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Resilience and Transformation of University Waste Management During COVID-19: A Case Study of Shahid Sadoughi University of Medical Sciences, Yazd

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ABSTRACT

Introduction: Universities are concentrated hubs of waste generation, and the COVID-19 pandemic has profoundly reshaped waste management dynamics. This study investigated the resilience and transformation of campus waste streams at Shahid Sadoughi University of Medical Sciences, Yazd, Iran, in 2020.

Materials and Methods: Monthly physical waste analyses were conducted across seven campus zones (dormitories, faculties, cafeterias, sports halls, and faculty clubs). Waste was manually sorted, weighed, and characterized according to ASTM D5231-92, and key physicochemical parameters (moisture, density, calorific value, and C/N ratio) were measured. Data were analyzed using descriptive and inferential statistics (SPSS) to compare the pre-pandemic, peak-pandemic, and post-peak periods.

Results: The results revealed an 81.6% reduction in total waste generation during the lockdown, alongside a major spatial shift. Waste output from academic and commercial areas (cafeteria: 90.8% decrease) collapsed, whereas dormitories became the primary source (49.3% decrease). Compositionally, organic waste increased sharply from 38.7% to 58.9%, whereas recyclables such as paper and cardboard declined drastically from 25.1% to 6.2%. These shifts reduced the calorific value by 25% and increased the moisture content, undermining the thermal treatment potential but enhancing the suitability for biological processing.

Conclusion: This study demonstrates how the pandemic acted as both a disruptive shock and a catalyst for transformation. This underscores the vulnerabilities of centralized waste management models while highlighting opportunities for adaptive and decentralized solutions, such as dormitory-level composting, that strengthen resilience and foster a more flexible and crisis-responsive system.

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Introduction

Solid waste management (SWM) is a critical pillar of urban health and sustainability. Its complexities are particularly evident in controlled environments, such as university campuses. These campuses are microcosms of cities, generating diverse waste streams from academic, residential, commercial and research activities. Effective SWM is not only an operational necessity but also a means of fostering environmental stewardship and supporting institutional sustainability goals [1].

The COVID-19 pandemic, declared in March 2020, abruptly reshaped global social and economic structures. Public health measures, including lockdowns, social distancing, and shifts to remote work and learning, have caused dramatic changes in human behavior, consumption patterns, and waste generation dynamics [2]. While numerous studies have documented the pandemic's impact on Municipal solid waste (MSW) at the city level, its effects on enclosed, complex systems, such as university campuses, remain less understood. This gap is significant because campuses have shifted from densely populated hubs to largely empty facilities, except for core residential units. This created a unique real-world experiment to observe the resilience and adaptability of institutional waste systems to sudden, large-scale stress.

Understanding these dynamics is important not only for historical documentation but also to inform the design of robust, evidence-based systems capable of withstanding future disruptions, including pandemics, natural disasters, and economic crises [3]. A resilience-focused approach to SWM emphasizes adaptability, modularity, and the capacity to absorb shocks while maintaining essential functions [4].

This study, conducted at Shahid Sadoughi University of Medical Sciences in Yazd, Iran, is uniquely positioned. Initially designed as a baseline assessment, the onset of the pandemic transformed it into a real-time longitudinal investigation of waste stream resilience and transformation under crisis conditions. This study quantitatively and qualitatively assessed the impact of the COVID-19 pandemic on the quantity, composition, and physicochemical characteristics of solid waste generated across the key functional areas of a university campus. The empirical findings were leveraged to develop a strategic framework for adaptive and resilient waste management in academic institutions and similar settings, turning crisis-induced challenges into actionable strategies for sustainable future planning.

Materials and Methods

Study Area and Sampling Timeline

This study was conducted at the central campus of Shahid Sadoughi University of Medical Sciences in Yazd, Iran. The study area included the university's main educational, residential, and service facilities, which together represent the principal sources of solid waste. A schematic map of the campus and the monitored sampling sites is presented in Figure 1 to illustrate their spatial distributions.

The data collection period covered the entire Iranian calendar year 1399 (March 2020 to March 2021), fully overlapping with the first major wave of the COVID-19 pandemic and the associated government-mandated lockdowns in Iran. To capture the dynamics of waste generation under different pandemic conditions, the study period was divided into three distinct phases:

- Phase 1 (Pre-Lockdown; March–May 2020): Representative of normal campus operations.
- Phase 2 (Peak Lockdown; June-August 2020): The period of the strictest restrictions, during which most university activities and dormitories were closed.
- Phase 3 (Partial Reopening; September-November 2020): Marked by a gradual and phased return to academic and residential activities [5].

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Figure 1: Campus of Shahid Sadoughi University of Medical Sciences and the study area.

Seven primary waste generation sources were identified and continuously monitored: (1) Golestan Male Dormitory, (2) Touba Female Dormitory, (3) Faculty Club (Professors' Residence), (4) School of Health, (5) Central Cafeteria (Self-Service Restaurant), (6) School of Medicine and Pharmacy, and (7) Imam Ali Sports Hall. These sites were selected because they constitute the main waste generation nodes of the campus and collectively encompass the residential, academic, recreational, and service functions of the university, making them essential for a representative assessment of campus-wide waste generation dynamics.

Waste Sampling and Physical Characterization

A comprehensive strategy for direct waste sampling and analysis was employed, strictly adhering to the standard method ASTM D5231-92 (Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste) [6]. Given the manageable total quantity of waste generated on campus, the entire waste stream from each source was collected for analysis on predetermined sampling days. Sampling was conducted for seven consecutive days each month to capture representative variations in waste generation. This period was selected to ensure that all campus subpopulations were included, as some groups, such as medical students and interns, were present only on specific days of the week [1].

The collected waste samples were transported to a designated, well-ventilated sorting site. Manual sorting was performed by trained personnel into predefined categories: organic/food waste, paper, cardboard, plastics (PET, HDPE, LDPE, PP, PVC, PS, nylon), glass (transparent, green, brown), metals (ferrous, aluminum), and other residual wastes [7]. Hazardous and infectious waste was not included in this study, as such materials were collected separately on campus and subjected to dedicated treatment and neutralization processes prior to disposal. All sorting and weighing procedures were carried out under strict COVID-19 health and safety protocols, including the use of personal protective equipment [8] such as masks, gloves, protective clothing, and adherence to distancing and disinfection guidelines. Each sorted fraction was weighed using a calibrated digital balance (Mettler Toledo, precision ±0.01 kg).

Physicochemical Analysis

Representative composite samples were prepared from the sorted waste fractions to ensure reliable laboratory characterization. For each major category, subsamples were proportionally collected according to their weight contribution, homogenized, and combined into a composite sample representing the overall waste stream. This approach ensured that the laboratory analysis reflected the true physicochemical properties of heterogeneous campus waste.

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Moisture content was determined by drying a known weight of sample in a laboratory oven at 105 °C until a constant weight was achieved [9]. The measurements were performed using a digital balance with a precision of ±0.01 g.

Density was measured following a standardized procedure by filling a cylindrical container of known volume (20 L) with compacted waste, leveling the surface, and weighing the contents. The procedure was repeated three times for each sample to ensure reproducibility [7].

Ash content was quantified by combusting oven-dried samples in a muffle furnace (Nabertherm, Germany) at 550 °C for a minimum of two hours, and subsequently until a stable weight was reached [10].

The calorific value (expressed as kcal/kg) was estimated using the Dulong empirical equation, which relates the heating value to the elemental composition of carbon, hydrogen, oxygen, and sulfur in the waste [7]. Although this approach is less precise than bomb calorimetry, it provides a reliable estimate in the absence of direct calorimetric measurements.

The carbon-to-nitrogen (C/N) ratio was determined using the Kjeldahl digestion method. Samples were digested with concentrated sulfuric acid in the presence of a catalyst, followed by distillation and titration with standardized boric acid and hydrochloric acid solutions [7]. This method enabled quantification of total nitrogen, which was combined with total organic carbon values to calculate the C/N ratio, providing an indicator of biodegradability and suitability for biological treatment processes.

Data Analysis

All collected data were compiled, organized, and meticulously cleaned using Microsoft Excel (Microsoft, 2020). Statistical analyses were performed using SPSS Statistics (Version16). Descriptive statistics, including mean, standard deviation, and percentage, were calculated for all variables [11].To rigorously analyze the pandemic's impact, the dataset was segmented into three distinct temporal phases based on university occupancy and government restrictions:

A one-way Analysis of Variance [12] was used to determine if the differences in mean waste generation and composition between these phases were statistically significant ($p < 0.05$). Where ANOVA indicated significance, post-hoc tests (Tukey's HSD) were applied to identify which specific phases differed from each other [11].

Results

The COVID-19 pandemic functioned as an unprecedented exogenous shock, offering a unique natural experiment to evaluate the resilience and adaptability of the university's solid waste management system. Statistical analysis demonstrated a highly significant reduction in overall campus waste generation (One-Way ANOVA, $p < 0.01$) This reduction, however, was not uniform across all campus facilities but instead exhibited strong spatial and temporal heterogeneity [13], as presented in Table 1 .

Table 1: Detailed Waste Generation Analysis by Location and Pandemic Phase (kg/day)

Location	Phase 1 (Pre-Pandemic) Avg. ± SD	Phase 2 (Peak Lockdown) Avg. ± SD	Phase 3 (Partial Reopening) Avg. ± SD	% Δ (Peak vs. Pre)
Male Dormitory	42.4 ± 5.2	21.5 ± 3.1	35.2 ± 4.8	- 49.3%
Female Dormitory	39.4 ± 4.8	0.0 ± 0.0	25.5 ± 3.8	- 100.0%
Central Cafeteria	163.8 ± 24.1	15.1 ± 5.2	110.3 ± 16.5	- 90.8%
Faculty of Medicine	13.0 ± 2.1	7.0 ± 1.5	13.2 ± 2.6	- 46.2%
Faculty of Health	15.2 ± 2.8	8.5 ± 1.8	14.5 ± 2.9	- 44.1%
Sports Hall	4.0 ± 1.5	0.0 ± 0.0	1.7 ± 0.8	- 100.0%
Faculty Club	3.0 ± 1.2	0.0 ± 0.0	2.7 ± 1.1	-100.0%
Campus Total	280.8 ± 28.5	51.7 ± 7.8	203.1 ± 22.3	- 81.6%

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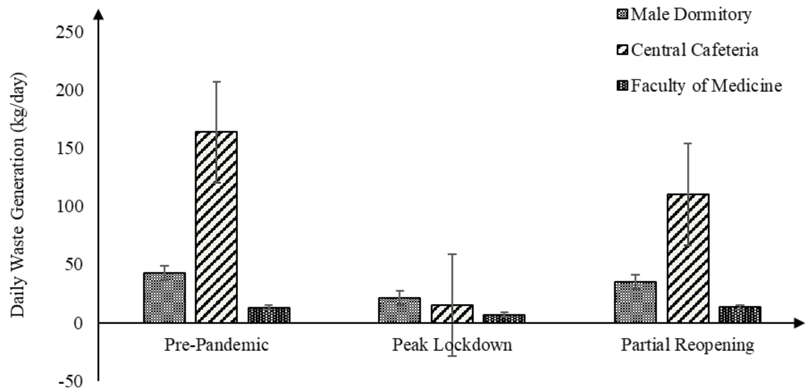

Figure 2: Comparison of Daily Waste Generation from Three Major Sources During Pandemic Phases ($p < 0.05$, Tukey's HSD).

After lockdown, essential academic units and dormitories rapidly regained their waste output, while non-essential facilities remained low or closed, shifting overall waste generation to core campus areas. This redistribution is visually summarized in Figure 2, which highlights three representative facilities (male dormitory, central cafeteria, and Faculty of Medicine).

The composition of the campus waste stream changed substantially between the pre-pandemic and peak lockdown phases, with direct implications for management strategies [14]. Table 2 and Figure 3 show a clear increase in organics and plastics, along with a decline in traditional recyclables.

Table 2: The Components of MSW in the Pre-Pandemic and Peak Pandemic Phases (Weighted Average Percentage)

Waste Component	Pre-Pandemic	Peak Lockdown	Δ (Percentage Points)
Organic Waste	38.7	58.9	+ 20.2
Paper & Cardboard	25.1	6.2	- 18.9
Plastics (Total)	18.2	21.5	+ 3.3
PET	4.5	7.8	+ 3.3
Film & Nylon	8.2	9.8	+ 1.6
Glass	6.1	1.4	- 4.7
Metals	3.6	1.6	- 2.0
Others	8.3	10.4	+ 2.1

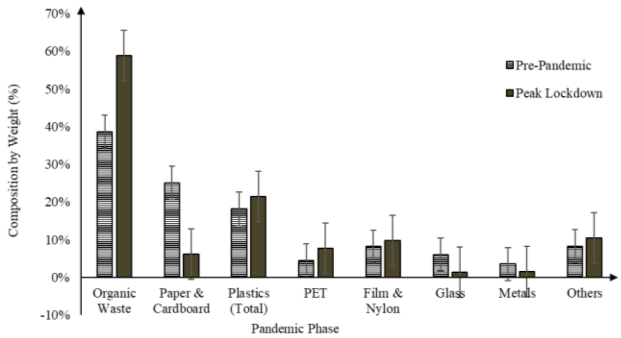

Figure 3: Shifts in MSW composition in the Pre-Pandemic and Peak Pandemic Phases

Table 3 demonstrates that during the lockdown, campus MSW exhibited higher moisture content and density, reduced calorific and ash values, and a lower C/N ratio, with important implications for transport efficiency, incineration feasibility, and composting suitability.

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Table 3: Physicochemical Characteristics of Campus MSW

Parameter	Phase 1 (Pre-Pandemic)	Phase 2 (Peak Lockdown)	Method/ Standard	Management Implication
Moisture Content (%)	45.6 ± 5.2	62.3 ± 6.8	ASTM D 2216	Increased leachate, transport cost, reduced calorific value
Density (kg/m^3)	185 ± 25	212 ± 30	ASTM D 5341	Higher transportation costs per volume
Ash Content (% dry wt.)	18.3 ± 3.1	12.5 ± 2.8	ASTM D 3174	-
Calorific Value (kcal/kg)	2850 ± 250	2150 ± 300	Calculated	Rendering incineration less feasible
C/N Ratio	28.5 ± 4.2	22.1 ± 3.5	-	More favorable for composting

Discussion

Impact on Waste Generation Patterns: A Quantitative Spatial-Temporal Analysis

Table 1 shows that while the campus total waste generation dropped by more than 80% during the peak lockdown, this decline was not evenly distributed. The central cafeteria underwent the most dramatic reduction (~91%), reflecting the suspension of conventional food service operations. Instead of on-site dining, meals were distributed as pre-packaged portions, eliminating the bulk of food preparation and associated waste at the cafeteria itself. By contrast, student dormitories retained partial waste generation due to the continued presence of specific groups, particularly senior medical students and interns whose clinical rotations required physical presence. This persistence of dormitory activity made them relatively more resilient nodes of waste generation.

Similarly, the Faculty of Medicine demonstrated only a partial decline in waste production during the lockdown (-46%) and rapidly returned to pre-pandemic levels in Phase 3. This pattern reflects the essential nature of medical education, which necessitated the continued presence of both students and faculty. In contrast, the Faculty of Health, though comparable in academic function, showed a slower recovery, consistent with more flexible remote learning models.

The zero values reported for facilities such as the female dormitory, sports hall, and faculty club during Phase 2 are not artifacts of measurement but directly reflect the complete suspension of activity in these spaces, as they were fully closed by government mandate.

When comparing recovery trajectories in Phase 3 to the pre-pandemic baseline, it becomes evident that the cafeteria partially rebounded (to 110.3 ± 16.5 kg/day, ~67% of pre-pandemic levels), while dormitories also regained substantial portions of their prior waste output. These shifts underscore a spatial redistribution of waste generation, with dormitories and essential faculties emerging as the dominant contributors during the lockdown and immediate post-lockdown phases.

These nodes were selected to illustrate the three dominant patterns observed: (1) partial but resilient continuity (dormitory), (2) near-complete collapse and partial rebound (cafeteria), and (3) partial decline with full recovery (medical faculty). Error bars indicate notable intra-phase variability, particularly in the cafeteria during Phase 2, likely reflecting irregular meal distribution schedules. Overall, these findings align with international reports that highlight the pandemic's differential impact on waste generation, depending on facility type and operational continuity (e.g., food service vs. residential vs. academic). The evidence strongly suggests that campus waste management systems must account for such heterogeneity, emphasizing localized strategies in times of crisis. For example, when centralized waste from the cafeteria collapsed, decentralized streams (dormitories, medicine faculty) gained relative importance, underscoring the need for flexible, location-specific interventions during periods of disruption.

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The campus waste profile shifted markedly from the pre-pandemic period to the height of the lockdown, requiring new management approaches, as Table 2 and Figure 3 reveal with higher levels of organics and plastics and a drop in conventional recyclables.

Compositional Transformation of the Waste Stream

The share of organic waste rose markedly (38.7% to 58.9%), mainly due to the closure of communal dining halls and the shift toward individually packaged meals, which generated more food residues in dormitories. Reduced on-site consumption of fresh food during restricted operations may also concentrate organic fractions. In contrast, paper and cardboard declined sharply (- 18.9%), reflecting the suspension of administrative work, library use, and in-person classes during the pandemic. Glass (- 4.7%) and metals (- 2.0%) also fell, consistent with the absence of cafeteria-based beverage consumption and large gatherings.

Plastic waste exhibited a mixed but upward trend in recent years. The total plastics increased slightly (+ 3.3%), with notable gains in PET bottles and films, largely driven by the reliance on bottled drinks and hygienic packaging. This aligns with global observations of heightened demand for single-use plastics during COVID-19 [15]. The "Others" fraction increased modestly (+ 2.1%) but contained disproportionate amounts of PPE, gloves, and disinfectant-related residues, particularly in the medical and residential zones. While numerically small, these materials represent new challenges for occupational safety and environmental risk .[16]

Overall, these findings underscore a dual challenge: the loss of high-value recyclables weakens economic recovery pathways for recycling systems, whereas the rise of organics and plastics imposes logistical and environmental burdens. The trends observed on campus echo global reports from urban waste systems [17]; however, the strong dormitory and medical influence in this setting highlights how institutional contexts produce distinctive waste dynamics under crisis conditions.

Alteration of Critical Waste Management Parameters

Pandemic-induced shifts in physicochemical characteristics directly altered treatment feasibility. Moisture content increased markedly (from 45.6% to 62.3%), surpassing the 50% threshold often cited as critical for thermal processes. This not only suppressed the calorific value but also intensified leachate generation and transport burdens, consistent with lockdown-related trends in other regions [18]. The waste density increased from 185 to 212 kg/m^3, suggesting higher collection efficiency but also greater transport energy demand and potential disruption in separation systems. Meanwhile, ash content declined (18.3% to 12.5%), reducing the inert load and favoring biological stabilization, although its benefit was negated by excessive moisture.

The calorific value decreased by approximately 25% (from 2850 to 2150 kcal/kg), falling below the 2500-3000 kcal/kg benchmark for standalone incineration [19, 20]. In contrast, the C/N ratio shifted from 28.5 to 22.1, which is near the optimal range for composting [21], indicating that biological treatment (composting, anaerobic digestion) would be more effective than thermal options under these altered conditions.

Overall, the pandemic redefined waste management priorities: energy recovery pathways became less feasible, while composting emerged as the most viable strategy, a trend also observed in higher-education institutions globally.

However, this study should be viewed in light of its unique context and limitations. The research was conducted during the extraordinary disruptions of the COVID-19 pandemic, which led to unprecedented fluctuations in waste generation patterns. These conditions, while providing a unique natural experiment, mean that the findings reflect a specific, non-normal operational period at a single university. Therefore, the generalizability of the results to stable, non-pandemic conditions may be limited.

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Conclusion

This study examined the resilience and transformation of waste management at the Shahid Sadoughi University of Medical Sciences during the COVID-19 pandemic. The pandemic caused spatially uneven impacts, exposing vulnerabilities in centralized waste points, such as cafeterias, while dormitories proved resilient and became key operational nodes. The waste composition shifted significantly, with a decline in high-value recyclables and an increase in organic and packaging plastics. These changes reduced the calorific value by 25% and increased the moisture content, limiting the feasibility of conventional waste-to-energy approaches and favoring biological treatment methods.

These findings highlight the need for flexible and adaptive strategies. Enhancing resilience requires decentralizing treatment infrastructure to manage localized surges, developing flexible collection agreements, and implementing real-time digital monitoring for rapid response. Integrating waste management into emergency plans ensures adaptability during crises, while targeted source reduction campaigns, especially in dormitories, can address the increased packaging waste.

Overall, the study emphasizes the need to shift from static, centralized systems to dynamic, resilient models capable of structural and functional adaptation, thereby securing both environmental sustainability and operational continuity.

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Conflict of Interest

The authors confirm that there are no conflicts of interest.

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Ethical Considerations

This study was conducted in accordance with the ethical standards of Shahid Sadoughi University of Medical Sciences.

Code of Ethics

(Ethic code: IR.SSU.SPH.REC.1399.154).

Authors' Contributions

Parvin Zamani contributed to data collection and manuscript writing. Masoomeh Bagheri assisted with data collection and coordination. Mehdi Mokhtari supervised and guided the overall project. Ehsan Abouee Mehrizi provided scientific guidance and oversaw project implementation. Mehdi Sarlak coordinated project execution and contributed to project leadership. Mehran Yazdandoust participated in data collection, critically revised the manuscript, and implemented final edits. All authors reviewed and approved the final version of the manuscript.

References

1.Hoornweg D, Bhada-Tata P. What a waste: a global review of solid waste management. 2012.
2.Hantoko D, Li X, Pariatamby A, et al. Challenges and practices on waste management and disposal during COVID-19 pandemic. J Environ Manage. 2021;286:112140.
3.Walker B, Holling CS, Carpenter SR, et al. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society. 2004;9(2).
4.Folke C. Resilience: the emergence of a perspective for social–ecological systems analyses. Global Environmental Change. 2006;16(3):253-67.
5.Mahmud TS, Ng KTW, Karimi N, et al. Evolution of COVID-19 municipal solid waste disposal behaviors using epidemiology-based periods defined by World Health Organization

guidelines. Sustain Cities Soc. 2022;87:104219.
6.American Society of Testing and Materials (ASTM). Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste.1998.
7.Azam M, Jahromy SS, Raza W, et al. Status, characterization, and potential utilization of municipal solid waste as renewable energy source: Lahore case study in Pakistan. Environ Int. 2020;134:105291.
8.Oron G, Appelbaum S, Guy O. Reuse of brine from inland desalination plants with duckweed, fish and halophytes toward increased food production and improved environmental control. Desalination. 2023;549:116317.
9.Fidelis R, Guerreiro EDR, Horst DJ, et al. Municipal solid waste management with recyclable potential in developing countries: current scenario and future perspectives. Waste Management & Research. 2023;41(9):1399-419.
10. Krishna V. Characterization and compositional analysis of municipal solid waste in developing and developed world—an insight. Solid Waste Management for Resource-Efficient Systems: Elsevier; 2024pp. 3-27.
11. Dehghanifard E, Dehghani MH. Evaluation and analysis of municipal solid wastes in Tehran, Iran. MethodsX. 2018;5:312-21.
12. Shah SA, Fontananova E, Cipollina A, et al. Harvesting Renewable energy from saltworks waste brines via reverse electrodialysis. ACS Omega. 2025; 10(28):29980-91.
13. Jayasinghe PA, Jalilzadeh H, Hettiaratchi P. The impact of COVID-19 on waste infrastructure: lessons learned and opportunities for a sustainable future. nt J Environ Res Public Health. 2023;20(5):4310.
14. Kulkarni BN, Anantharama V. Repercussions of COVID-19 pandemic on municipal solid waste management: challenges and opportunities. Sci Total Environ. 2020;743:140693.
15. Vanapalli KR, Sharma HB, Ranjan VP, et al. Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. Sci Total Environ. 2021;750:141514.
16. Klemeš JJ, Van Fan Y, Tan RR, et al. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renew Sustain Energy Rev. 2020;127:109883.
17. Somani M, Srivastava AN, Gummadivalli SK, et al. Indirect implications of COVID-19 towards sustainable environment: an investigation in Indian context. Bioresour Technol Rep. 2020;11:100491.
18. Tripathi A, Tyagi VK, Vivekanand V, et al. Challenges, opportunities and progress in solid waste management during COVID-19 pandemic. Case Stud Chem Environ Eng. 2020;2:100060.
19. IETC U. Waste to Energy: Considerations for Informed Decision-Making. Osaka, Japan: UNEP International Environmental Technology Center; (IETC) [Internet]. 2019.
20. Themelis NJ, Mussche C, editors. Municipal solid waste management and waste-to-energy in the United States, China and Japan. 2nd international academic symposium on enhanced landfill mining, Houthalen-Helchteren; 2013. p 35-50.
21. Haug R. The practical handbook of compost engineering: Routledge; 2018.