period.

During the pandemic, most jurisdictions exhibited a decrease in food waste. This finding contradicts previous studies, which stated that food waste increased during the pandemic because of stockpiling and panic buying. However, there were several exceptions. Cluster analysis revealed that during the pandemic, the cluster with the highest COVID-19 infection rate had the most food waste and food and lodging employment. This suggests that COVID-19 instances may generate more food waste in jurisdictions with high concentrations of food and lodging employment. Furthermore, the same cluster did not have the highest level of food waste generation prior to COVID-19. Future research should therefore analyze why jurisdictions with high concentrations of food and lodging services generated more food waste despite social distancing measures and a decrease in employment during the pandemic.

The generation of medical waste increased substantially in 2021 but not in 2020. Furthermore, the jurisdictions with the highest level of medical waste did not alter during the study period, suggesting that medical waste increased in most jurisdictions as the number of COVID-19 cases grew. These results support prior findings, which implied that the amount of medical waste rapidly increased during COVID-19. Nevertheless, approximately half of the jurisdictions saw a decrease in medical waste at the gus level in

Table 3
Mean value of variables in each cluster.

Year	Cluster	Plastic waste	Food waste	Medical waste	COVID-19 infection	Food and lodging industry employment (square km)	Population (square km)
2019	1	8.6	161.0	6.4	0.0	3489.1	13703.6
	2	24.8	210.2	29.1	0.0	1112.8	6769.9
	3	7.8	89.4	4.0	0.0	689.0	17417.3
	4	17.2	88.7	9.6	0.0	1028.8	20135.1
2020	1	6.3	175.3	7.4	2.1	2713.9	13517.6
	2	21.1	144.5	17.2	2.0	959.7	9851.8
	3	11.5	76.2	2.5	1.8	536.6	15599.2
	4	22.0	80.9	6.1	1.6	723.5	20607.5
2021	1	15.9	178.0	12.2	27.9	2693.7	13231.6
	2	15.0	140.2	19.8	23.0	916.4	9635.2
	3	28.3	78.8	5.8	20.7	515.8	18438.2
	4	14.0	78.1	5.1	21.5	650.4	18106.7

*Note: Total MSW, and plastic, medical, and food waste are in kg per capita scale. COVID-19 infection scale comprises the number of individuals infected per 1000 citizens.

2020. Despite an increase in COVID-19 cases, three jurisdictions produced less medical waste in 2021 than in 2020. This may be because hospitals prioritized COVID-19 patients and reduced other regular medical activities, resulting in a minimal increase or decrease in medical waste. Future research should investigate the trend changes in medical activity to better understand why medical waste decreased in some jurisdictions during the pandemic. Although there was a rapid increase in medical waste in South Korea during the pandemic in 2021, it was minimal in comparison to the overall MSW amount. In Seoul, the primary treatment method for medical waste is incineration which resulted in over 95% of medical waste being incinerated in 2020 and 2021 [20]. This implies that the increase in medical waste during the pandemic in South Korea was manageable, contradicting previous research that highlighted the detrimental effects of substantial increases in medical waste during COVID-19.

The challenges faced by waste management systems during the COVID-19 period were also highlighted. Food waste decreased during the pandemic, plastic waste increased by less than 2% of the total MSW created in Seoul, and the total amount of MSW increased by a small percentage. During 2021, compared to the pre-COVID-19 period, medical waste increased by only 1 kg per capita, and more than 95% of it was incinerated. Therefore, no evidence of an emergency was observed in waste management systems as a result of the outbreak of COVID-19 in this study. Nevertheless, several jurisdictions reported substantial increases in waste during the pandemic, necessitating additional research using case studies.

This study had several limitations. First, annual data were used to examine waste generation during the pandemic. Although shorter time periods would provide more information regarding fluctuations in waste generation, only annual data were available. Second, the study's scope was limited to South Korea, where all jurisdictions have a universal waste policy. Further research in other countries is needed to generalize the results of this study. Third, this study was unable to conduct a panel analysis owing to a limited number of samples and time periods. As a result, this study only provides a preliminary assessment of COVID-19's impact on plastic, food, and medical waste.

6. Conclusions

The current study raised a number of key issues in COVID-19 waste management. Past research has frequently emphasized that increased waste generation during COVID-19 will negatively impact the environment, creating health hazards. However, some studies claim that the pandemic has had little impact on MSW waste amount [12,24]. The important contribution of the current study is that it shows that not all wastes at the local level increased during the pandemic. During the pandemic, plastic waste showed a sharp increase, but at the local level, some jurisdictions recorded a decline. For food waste, the overall trend was downward; however, several jurisdictions showed an increase. Medical waste did not increase in the first year of the pandemic but showed an increase in the second year. Notably, some jurisdictions generated less waste even at the peak of the pandemic.

The current study contributes to the literature by presenting that during a pandemic such as COVID-19, researchers should consider the possibility that not all regions experience problems in waste management. Therefore, regional studies of waste management are necessary to examine disparities in outcomes despite facing the same pandemic. The factors that create excessive waste generation in some regions should also be identified. Future studies should focus on identifying the determinants of waste generation rates and developing region-specific waste management policies.

Author contribution statement

Seejeen Park: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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