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Evolution of COVID-19 municipal solid waste disposal behaviors using epidemiology-based periods defined by World Health Organization guidelines

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ABSTRACT

This study aims to identify the effects of continued COVID-19 transmission on waste management trends in a Canadian capital city, using pandemic periods defined from epidemiology and the WHO guidelines. Trends are detected using both regression and Mann-Kendall tests. The proposed analytical method is jurisdictionally comparable and does not rely on administrative measures. A reduction of 190.30 tonnes/week in average residential waste collection is observed in the Group II period. COVID-19 virulence negatively correlated with residential waste generation. Data variability in average collection rates during the Group II period increased (SD=228.73 tonnes/week). A slightly lower COVID-19 induced Waste Disposal Variability (CWDW) of 0.63 was observed in the Group II period. Increasing residential waste collection trends during Group II are observed from both regression (b = +1.6) and the MK test (z = +5.0). Both trend analyses reveal a decreasing CWDV trend during the Group I period, indicating higher diversion activities. Decreasing CWDV trends are also observed during the Group II period, probably due to the implementation of new waste programs. The use of pandemic periods derived from epidemiology helps us to better understand the effect of COVID-19 on waste generation and disposal behaviors, allowing us to better compare results in regions with different socio-economic affluences.

List of acronyms

CWDV	COVID-19 induced Waste Disposal Variability
CT	Community Transmission
ICU	Intensive care unit
IQR	Interquartile Range
MK	Mann-Kendall
WHO	World Health Organization

1. INTRODUCTION

Following the outbreak in December 2019, COVID-19 was designated as a pandemic on March 12th, 2020, (Ciotti et al., 2020). Since then, confirmed infection cases exceeded 528 million with a global death toll of nearly 6 million by June 3rd, 2022 (WHO, 2022a). Among the total confirmed cases, 16.53% (WHO, 2022b; WHO, 2022c) were reported from North America. As of June 2nd, 2022, the total number of cases ranged from 3,530 to 1,305,100 across Canadian provinces and territories (Government of Canada, 2022). Differences in socio-economic status of the jurisdictions could be responsible for a varying distribution of COVID-19 cases (Chew et al., 2021; Aral & Bakir, 2022; Gaisie et al., 2022). In the Province of Saskatchewan alone, about 138,710 total cases were reported with either a confirmed positive or probable COVID-19 infection (Government of Canada, 2022). Changes in waste quantity and composition during the pandemic are observed across the globe, however the findings are not entirely consistent, as discussed in the literature review. The goal of the present study is to examine municipal solid waste generation characteristics and recycling trends using public epidemiological data and the WHO guidelines. The use of epidemiology-based pandemic periods in waste studies is original, and the proposed analytical approach could minimize the effects of abrupt behavioral changes of the waste generators due to public health order.

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2. LITERATURE REVIEW

2.1. Waste quantity and composition during the COVID-19

The COVID-19 pandemic and the subsequent lockdowns had significant effects on solid waste management which has received greater research focus during this time due to the infectious nature of the SARS-CoV-2 virus. Globally, the COVID-19 pandemic has altered both the amount and composition of solid waste (Richter et al. 2021a; Yousefi et al., 2021; Mahyari et al. 2022). Throughout the pandemic, behavioral changes of waste generators and the government-imposed administrative measures have led to variations in waste collection (Ikiz et al. 2021, Richter et al., 2021b), waste processing (Purnomo et al. 2021, Bardi and Oliaee, 2021), and waste disposal (Richter et al., 2021a, Wang et al. 2021). However, the effects of COVID-19 on waste generation and disposal behaviors are not consistent globally, and often vary according to differences in geographic locations, socio-economic conditions, and governmental administrative measures. Urban and Nakada (2021) found that solid waste generation decreased in Brazilian cities when temporary COVID-19 health measures were in effect. A similar decline in waste generation in Lisbon was documented by Sarmento et al. (2022). In contrast, Filho et al. (2021a) reported a higher waste generation rate in connection with an increased consumption of packed foods among 204 participants from 23 countries, and an abrupt influx of plastic packaging waste in the residential waste stream (Filho et al., 2021b).

Findings from waste composition studies during the COVID-19 pandemic are also inconsistent, specifically with respect to plastic, food, and biomedical wastes. The increased sense of hygiene during the global pandemic has contributed to an increase in the plastic waste from packaging materials and personal protective equipment (Vanapalli et al. 2021, Wang et al. 2021). Plastic usage in the healthcare industry experienced an exponential growth (Torkayesh & Simic, 2022). On the other hand, plastic usage in commercial industries was found to decrease owing to their restrained operation hours during lockdowns (Fan et al., 2021), reducing the total plastic waste. Studies on the generation of food waste during the pandemic are also not entirely consistent. Rodgers et al. (2021) conducted an online survey and found that food waste decreased in the United States during the COVID-19 pandemic due to increased home cooking, alternative food choices, and fewer trips to grocery stores. However, Babbitt et al. (2021) reported an increase in food waste in New York using an online survey due to residents stockpiling and bulk buying during pandemic. On the contrary, Laila et al. (2021a) attributed the decrease in food waste in Canadian households to adopted food management strategies such as meal planning and cautious buying. Richter et al. (2021b) examined the landfill disposal records in Regina, the capital city of Saskatchewan, Canada, and reported a sharp increase in residential waste disposal during the first wave of COVID-19 despite a mild reduction in overall disposal rate, and attributed this in part to increased food waste generation. The biomedical waste disposal rates also change geographically. Biomedical waste in Bangladesh was found to increase by 25 times during COVID-19 (Chowdhury et al., 2022). Al-Omran et al. (2021) also reported an increase in COVID-19 medical waste with the increase in the number of new cases in the Kingdom of Bahrain. COVID-19 patients, as well as facilities that quarantine them, contributed to the surge in biomedical waste (Valizadeh et al., 2021; Thakur, 2022). Singh et al. (2022), on the other hand, reported a sharp decrease in hospital waste in Dehli, the capital city of India. Similarly, Richter et al. (2021a) reported a decrease in biomedical waste disposal in Regina, Canada, during pandemic.

2.2. Inconsistencies on COVID-19 waste studies

Some of these apparent discrepancies in literature may be explained in part by the differences in defining the COVID-19 periods. Aurpa (2021) found a positive association of plastic waste generation with COVID-19 confirmed cases during pandemic in Irving, Texas, United States. Aurpa (2021) curtailed the pandemic period between April 2020 and December 2020, and the study considered the start of vaccination as a terminal point. In a Canadian study, Richter et al. (2021b) documented an increase in household waste in Regina during the COVID-19 lockdown, while there was an overall decline in the total waste disposal (Richter et al., 2021a). Evidently, no attempt has been made to define the pandemic periods based solely on the virulence of COVID-19 in North America (Aurpa, 2021; Richter et al., 2021a; Richter et al., 2021b) and in other places (Filho et al., 2021b; Hantoko et al., 2021; Urban & Nakada, 2021).

Temporal trends based on administrative COVID-19 measures such as lockdown and vaccination protocol (Ragazzi et al., 2020, Aurpa 2021, Vu et al., 2021a) are helpful in studying short-term behavioral changes such as panic buying, stockpiling, and elevated sense of personal hygiene. However, the use of governmental administrative measures probably overestimated the impact of COVID-19 on solid waste management because administrative periods depend heavily on the economic (Auray & Eyquem, 2020; Fosco & Zurita, 2021), social (Tisdell, 2020; Yezli & Khan, 2020), and political (Acedański, 2021; Besley & Dray, 2022) affluence of the study area.

This study instead aims to identify the effects of continued COVID-19 transmission on solid waste management trends, using pandemic periods defined from epidemiology and the World Health Organization (WHO) guidelines. The proposed definition of study periods does not rely on the COVID-19 administrative measures, and is less sensitive to the political and socio-economic differences of the study area. It is hypothesized that the use of pandemic periods derived from epidemiology will help us to better understand the effect of COVID-19 on waste generation and disposal behaviors, allowing us to better compare results in regions with different socio-economic affluences.

2.3. Study objectives, novelty, and contribution

The study objectives are to (i) define the COVID-19 pandemic periods with respect to solid waste management using public epidemiological data and the WHO guidelines, and (ii) examine waste generation characteristics and recycling trends in view of the level of transmission in the City of Regina, Canada, using linear regression and Mann-Kendall tests. The use of epidemiology-based pandemic periods in COVID-19 waste studies is original, and we are not aware of any similar works. The proposed analytical approach could minimize the effects of abrupt behavioral changes of the waste generators induced by the administrative health measures and public orders imposed by regulators such as lockdown and mandatory self-quarantine. It is believed that the use of pandemic periods based on epidemiology can better capture the effects of viral COVID-19 exposure on waste generation and recycling. This study adopts WHO guidelines on COVID-19 epidemiology (WHO, 2021) to define the pandemic periods, overcoming jurisdictional and demographic barriers between countries. The approach is versatile and could facilitate rapid comparisons on COVID-19 waste generation and recycling trends between jurisdictions.

The proposed analytical framework has great practical significances on the development of data-driven waste policy. Mahyari et al. (2022) reviewed 299 COVID-19 waste management studies and found that majority (62%) of them is of descriptive nature. The present work specifically focus on data analysis, allowing waste facility operators and policy makers to better allocate and prioritize resources during a global pandemic.

3. MATERIALS & METHODS

Fig. 1 shows the steps of the analytical framework adopted in this study. Pandemic periods were first established using the epidemiological patterns of the study area. Trends in waste generation and recycling were analyzed related to the periods. The following sections contain a brief detail of each component of the flowchart.

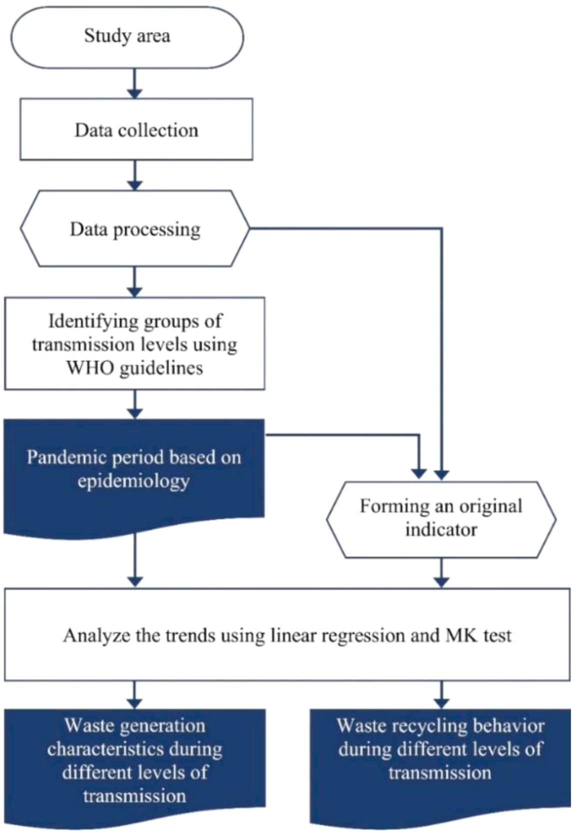

Fig. 1. Methodological flowchart.

3.1. Study area

To identify the trends in waste disposal behaviors based on COVID-19 epidemiology, a zone near the city of Regina has been selected. The impacts of the early waves of COVID-19 on waste disposal rates at the Regina landfill have been reported previously (Richter et al., 2021a; Richter et al., 2021b, Vu et al., 2021b). The city has a population of about 215,000 with a population density of nearly 2,100 cap/km^2 (Statistics Canada, 2017a). Following the outbreak in March 2020, the city reported on March 12th, 2020 its first confirmed case. Between March 18th, 2020 and October 20th, 2021, an average of 187.11 hospitalized COVID-19 cases were reported weekly in the Regina zone (Government of Saskatchewan, 2022a). Most biomedical waste generated at the hospitals is collected by private contractors. Along with the biomedical waste from the hospitals, waste from five different streams are being co-disposed at the Regina landfill. Other streams include mixed solid waste, construction and demolition waste, asphalt only, mixed asphalt shingles, and grit (Adusei et al. 2022). The Regina landfill has been serving all the nearby communities since 1961 (Strunk, 2009), and has an active groundwater monitoring program (Pan et al., 2019a,b) and a landfill gas management system (Bruce et al. 2017, Bruce et al. 2018). Over 30% of the waste disposed in the Regina landfill are collected via residential curbside collection (City of Regina, 2020). A city-wide waste collection system serves 67,000 properties via residential curb-side pickup in Regina (City of Regina, 2022).

3.2. Data collection and processing

Epidemiological data such as the records of inpatient and intensive care unit (ICU) hospitalizations between March 18th, 2020 and January 24th, 2022 were acquired from the provincial portal (Government of Saskatchewan, 2022a). The sum of inpatient and ICU hospitalizations represents the hospitalized cases in this study. Other epidemiological records such as new cases and deaths were obtained from a separate public portal (Government of Saskatchewan, 2022b). All these health and ICU records were reported from healthcare facilities from 27 communities across the Regina zone, including the City of Regina (Government of Saskatchewan, 2022c).

Inconsistencies in Canadian waste data using questionaries' are not unusual (Wang et al., 2015). Hence, collection and disposal data are obtained directly from historical records at Regina landfill from January 1st, 2013 to October 26th, 2021 (Eslami et al. 2022a; 2022b). The amount of waste that was collected via residential curbside pickup program in Regina has been reported as total residential waste collected in this study. Total waste disposed refers to the sum of waste from all six different waste streams that was co-disposed at the Regina landfill within the 8.8-year study period. Recyclables are processed by another unit and not included in the collection and disposal data.

The daily landfill records and epidemiological records were verified and validated, and then aggregated into weekly datasets. The weekly sets were adopted in this study to reduce irregularities such as zero disposal rates during statutory holidays and minimize the lagging effects of COVID-19 laboratory testing on epidemiological data.

3.3. Statistical strategy to establish pandemic period

The records of COVID-19 hospitalized cases and ICU data in the Regina zone during the study period were averaged over two weeks to account for fluctuations detected in the preliminary trials. Given a metropolitan census population of under 236,500 (Statistics Canada, 2017b), the weekly average hospitalized cases were reported as number of cases per 100,000 people. The thresholds of epidemiological indicators implemented to identify the levels of community transmission (CT 1 ~ CT 4) can be found in the supplementary Table 1. The thresholds for CT level were adopted from the WHO interim guidance (WHO, 2021). Among the epidemiological indicators, hospitalized cases were selected to define the pandemic period. The four levels of transmission were aggregated into two distinct groups (i.e., Group I period: CT 1 + CT 2, Group II period: CT 3 + CT 4), to account for transitional phases of transmission and to ensure a continuous timeline with reasonable data points ($n > 30$) for meaningful trend analyses in each group.

3.4. Formulation of an original indicator

An original indicator known as COVID-19 induced Waste Disposal Variability (CWDV) is proposed to determine the temporal variations of waste disposal rates. CWDV quantifies the change in waste disposal due to COVID-19 transmission and is less sensitive to administrative measures. CWDV compares the waste disposal rates before and during COVID-19 within a given jurisdiction using epidemiological data (Eq. 1). CWDV is a dimensionless parameter and can be easily computed using readily available epidemiological records. Since epidemiological data is freely accessible, CWDV is versatile and can be applied elsewhere.

Waste data from different time periods are required to compute CWDV. Based on epidemiology, weekly waste disposal data between the week of March 18th, 2018 and October 20th, 2019 has been selected as the waste disposal period prior to the COVID-19 transmission. Weekly waste disposal data between the week of March 18th, 2020 and October 20th, 2021 has been considered as waste disposal period during COVID-19. A two-year interval between these time series data has been adopted to avoid overlapping with the earlier waves of COVID-19. Waste disposal prior to March 18th, 2018 was not considered to avoid including potential long-term effects at the Regina landfill (Richter et al. 2021a). Weekly CWDV between March 18th, 2020 and October 20th, 2021 were calculated and examined. CWDV uses epidemiological records to capture the direct effect of COVID-19 virulence on waste disposal behaviors at a given jurisdiction. A lower CWDV value at a given time may indicate a lower amount of waste being disposed or a decrease in waste generation, or an increase in waste recycling, or a combination of these factors.

$$\mathrm{CWDV} = \frac{\text{Waste disposal rate during epidemiological COVID} - 19 \text{ period (tonnes/week)}}{\text{Waste disposal rate before epidemiological COVID} - 19 \text{ period (tonnes/week)}} \quad (1)$$

3.5. Analyzing trends

Waste generation is complex and depends on many socio-economical and climatic factors, and trend analysis is conducted in this study to identify the evolution of the waste generation behaviors with respect to time. Both linear regression and Mann-Kendall (MK) test were used to detect trends in residential waste collection and CWDV in this study. A similar analytical approach was adopted by Chowdhury et al. (2017) for detection of trends of waste diversion in Ontario, Canada. In this study, residential waste collection rate and CWDV were considered independent variables, whereas epidemiology-based periods were considered dependent variables to analyze the trends.

3.5.1. Linear regression analysis

Linear regression analysis is commonly used to detect linearity between variables within the temporal datasets. The regression line is expressed using the following Eq. (2).

$$Y = a + bX \quad (2)$$

where,
Y = dependent variable
X = independent variable
a = intercept
b = slope

The coefficient of determination (R^2) of the resulting equation indicates the degree of fitness of the line in terms of the variables considered. A value of R^2 closer to 1.0 indicates an increasing linearity (Forthofer et al., 2007). The non-zero slope of the best-fit line can be positive (increasing trend) or negative (decreasing trend).

3.5.2. Mann-Kendall (MK) test

Unlike linear regression, the MK test is a non-parametric statistical tool to identify trends within a temporal dataset. Given the sample size, the use of the MK test may be advantageous as the normality of the set is not required. The MK test is also less sensitive to outliers (Wang et al. 2020). For this study, the MK test module under the time series analysis in XLSTAT 2020 was used. It calculates the S statistic and its variance following the Eq. (3) and Eq. (4) respectively (Mann 1945; Kendall and Gibbons 1990; Addinsoft, 2020).

$$S = \sum_{i=1}^{x-1} \sum_{j=i+1}^{x} \mathrm{sgn}(x_j - x_i) \quad (3)$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5)}{18} \text{ when } n > 8 \quad (4)$$

where, n = number of data points x_i (i = 1, 2, 3 …. n) = independent variables

The standardized z-statistic was calculated using the Eq. (5).

$$z = \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \text{ when } S > 0 \quad (5)$$

$$z = 0 \text{ when } S > 0$$

$$z = \frac{S+1}{\sqrt{\mathrm{Var}(S)}} \text{ when } S > 0$$

The p-values derived from XLSTAT 2020 along with the calculated z-statistic can be interpreted as indicated in the supplementary Table 2.

4. RESULTS & DISCUSSIONS

4.1. Defining pandemic periods for waste management

The temporal variations in average weekly hospitalized cases in the Regina zone from March 18th, 2020 to October 21st, 2020 are shown in Fig. 2. In this study, the periods are defined by the epidemiological data using the criteria stated in Supplementary Table 1. The combined CT 1 lasted for a total 26 weeks, and the combined CT 2 lasted for a total of 6 weeks. CT 3 lasted for a total of 4 weeks, and the duration of CT 4 was 48 weeks during the study period. The maximum value of 303 cases per 100,000 people is observed on April 14th, 2021. The temporal data is used to divide the time series into two distinct groups for trend analysis, using the criteria shown in Supplementary Table 3. The duration of the Group I and Group II periods are 32 weeks and 52 weeks, respectively. The split between Group I and Group II in this study was about 38:62. Trend analyses with respect to both periods are discussed in the following sections.

The boxplots in Fig. 3 shows the epidemiological data (i.e., hospitalized cases, new cases, and deaths) distributions during both groups. The cross symbol represents the mean value and the central bar represents the median. The bottom and top edges of the box represent the first and third quantile, and the whiskers outside of the box represent the minimum and maximum values. Comparisons between epidemiological records in Figs. 3a and 3b show distinct distributions between the Group I and II pandemic periods and confirms the robustness of forming two different groups of pandemic periods.Trend analyses were separately conducted to the groups, as discussed in Section 4.3.

The averages and medians of all of the epidemiological records during Group I period were significantly lower than Group II period, indicating minimal spread of COVID-19 cases during Group I period. The weekly average number of hospitalized cases, new cases, and deaths increased by nearly 51-, 27-, and 90-times during Group II period, respectively (Fig. 3b), likely due in part to a new variant of the virus, B.1.1.7, in the Regina zone (Goverment of Saskatchewan, 2021). According to the government portal, carriers of this variant were diagnosed and confirmed during Group II period in February 2021 (Goverment of Saskatchewan, 2021). The strain of B.1.1.7 had a higher transmissibility than the earlier variants (Frampton et al., 2021), which may have led to higher COVID-19 epidemiological case records during Group II period (Fig. 3b).

Relatively higher data variabilities are observed in Group I period (Fig. 3a), in part due to the shorter period of 32 weeks (Supplementary Table 3). The hospitalized cases and new cases appear to be normally distributed during Group II period, with negligible differences between the mean and median values (Fig. 3b). However, COVID-19 deaths are considerably skewed, with a long tail of low death cases. The skewness may be partly due to the improvement in our understanding of COVID-19 treatments since its first outbreak (Ledford 2020).

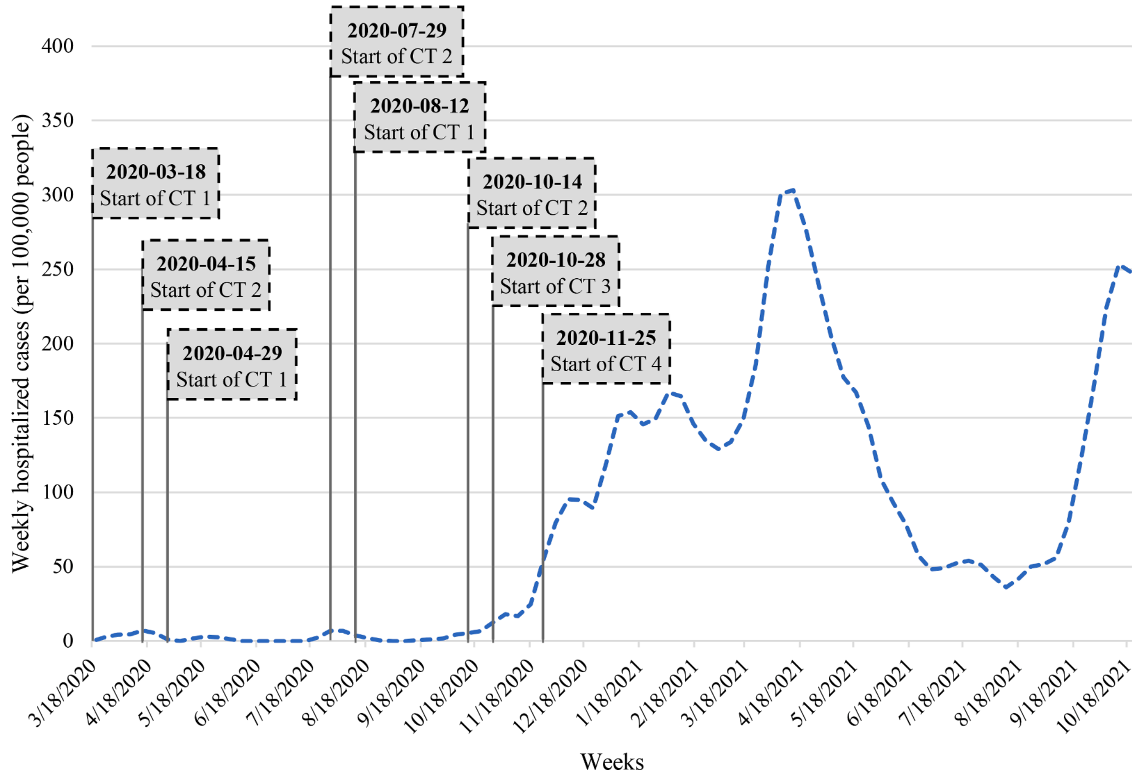

Fig. 2. Temporal variations of hospitalized cases in the Regina zone.

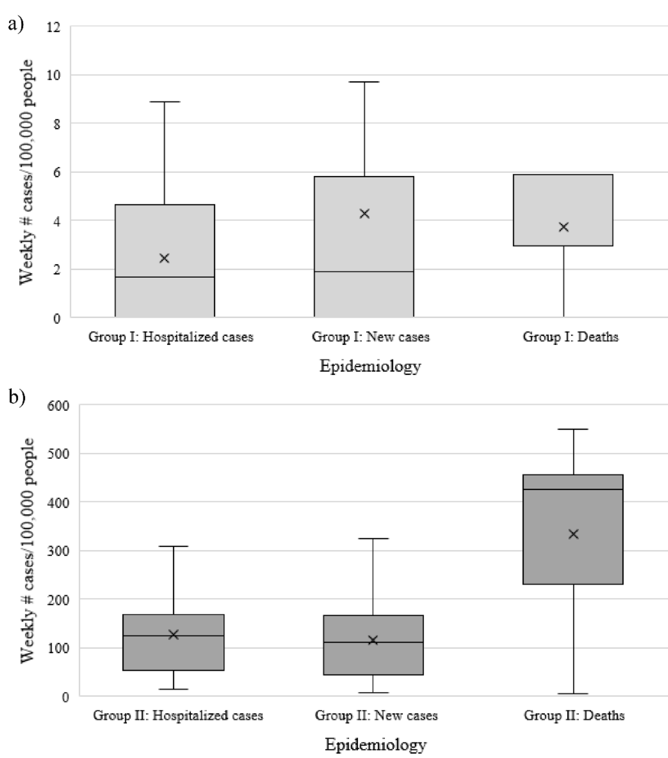

Fig. 3. Distribution of epidemiological data during (a) Group I and (b) Group II of the transmission time period.

4.2. Residential waste collection and COVID-19 induced waste disposal variability

Differences in residential waste collection rates are observed between the Group I and Group II periods. A significant reduction (190.30 tonnes/week) in average waste collected from city households is observed in the Group II period (Table 2). The maximum and minimum collection rates were also lower in the Group II period. The results are interesting as one would generally expect higher residential waste collection rates in the Group II period due to less recycling activities. In many countries, recycling operations were stopped or limited owing to the risk of transmission of COVID-19 via handling solid waste (Yousefi et al., 2021). In this study, COVID-19 virulence appears to have reduced the residential waste generation, probably due to less waste generators at home due to hospitalization.

Despite the overall reduction in average collection rates, data variability increased to a standard deviation of 228.73 tonnes/week (Table 2). The higher data variability during the Group II period may be attributed to several opposing factors on COVID-19 residential waste generation. Quarantined households generated an increased amount of waste resulting from the extensive use of personal protective equipment (Hantoko et al., 2021) and higher food consumption rates (Sidor and Rzymski 2020). Quarantined residents were found relying on online food and grocery delivery services (Filho et al., 2021a), increasing single-use plastic cutlery and packaging waste. A portion of this packaging might end up in the residential waste stream due to a higher risk of viral transmission (Oliveira et al., 2021). On the other hand, more home cooking with cautious meal planning reduced residential food waste generation during COVID-19 (Laila et al. 2021a, Rodgers et al. 2021). A decline in overall waste generation rates is also reported by Urban and Nakada (2021) and Sarmento et al. (2022). These opposing factors likely affected households in different ways, explaining the higher data variabilities in the Group II period.

CWDW measures the temporal variabilities in waste disposal behaviors. Unlike the collection rate, the disposal rate includes residential, industrial, commercial, and institutional wastes, as well as other special waste streams. Compared to the Group I period, decreasing average CWDWs are observed in the Group II period. Average CWDW were slightly lower in the Group II period (0.63), with a higher standard deviation (0.13). A higher variability (0.99) is observed in the maximum

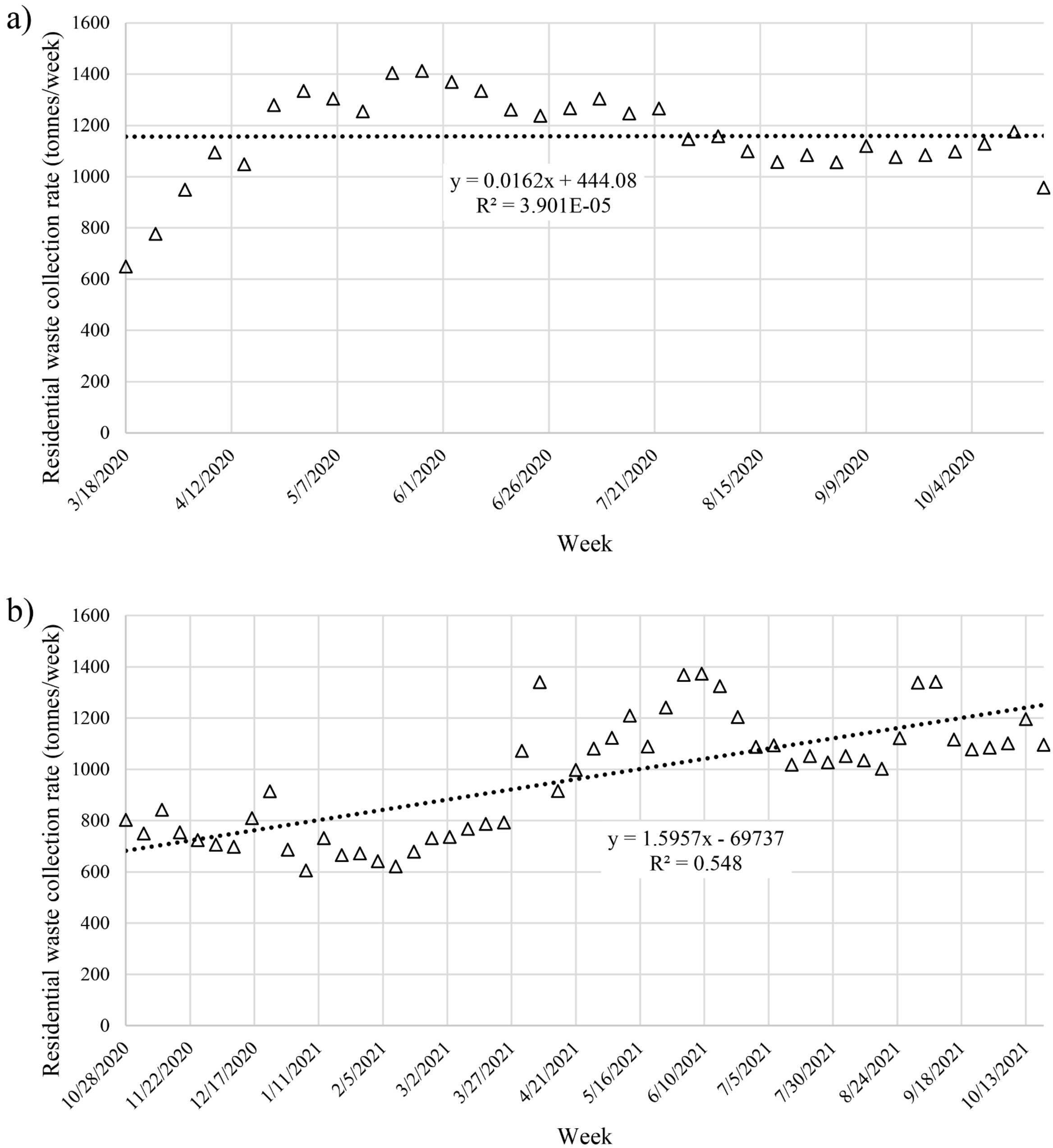

Fig. 4. Temporal variations of residential waste collection rate during a) Group I & b) Group II periods.

value during the Group II period. Overall, the effects of COVID-19 virulence on disposal rates appear less sensitive than on collection rates. Curbside waste collection rate depends on the number of waste generators at home, which inversely related to the hospitalization rate.

4.3. Trend analysis

Both simple linear regression analysis and the MK test fail to detect a statistically significant trend on the residential waste collection rate in Group I (Supplementary Table 3). The trend lines and the R^2 values are shown graphically in Figs. 4a and 5a. The collection rates fluctuated from 649.3 tonnes/week to 1,412.2 tonnes/week, as shown in Fig. 4a. This could be partly due to a shorter epidemiological duration in Group I than in Group II (Table 1). However, increasing trends are observed in both the linear regression ($b = +1.6$) and MK test ($z = +5.0$) in the Group II period. Online shopping was increasingly popular during the subsequent COVID-19 waves (Hodbod et al., 2021), contributing to the increased generation of packaging waste (Pinos et al., 2022). The national retail sales record supports this observation. Specifically, the seasonally adjusted monthly average retail E-commerce sales increased by nearly 7% from the Group I period across Canada (Statistics Canada, 2022). Fig. 4b shows the collection rates during the Group II period.

Both trend analyses reveal a decreasing CWDV trend during the Group I period (Supplementary Table 3). The linear regression exhibits a mild decreasing trend ($b = -0.0005$) with a weak R^2 of 0.13 (Fig. 5a). The MK test revealed a statistically significant ($p<0.05$) downward trend ($z = -2.25$) in CWDV (Supplementary Table 3). The decreasing CWDV trend could indicate an increasing amount of waste being recycled, diverting the waste from landfill disposal. This could be due to the restoration of normal operation of recycling facilities in the City of Regina during the Group I period. The recycling division of Saskatchewan Association of Rehabilitation Centres resumed its operation in the City of Regina on June 15th, 2020 (Rattray, 2020). The reopening date corresponding well to the trough between the weeks of June 10th to 17th

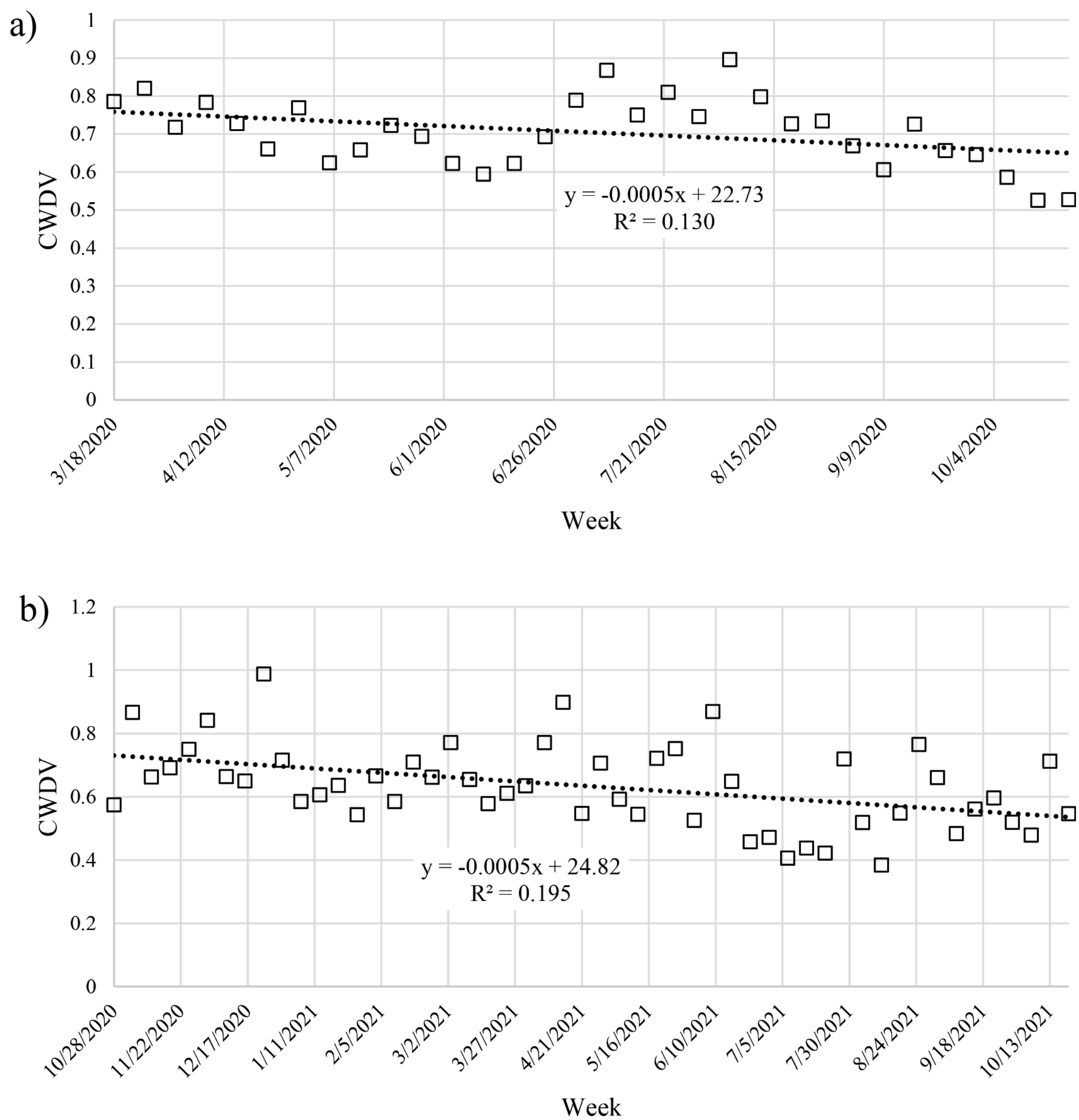

Fig. 5. Temporal variations of CWDV during a) Group I and b) Group II periods.

Table 1
Descriptive statistics for residential waste collection rate and CWDV indicator.

	Residential waste collection rate (tonnes/week)		CWDV indicator (-)	
	Group I	Group II	Group I	Group II
Minimum	649.30	605.60	0.53	0.38
Average	1,157.46	967.16	0.70	0.63
Maximum	1,412.22	1,372.80	0.90	0.99
Standard Deviation	170.39	228.73	0.09	0.13

(0.59<CWDV< 0.62, Fig. 5a).

As shown in Supplementary Table 3, statistically significant ($p<0.05$) downward CWDV trends are observed in both the linear regression (b = -0.0005) and the MK test (z = -3.133) during the Group II period. Changes of CWDV are graphically shown in Fig. 5b. This could suggest an overall increase in waste recycling during the Group II period.

Given that waste handling was considered as a vector for the virus (Yousefi et al., 2021), one would expect an observable decline in waste recycling during Group II with higher COVID-19 virulence. Towards the end of the Group I period, a pilot scale curbside organic waste collection program was implemented in September 2020 (CBC, 2021). The program's continued operation during the Group II period of transmission could have increased the amount of waste being recycled. Moreover, the financial support to the province-wide beverage container collection and recycling system increased by 17.8% in the fiscal year of 2020-2021 as compared to 2019-2020 (Goverment of Saskatchewan,

Table 2
Trend analysis results for residential waste collection rate and CWDV indicator.

	Regression			Mann-Kendall test		
	Slope, b	R^2	*p-value*	*S*	*z*	*p-value*
Residential waste collection rate						
Group I	0.016	< 0.001	0.973	-84	- 1.346	0.180
Group II	**1.596**	**0.548**	**< 0.001**	**642**	**+ 5.058**	**< 0.001**
CWDV indicator						
Group I	**- 0.001**	**0.130**	**0.043**	**-140**	**- 2.254**	**0.023**
Group II	**- 0.001**	**0.195**	**0.001**	**-398**	**- 3.133**	**0.002**

Note: Statistically significant results are bolded.

2020). Such an increase in financial resources might have contributed to an increase in the city-wide waste recycling. The city also reported a 10.5 % increase in waste diversion in 2020 than 2019 (City of Regina, 2020).

The results of trend analysis suggest that a longer pandemic period seems to detect stronger trends in residential waste collection rate and CWDV. While defining the pandemic periods, we found that epidemiology-based pandemic periods could be nearly 5- to 7-times longer than COVID-19 lockdown. Therefore, the trends based on epidemiology-based periods might be more appropriate in developing data-driven waste policy during a future pandemic.

5. LIMITATIONS AND FUTURE WORK

The results of this study are directly related to transmission levels defined by the WHO guideline. The trends were found to be sensitive to the periods defined by the epidemiological data. If available, local health monitoring guidelines can also be used – however, the resulting trends may be less comparable across jurisdictions. Given the indirect evidence, we have attributed the decreasing trends of residential collection and CWDV to the increase in waste recycling; yet, direct evidence is not available to verify this claim. It is suggested for cities to systematically collect data on recyclables. The pandemic periods used in this study can be extended further based on updated epidemiological records. It might also be used to identify the trends in waste generation and recycling on the verge of an epidemiologic transition when more waste data becomes available. Finally, the proposed epidemiology-based analytical framework using CWDV and trend analysis is meant to facilitate comparison between jurisdictions. Data variance and characteristics should be checked before selection of the trend analysis tools. Many other socio-economical and geographical factors should also be considered in combination to evaluate waste management systems in different jurisdictions (Karimi et al, 2022; Richter et al. 2022).

6. CONCLUSIONS

The literature review suggests that all COVID-19 waste studies rely on local governmental administrative health measures or pubic orders to define COVID-19 time parameters. There are no published studies that specifically consider the effect of different levels of COVID-19 viral transmission on waste generation, recycling, and disposal behaviors. In this study, a jurisdictionally comparable analytical method is proposed. The COVID-19 epidemiological data was used to define consistent periods in the time series and to examine trends in waste generation and recycling behaviors.

The averages and medians of all of the epidemiological records during the Group I period were considerably lower. The weekly average number of hospitalized cases, new cases, and deaths were nearly 51-, 27-, and 90-times higher during Group II, respectively. Higher data variabilities are also observed in the Group I period, probably due to the slightly shorter period. Unlike hospitalized cases and new cases, COVID-19 death data during the Group II period is considerably skewed, with a long tail of low death cases.

A reduction of 190.30 tonnes/week in average residential waste collection is observed in the Group II period. It appears that COVID-19 virulence negatively correlated with residential waste generation. Data variability in average collection rates during the Group II period increased, with a standard deviation of 228.73 tonnes/week. The higher data variability may be attributed to several opposing factors on COVID-19 residential waste generation. An average CWDW of 0.63 was slightly lower in the Group II period, with a higher standard deviation of 0.13.

Increasing trends on the residential waste collection rate during Group II are observed from both linear regression ($b = +1.6$) and the MK test ($z = +5.0$). Both trend analyses reveal a decreasing CWDV trend during the Group I period, with a linear regression line slope of -0.0005 and a MK test z statistic of -2.25. The decreasing CWDV trend could indicate an increasing amount of waste diversion from the Regina landfill. Decreasing CWDV trends are again observed during the Group II period, with a linear regression line slope of -0.0005 and a MK test z statistic of -3.133. The decrease trend in CWDV is probably due to the implementation of the pilot scale curbside organic waste program and more financial resources attributed to waste management. The study results were found to be sensitive to the time periods. Caution should be used during the data assessment and interpretation process when different guidelines are used.

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.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scs.2022.104219.

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