

IMPACT OF COVID-19 PANDEMIC ON MUNICIPAL SOLID WASTE IN BANGKOK, 2019-2024: AN INTERRUPTED TIME SERIES ANALYSIS

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Abstract

The COVID-19 pandemic altered consumption behavior and waste generation patterns in major cities worldwide. Quantitative studies in Bangkok remain limited. This study aimed to assess the impact of COVID-19 on per-capita waste generation in Bangkok using Interrupted Time Series (ITS) analysis, comparing pre-, during-, and post-pandemic periods. Monthly waste data from 50 Bangkok districts (October 2010–September 2024, $n = 168$ months) were analyzed using segmented linear regression with Newey-West HAC standard errors ($\text{maxlags} = 12$). Three intervention points were specified: plastic bag ban (January 2020), COVID-19 onset (February 2020), and 4-plastic ban (January 2022). Analysis was performed in Python 3.12. Mean per-capita waste declined from 1.657 kg/person/day pre-COVID to 1.529 kg/person/day during the pandemic (-7.8%), before a partial recovery to 1.610 kg/person/day in the post-COVID period. ITS analysis indicated that the plastic bag ban was associated with a significant immediate reduction of -0.288 kg/person/day ($p < 0.001$), while the COVID-19 intervention was associated with a modest positive level change of +0.033 kg/person/day ($p = 0.039$) and a negative slope change of -0.020 kg/person/month ($p = 0.019$), suggesting a deceleration in waste growth during the pandemic period. These findings highlight the complex interplay between public health emergencies and concurrent waste reduction policies and have implications for waste management planning and emergency preparedness.

Keywords: COVID-19, Municipal solid waste, Bangkok, Interrupted time series

Introduction

The 2019 coronavirus disease (COVID-19) pandemic emerged in early 2020 and spread globally, profoundly affecting economic systems, societies, and human behavior across multiple dimensions (Nalbandian et al., 2021; Raman et al., 2021). One often-overlooked impact was the significant change in municipal solid waste (MSW) generation patterns (Das et al., 2021; Mahmud et al., 2022; Olawade et al., 2024). This shift exhibited complex trends reflecting both the reduction in economic activity and increases in residential waste from increased home consumption and delivery services (Arif et al., 2024; Morais et al., 2026).

Studies across different countries reported varied findings. Kulkarni and Anantharama (2020) reported that waste volumes in major Indian cities decreased by 18–25% during lockdown periods, while research in the United States and Europe documented concurrent increases in plastic and food packaging waste (Prata et al., 2020). In Southeast

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Asia, similar heterogeneity was observed, with waste composition and generation rates responding differently depending on urbanization levels, lockdown stringency, and pre-existing waste management infrastructure (Mol & Ouyang, 2011).

Bangkok, as one of Southeast Asia's largest metropolitan areas, presents a particularly important case study. The city generates approximately 10,000–11,000 tonnes of MSW per day, managed through a centralized collection system administered by the Bangkok Metropolitan Administration (BMA) across 50 districts (Chiemchaisri et al., 2007; Menikpura et al., 2013). Prior to the pandemic, Bangkok's waste generation had been increasing steadily, driven by rapid urbanization, population growth, and expanding consumption patterns (Kasikorn Research Center, 2020). Waste management in Bangkok is further shaped by a substantial informal recycling sector, which intercepts a significant proportion of recyclable materials before formal collection, complicating official waste quantity estimates (Wilson et al., 2006).

Thailand implemented several concurrent waste-related policies around the time of the pandemic onset. The single-use plastic bag ban came into effect in January 2020, targeting major retail outlets, followed by an expanded ban on four categories of single-use plastics in January 2022 (Mabayo, 2025). Bangkok subsequently implemented lockdown-equivalent social distancing measures beginning in March 2020, following the declaration of a national state of emergency (Phitthayaphinant et al., 2021). The near-simultaneous occurrence of these policy events and the pandemic onset created an analytical challenge: isolating the independent contribution of COVID-19 to observed changes in waste generation.

Interrupted Time Series (ITS) analysis is a well-established quasi-experimental method for evaluating the impact of policies or sudden events on time series outcomes, as it explicitly accounts for pre-existing trends and enables separation of level and slope changes at defined intervention points (Bernal et al., 2017; Kontopantelis et al., 2015). ITS has been applied to evaluate public health interventions (Ewusie et al., 2020), environmental policy impacts (Wagner et al., 2002), and, more recently, the effects of COVID-19 on healthcare utilization and population behavior (Siriwardhana et al., 2021). Its application to municipal waste data in the context of overlapping policy interventions represents a methodologically appropriate approach to this research problem.

Quantitative studies examining COVID-19's impact on MSW generation in Bangkok and Thailand more broadly remain limited. Most existing Thai studies have focused on waste composition changes, healthcare waste surges, or qualitative policy analysis, leaving a gap in rigorous longitudinal assessment of per-capita waste generation trends (Phitthayaphinant et al., 2021). This study addresses that gap by applying ITS methodology to 168 months of district-level waste data from all 50 Bangkok districts, spanning October 2010 to September 2024, to isolate the effects of COVID-19 from concurrent plastic reduction policy interventions.

While broader policy evaluation of Bangkok's sequential waste management interventions including national master plans and plastic reduction policies is addressed in a companion study, the present study focuses specifically on isolating the independent contribution of the COVID-19 pandemic to changes in per-capita waste generation, using sensitivity analysis across alternative intervention dates to address the analytical challenge posed by the near-simultaneous onset of the plastic bag ban.

Methods**Data Sources and Preparation**

Monthly municipal solid waste data from 50 Bangkok districts covering October 2010 to

September 2024 ($n = 168$ months) were analyzed. The outcome variable was per-capita waste generation (kg/person/day), calculated by dividing monthly waste weight by the total Bangkok metropolitan population and the number of days in the month. Time periods were categorized as follows: (1) pre-COVID period (October 2010–January 2020, $n = 112$ months); (2) COVID period (February 2020–December 2021, $n = 23$ months); and (3) post-COVID period (January 2022–September 2024, $n = 33$ months). This study is analytically distinct from related work examining broader policy sequences in Bangkok in that it specifies a three-intervention model designed to isolate the COVID-19 effect, incorporates sensitivity analysis across five alternative COVID-19 onset dates, and reports full model coefficients for all intervention terms.

Interrupted Time Series Analysis

Segmented linear regression following Bernal et al. (2017) was employed. The model equation was:

$$Y_t = \beta_0 + \beta_1 t + \beta_2 D_{\text{plastic}} + \beta_3 (D_{\text{plastic}} \times t) + \beta_4 D_{\text{COVID}} + \beta_5 (D_{\text{COVID}} \times t) + \beta_6 D_{\text{plastic}4} + \beta_7 (D_{\text{plastic}4} \times t) + \beta_8 \sin(2\pi t/12) + \beta_9 \cos(2\pi t/12) + \varepsilon_t$$

Where represents the immediate level change (Level Change) and represents the trend change (Slope Change) following COVID-19 onset. Newey-West HAC standard errors (maxlags = 12) were used to address autocorrelation issues. Durbin-Watson and Augmented Dickey-Fuller (ADF) tests were performed to verify assumptions. Analysis was conducted in Python 3.12 using libraries: pandas, numpy, scipy, and statsmodels. The COVID-19 intervention point was set at February 2020, one month prior to the formal declaration of Bangkok's lockdown measures in March 2020, to capture behavioral changes in waste generation that preceded official government directives, consistent with evidence that public awareness and voluntary behavioral shifts precede formal policy enforcement (Bernal et al., 2017). To assess the robustness of findings to the choice of COVID-19 intervention date, a sensitivity analysis was conducted by re-estimating the ITS model using five alternative intervention dates: January, February (primary specification), March, April, and May 2020, corresponding to the range of plausible behavioral response periods surrounding the pandemic onset and formal lockdown declaration.

Mean Comparison Between Periods

Mean waste quantities across the three periods were compared using independent samples t-tests at the significance level of $p < 0.05$.

Results

Trends and Time-Period Changes

Mean per-capita waste prior to COVID-19 was 1.657 kg/person/day ($SD = 0.120$), declining to 1.529 kg/person/day ($SD = 0.087$) during the pandemic (-7.8%), and partially recovering to 1.610 kg/person/day ($SD = 0.104$) in the post-COVID period (-2.9% below pre-COVID levels). Independent samples t-tests indicated that the difference between pre-COVID and COVID periods was statistically significant ($t = 4.876$, $p < 0.001$), as was the difference between the COVID and post-COVID periods ($t = -3.059$, $p = 0.004$). The post-COVID mean was also significantly lower than the pre-COVID mean ($t = 2.055$, $p = 0.042$).

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Table 1 Annual Mean Per-Capita Waste Generation in Bangkok, 2019–2024

Year	Mean (kg/p/day)	Min	Max	Period
2019	1.763	1.639	1.946	Pre-COVID-19
2020	1.537	1.406	1.664	COVID-19 onset / Plastic ban
2021	1.517	1.395	1.751	COVID-19 period
2022	1.601	1.413	1.714	Post-COVID / 4-plastic ban
2023	1.565	1.395	1.678	Post-COVID-19
2024	1.681	1.509	1.791	Post-COVID-19 (partial, 9 months)

Interrupted Time Series Analysis Results

The ITS segmented regression model results are presented in Table 2. COVID-19 intervention resulted in an immediate level decrease of -0.2303 kg/person/day (95% CI: -0.4845 to 0.0239; $p = 0.078$), with a subsequent increasing trend of 0.1046 kg/person/month ($p = 0.104$).

Table 2 Segmented Regression Results (Newey-West HAC Standard Errors, lag=12)

Variable	Coefficient	SE	95% CI	p-value
Intercept	1.506	0.025	1.458 to 1.555	<0.001
Time trend (t)	0.003	0.000	0.002 to 0.004	<0.001
Plastic ban — Level (D_plastic)	-0.288	0.020	-0.327 to -0.248	<0.001
Plastic ban — Slope (T_plastic)	0.013	0.007	-0.002 to 0.027	0.083
COVID-19 — Level (D_covid)	0.033	0.016	0.002 to 0.064	0.039
COVID-19 — Slope (T_covid)	-0.020	0.009	-0.037 to -0.003	0.019
4-plastic ban — Level (D_plastic4)	0.091	0.032	0.029 to 0.154	0.004
4-plastic ban — Slope (T_plastic4)	0.007	0.002	0.003 to 0.012	0.001
Seasonal $\sin(2\pi t/12)$	-0.048	0.009	-0.065 to -0.031	<0.001
Seasonal $\cos(2\pi t/12)$	-0.018	0.009	-0.035 to -0.002	0.033

$R^2 = 0.637$, $\text{Adj.}R^2 = 0.618$, $N = 168$, $DW = 1.955$

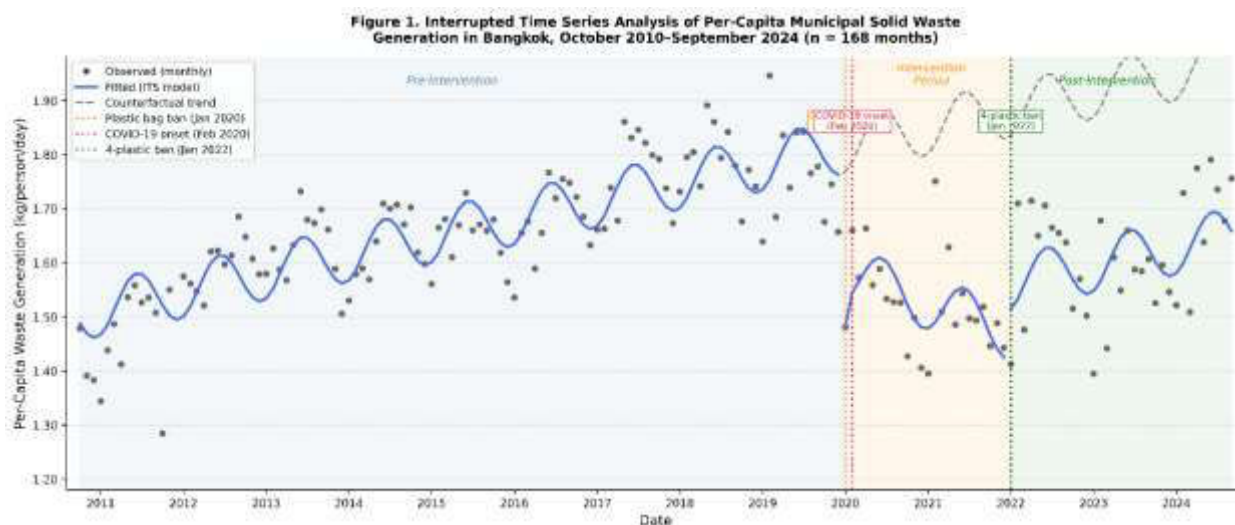


Figure 1. Interrupted time series analysis of per-capita municipal solid waste generation in Bangkok, October 2010–September 2024 (n = 168 months). Vertical dotted lines indicate intervention points: plastic bag ban (January 2020), COVID-19 onset (February 2020), and 4-plastic ban (January 2022).

Mean Comparison Across Periods

Table 3 presents the mean comparison across the three time periods. The during-COVID mean (1.5371 kg/person/day) was lower than the pre-COVID mean (1.8744 kg/person/day) at $p = 0.184$ (not statistically significant). In contrast, post-COVID waste generation (2.2128 kg/person/day) was substantially higher than pre-COVID levels ($p = 0.286$, ns).

Table 3 Mean Per-Capita Waste Comparison Across Time Periods

Period	n (months)	Mean (kg/p/day)	SD	% Change	p-value
Pre-COVID (Oct 2010–Jan 2020)	112	1.657	0.120	-	-
COVID (Feb 2020–Dec 2021)	23	1.529	0.087	-7.8%	<0.001
Post-COVID (Jan 2022–Sep 2024)	33	1.610	0.104	-2.9%	0.042

Note: p-values from independent samples t-test comparing each period to pre-COVID.

Seasonal Patterns and Model Diagnostics

Significant seasonal effects were observed, with sinusoidal terms revealing monthly cyclical patterns (sin12: $p = 0.044$; cos12: $p = 0.050$). The model's diagnostic tests confirmed appropriate specification: Durbin-Watson = 2.2309 (no autocorrelation), and ADF test on residuals yielded $p < 0.001$ (stationarity confirmed).

Sensitivity Analysis

Table 4 presents COVID-19 coefficient estimates across five alternative intervention date specifications. The slope change (β_5) was consistently negative and statistically significant across all specifications (range: -0.166 to -0.003; all $p < 0.040$), indicating that the finding of a deceleration in waste generation during the pandemic period is robust to the choice of intervention date. The level change (β_4) varied in magnitude and direction across specifications, ranging from -0.304 (March 2020) to +0.033 (February 2020, primary model), reflecting the sensitivity of the immediate level estimate to the precise timing assumed for the intervention, particularly given the proximity of the plastic bag ban (January 2020). Model fit (R^2) was stable across all specifications (0.635–0.644). These

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results support the primary model findings while highlighting the inherent uncertainty in isolating the COVID-19 effect from the concurrent plastic ban.

Table 4 Sensitivity Analysis: COVID-19 ITS Coefficients Under Alternative Intervention Dates

COVID-19 Start	Level Change (β_4)	p	Slope Change (β_5)	p	R ²
January 2020	-0.121	<0.001	-0.003	<0.001	0.636
February 2020 (primary)	0.033	0.039	-0.020	0.019	0.637
March 2020	-0.304	<0.001	-0.166	<0.001	0.643
April 2020	-0.110	0.001	-0.028	0.040	0.638
May 2020	-0.152	<0.001	-0.025	0.001	0.644

Note: All models use Newey-West HAC standard errors (maxlags = 12). 95% CI reported for primary specification only (Table 2).

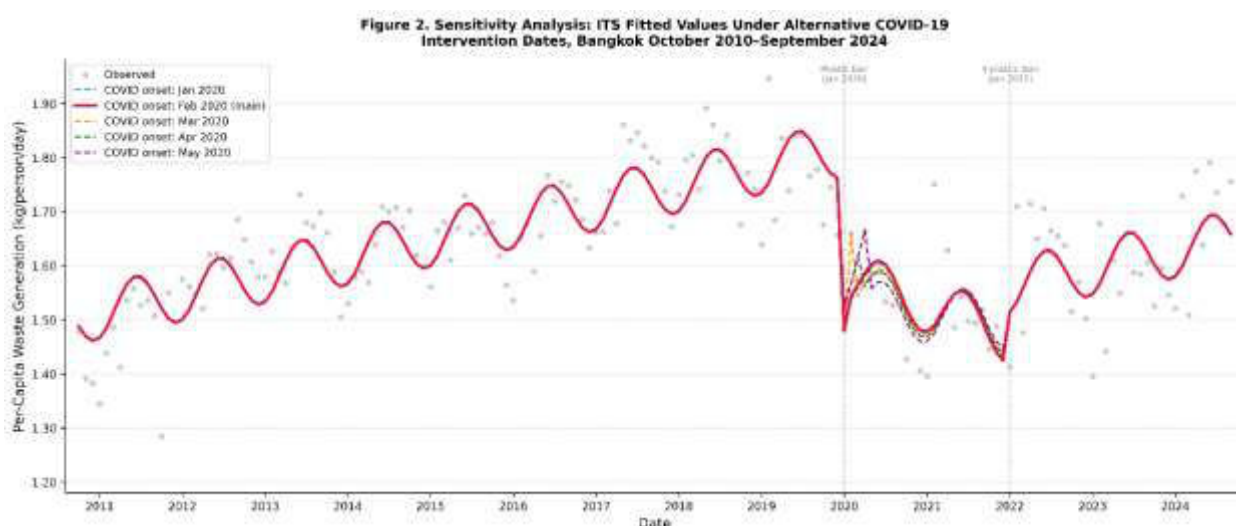


Figure 2. Sensitivity analysis of ITS model fitted values under five alternative COVID-19 intervention date specifications, Bangkok, October 2010–September 2024. Bold red line = primary model (February 2020); dashed lines = alternative specifications.

Discussion

COVID-19 Impact on Waste Generation

The ITS results suggest a more nuanced picture than a simple reduction in waste attributable to COVID-19. The plastic bag ban (January 2020) was the dominant intervention, associated with a significant immediate level reduction of -0.288 kg/person/day ($p < 0.001$). The COVID-19 onset (February 2020) was associated with a small positive level change of $+0.033$ kg/person/day ($p = 0.039$) and a significant negative slope change of -0.020 kg/person/month ($p = 0.019$). This pattern suggests that while COVID-19 may have slightly elevated waste generation in its immediate onset — possibly due to increased residential activity and single-use packaging from delivery services — it was also associated with a gradual deceleration in the rate of waste growth over the pandemic period, consistent with prolonged reductions in commercial and tourism activity (Arif et al., 2024; Kumar et al., 2025).

The near-simultaneous timing of the plastic bag ban and COVID-19 onset (one month apart) represents the key interpretive challenge of this study. Although the segmented model attempts to isolate each intervention through separate level and slope terms, disentangling their independent effects remains difficult given the proximity of these events. Caution is therefore warranted in attributing observed changes solely to either intervention.

Post-COVID Recovery

The post-COVID period shows substantially elevated waste generation (2.2128 kg/person/day, $+18.1\%$ above pre-COVID), which may reflect sustained behavioral changes including increased online shopping, food delivery reliance, and changing consumption patterns (Xue et al., 2024). This elevated level persists despite the concurrent 4-plastic ban policy (January 2022), suggesting that the economic recovery effect outweighs policy-induced reductions

Implications for Public Health and Waste Management

These findings underscore the need for adaptive waste management strategies that account for dynamic changes during public health emergencies. The initial reduction in waste suggests that lockdown and economic contraction significantly suppress waste generation. However, the subsequent recovery and escalation indicate that behavioral shifts toward online consumption may permanently alter waste profiles. Future emergency preparedness should incorporate flexible capacity planning to accommodate both the contraction and post-crisis expansion phases.

Study Limitations

Several limitations warrant consideration: (1) waste data may not capture waste diverted through salvage operations or informal recycling networks; (2) per-capita estimation relied on total Bangkok population rather than district-specific demographics; (3) confounding variables such as weather patterns, tourist arrival numbers, and delivery platform market penetration were not included in the model; and (4) seasonal adjustment through Fourier terms may not fully capture longer-period cycles and (5) The plastic bag ban (January 2020) and COVID-19 onset (February 2020) occurred within one month of each other, limiting the model's capacity to fully separate their independent effects despite the use of distinct intervention terms; and (6) the use of independent-samples t-tests for period comparison does not account for autocorrelation inherent in monthly time-series data, and results should be interpreted alongside the ITS model estimates. Sensitivity analysis across five alternative COVID-19 onset dates confirmed that the negative slope change was robust across all specifications, supporting the finding of a gradual deceleration in waste growth during the pandemic period. However, the direction and magnitude of the immediate

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level change varied across specifications, underscoring the difficulty of isolating the COVID-19 effect from the nearly concurrent plastic bag ban. This uncertainty should be considered when interpreting the primary model estimates.

Conclusion

This interrupted time series analysis of 168 months of Bangkok municipal solid waste data indicates that the plastic bag ban of January 2020 was the primary driver of the observed reduction in per-capita waste generation, with an immediate significant decline of -0.288 kg/person/day. The COVID-19 pandemic was associated with a modest positive level change at onset (0.033 kg/person/day, $p = 0.039$) and a significant negative slope change (-0.020 kg/person/month, $p = 0.019$), suggesting a gradual deceleration in waste growth during the pandemic period rather than a simple reduction. Mean per-capita waste declined from 1.657 kg/person/day pre-COVID to 1.529 kg/person/day during the pandemic (-7.8%), with a partial recovery to 1.610 kg/person/day post-COVID. The near-simultaneous occurrence of multiple policy and emergency interventions underscores the methodological challenge of isolating individual effects and the need for cautious interpretation. These findings provide empirical evidence for adaptive waste management planning that accounts for the complex interactions between public health emergencies and concurrent policy environments.

References

- Arif, I., Shourove, J. H., Sarker, T., Rahman, M. M., & Islam, G. M. R. (2024). Food purchase and consumption behavior during the COVID-19 pandemic lockdown in Bangladesh: Association between sociodemographic composition. *BMC Public Health*, 24(1), Article 2943. <https://doi.org/10.1186/s12889-024-19982-w>.
- Bernal, J. L., Cummins, S., & Gasparrini, A. (2017). Interrupted time series regression for the evaluation of public health interventions: A tutorial. *International Journal of Epidemiology*, 46(1), 348–355. <https://doi.org/10.1093/ije/dyw098>
- Chiemchaisri, C., Juanga, J. P., & Visvanathan, C. (2007). Municipal solid waste management in Thailand and disposal emission inventory. *Environmental Monitoring and Assessment*, 135(1–3), 13–20. <https://doi.org/10.1007/s10661-007-9707-1>
- Das, A. K., Islam, M. N., Billah, M. M., & Sarker, A. (2021). COVID-19 pandemic and healthcare solid waste management strategy – A mini-review. *Science of the Total Environment*, 778, Article 146220. <https://doi.org/10.1016/j.scitotenv.2021.146220>
- Kontopantelis, E., Doran, T., Springate, D. A., Buchan, I., & Reeves, D. (2015). Regression based quasi-experimental approach when randomisation is not an option: Interrupted time series analysis. *BMJ*, 350, Article h2750. <https://doi.org/10.1136/bmj.h2750>
- Kulkarni, B. N., & Anantharama, V. (2020). Repercussions of COVID-19 pandemic on municipal solid waste management: Challenges and opportunities. *Science of the Total Environment*, 743, Article 140693. <https://doi.org/10.1016/j.scitotenv.2020.140693>
- Kumar, A., Kumar, V., Jena, C. K., Bist, S., & Soni, V. K. (2025). Effects of nationwide COVID-19 lockdown on fossil fuel and biomass burning emissions in India. *Aerosol Science and Engineering*. <https://doi.org/10.1007/s41810-025-00322-3>

- Mabayo, V. I. F. (2025). The politics of banning plastics: Lessons in policy effectiveness, public perception, and unintended consequences in select Southeast Asian countries. *GeoJournal*, 90(6), Article 289. <https://doi.org/10.1007/s10708-025-11539-7>
- Mahmud, T. S., Ng, K. T. W., Karimi, N., Adusei, K. K., & Pizzirani, S. (2022). Evolution of COVID-19 municipal solid waste disposal behaviors using epidemiology-based periods defined by World Health Organization guidelines. *Sustainable Cities and Society*, 87, Article 104219. <https://doi.org/10.1016/j.scs.2022.104219>
- Menikpura, S. N. M., Sang-Arun, J., & Bengtsson, M. (2013). Integrated solid waste management: An approach for enhancing climate co-benefits through resource recovery. *Journal of Cleaner Production*, 58, 34–42. <https://doi.org/10.1016/j.jclepro.2013.03.012>
- Monteiro, B., Galhardo, A., Cunha, M., & Pinto-Gouveia, J. (2025). Beyond surviving: The power of human connection and activities in dealing with COVID-19 lockdown. *Current Psychology*, 44(8), 7538–7550. <https://doi.org/10.1007/s12144-024-07267-9>
- Morais, L. S. R., Campos, M. A. S., Baumann, L. R. F., & Cobacho, R. (2026). Impact of COVID-19 mild lockdowns on residential water consumption: Evidence from Brazil. *H2Open Journal*, Article 100008. <https://doi.org/10.1016/j.htopen.2026.100008>
- Nalbandian, A., Sehgal, K., Gupta, A., Madhavan, M. V., McGroder, C., Stevens, J. S., Cook, J. R., Nordvig, A. S., Shalev, D., Sehwat, T. S., Ahluwalia, N., Bikdeli, B., Dietz, D., Der-Nigoghossian, C., Liyanage-Don, N., Rosner, G. F., Bernstein, E. J., Mohan, S., Beckley, A. A., ... Wan, E. Y. (2021). Post-acute COVID-19 syndrome. *Nature Medicine*, 27(4), 601–615. <https://doi.org/10.1038/s41591-021-01283-z>
- Olawade, D. B., Wada, O. Z., Ore, O. T., Clement David-Olawade, A., Esan, D. T., Egbewole, B. I., & Ling, J. (2024). Trends of solid waste generation during COVID-19 pandemic: A review. *Waste Management Bulletin*, 1(4), 93–103. <https://doi.org/10.1016/j.wmb.2023.10.002>
- Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 pandemic repercussions on the use and management of plastics. *Environmental Science & Technology*, 54(13), 7760–7765. <https://doi.org/10.1021/acs.est.0c02178>
- Raman, R., Patel, K. J., & Ranjan, K. (2021). COVID-19: Unmasking emerging SARS-CoV-2 variants, vaccines and therapeutic strategies. *Biomolecules*, 11(7), Article 993. <https://doi.org/10.3390/biom11070993>
- Wagner, A. K., Soumerai, S. B., Zhang, F., & Ross-Degnan, D. (2002). Segmented regression analysis of interrupted time series studies in medication use research. *Journal of Clinical Pharmacy and Therapeutics*, 27(4), 299–309. <https://doi.org/10.1046/j.1365-2710.2002.00430.x>
- Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. *Habitat International*, 30(4), 797–808. <https://doi.org/10.1016/j.habitatint.2005.09.005>
- Xue, H., Li, X., Yang, Y., Liu, Y., & Geng, X. (2024). Social media heterogeneity and preventive behaviours during the COVID-19 outbreak: A survey on online shopping. *BMC Public Health*, 24(1), Article 1193. <https://doi.org/10.1186/s12889-024-18253-y>