UMSHA Press

AJEHE
Avicenna Journal of Environmental Health Engineering
Avicenna J Environ Health Eng, 2023; 10(1):65-71. doi:10.34172/ajehe.2023.5381
http://ajehe.umsha.ac.ir

Review Article

Medical Waste Increase During COVID-19 Pandemic in Asia: A Meta-analysis

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Article history:
Received: June 11, 2023
Accepted: June 20, 2023
ePublished: June 29, 2023

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Abstract

The coronavirus disease 2019 (COVID-19) prevalence increased hospital admissions and caused a higher rate of medical waste. In this study, the status of medical wastes and recommended disinfecting methods were reviewed before and during the COVID-19 pandemic in Asia. The published papers, library searching, and website browsing with no language restrictions were used to conduct this analytical-descriptive study before the pandemic until the early months of 2020. The results showed that generation rates of medical waste (GRMW), including surgical gloves, face masks, and the like increased by 10%, 12%, 23%, 28%, 97%, 425, and 1262% in Iran, Tehran, China, Malaysia, Dhaka, Wuhan, and King Abdullah University Hospital, respectively, in 2020 regarding the normal period without any pandemic. The capital or the most engaged city in each country produced higher GRMW compared with the whole country so that the GRMW in Iran, Bangladesh, and China were 13.2%, 29.2%, and 70.4% lower than that in Tehran, Dhaka, and Wuhan, respectively. The GRMW also indicated reverse trends with the number of hospital beds, population, and accumulated confirmed cases.

Keywords: COVID-19, Medical waste, Generation rate, Waste management, Disinfecting methods

Please cite this article as follows: Jafarzadeh N, Maleki H. Medical waste increase during COVID-19 pandemic in asia: a meta-analysis. Avicenna J Environ Health Eng. 2023; 10(1):65-71. doi:10.34172/ajehe.2023.5381

1. Introduction

The fundamental concerns of the recent decades are waste management and associated health and environmental outcomes. Medical wastes that coincided with the development of science and technology became one of the most important environmental challenges, especially in developing countries (1). Medical wastes include domestic, infectious, pathological, sharp, pharmaceutical, chemical, and radioactive wastes. For the first time, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was released in Wuhan, China, and became a major concern worldwide a few months later (2). The infected person often exhibits symptoms similar to a cold (3, 4). Compliance with healthcare principles (e.g., hand washing, social distancing, wearing face masks, and the like) and waste management decreased the spread of the virus especially in schools, supermarkets, meat processing plants, and hospitals (5, 6). SARS-CoV-2 survived several hours on different surfaces; for example, it survives 4 hours on copper, 6 hours on stainless steel, and 3 hours on plastic (4, 7, 8). Another study showed that this virus can survive even to 9 days on plastic, glass, and metal objects (7). The virus often infects people by transferring from high-touch surfaces and coughing. Since the tools used for the treatment of infected people may transfer the active SARS-CoV-2, they are considered infectious wastes. The rise in the amount of infectious and medical wastes caused extra concerns about their management (9). These wastes could have critical consequences on health and the environment.

Extra amounts of personal protective equipment (i.e., gloves, gowns, shoe covers, head covers, masks, respirators, eye protection, face shields, and goggles) became infectious wastes when SARS-CoV-2 prevailed worldwide. These kinds of wastes could also dominate viral diseases in society (10). To say the least, the amount of medical waste increased dramatically during the pandemic; however, the incomplete management of these wastes redoubled environmental and public health concerns (10). Improper collection, disinfecting, transportation, or disposal of medical wastes are the most influential and common phases that cause considerable environmental and health issues, especially during the coronavirus disease 2019 (COVID-19) period (11). In addition to the inappropriate management of solid wastes, the weak design of solid waste containers is one of the reasons that increased the contamination of solid wastes, especially in Asia. The lack of sufficient resources also negatively affected the management of wastes, particularly in countries where open dumping is the most frequent strategy for the management of solid wastes (12,13).

Numerous studies investigated COVID-19-related health and environmental issues as well as the amount of produced medical waste based on many assumptions (e.g., population, COVID-19 cases, urban population portion, and daily rate of facemask use) which led to a considerable amount of medical waste. However, this study aimed to eliminate these assumptions and analyze the amount of the real produced medical wastes before and during the coronavirus pandemic in Asia. The data were collected from responsible organizations or reported in research papers. Different technologies were also evaluated to present the most applicable method for disinfection of medical wastes.

2. Materials and Methods

2.1. Study Design

All published reports and papers, mostly until 2020, that evaluated the relationship between COVID-19 incidences and medical wastes were gathered and reviewed to present the status of medical wastes before and during the COVID-19 pandemic. The same process was used for the evaluation of recommended disinfecting devices. Due to the irregular situation at the beginning of the pandemic, the generation rate of medical waste was at the highest amount; therefore, the early months of 2020 were considered in this study. Information was obtained from Web of Science, Scopus, PubMed, Google Scholar, The World Health Organization (WHO), and relevant websites. In the first step, the following items were searched to find appropriate documents: Waste, medical wastes, waste management, hospital wastes, clinical wastes, COVID-19 exposure, COVID-19 transmission, COVID-19 cases and deaths, autoclave, microwave, chemical disinfecting, landfilling, incinerators, China, India, Bangladesh, Australia, and Malaysia. In the current study, the total number of documents included 39 references of which 30 references were used and analyzed in the results and discussion section (Fig. 1). The results and discussion of the study were evaluated in two sections: (a) The generation rate of medical waste before and during the COVID-19 pandemic and (b) Disinfecting methods of medical wastes during the COVID-19 pandemic.

No language limitation was imposed in the current study. This study was conducted based on the available information, including population, the generation rate of medical waste, hospital beds, and the number of patients in Asia. One of the limitations of this study was the lack of available statistics on the number of confirmed coronavirus cases per city in most countries. Furthermore, the generation rate of medical waste was often reported as kg per (bed/day) by previous studies, and there was a lack of data for the generation rates of medical waste (GRMW) as kg per (patient/day).

2.2. Statistical Analysis

Analysis of variance (ANOVA) was conducted on quantitative data. This test evaluates the mean values of two or more groups of data to show whether the mean differences are significant or not. ANOVA is somehow the

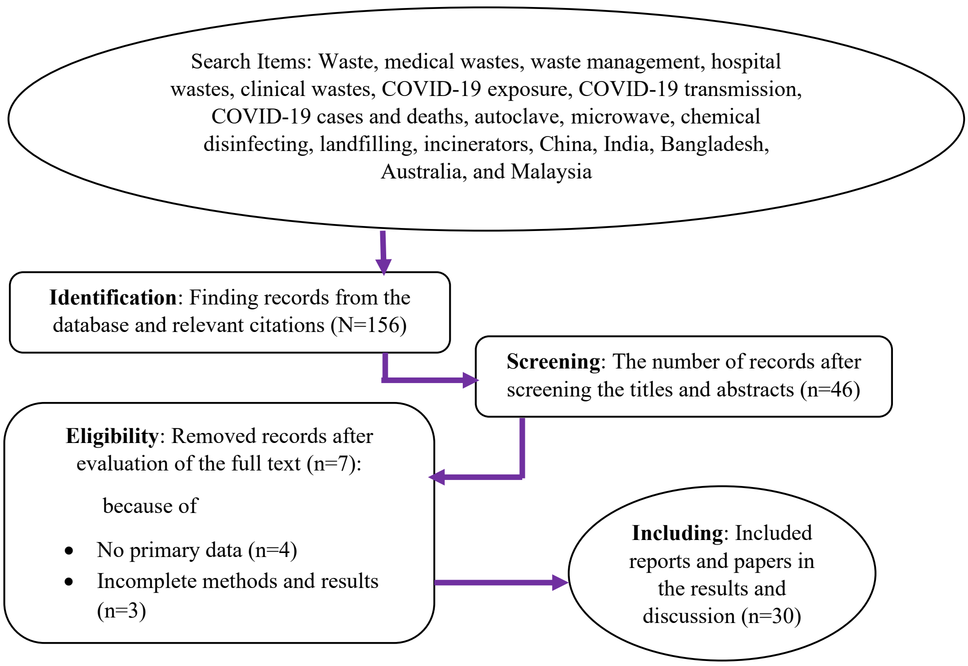

Fig. 1. Searched Items, Screened and Included Papers, Evaluating GRMW by Preferred Reporting Items for Systematic Reviews and Meta-analysis in the Current Study. *Note.* GRMW: Generation rates of medical waste

extension of the t-test. In the current study, ANOVA and boxplot were performed to show whether there was any significant difference in GRMW for different scenarios. The first scenario was the difference in GRMW before and during the COVID-19 pandemic. The second scenario investigated the difference in GRMW between the cities highly engaged in coronavirus compared to their country.

3. Results and Discussion

3.1. The Generation Rate of Medical Waste Before and During the COVID-19 Pandemic

The highest tonnage of medical waste was found in China before and during the COVID-19 pandemic (Tables 1 and 2). According to the current study, medical wastes were produced about 115, 444.8, 483.3, and 6067 tons/day in Malaysia, Iran, Bangladesh, and China, respectively. The amount of discharged facemasks in these countries was also estimated at 122, 309, 310, and 4214 tons/day (2). Only in Malaysia, the amount of facemask waste was higher than the daily tonnage of medical waste. This is probably because COVID-19 was not dominant in Malaysia when the daily amount of medical waste was reported. The highest GRMW was found at about 3.38 kg/(bed/day) in Tehran, Iran, before the pandemic, while the highest GRMW during the pandemic was observed in Dhaka at 4.8 kg/(bed/day). The GRMW from the largest to the lowest was observed to be 3.38, 2.98, 1.89, 1.55, 0.96, 0.71, and 0.56 kg/(bed/day) in Tehran, Iran, Bangladesh, Malaysia, Jordan, China, and Wuhan before the pandemic, respectively. However, during the pandemic, the descending GRMW was observed in Dhaka, Tehran, Bangladesh, Iran, Wuhan, Malaysia, and China with 4.8, 3.8, 3.4, 3.3, 2.94, 1.98, and 0.87 kg/(bed/day), respectively.

In the current study, GRMW was reported in three countries where one of their megacities presented its own GRMW during the pandemic. Accordingly, GRMW was lower in China, Iran, and Bangladesh compared to Wuhan, Tehran, and Dhaka, respectively, during the pandemic. The decreasing percentages were 70%, 13%, and 29% in Wuhan, Tehran, and Dhaka, respectively (Fig. 2). However, this trend was not followed in China before the pandemic, and GRMW in China (0.71 kg/(bed/day)) was larger than that in Wuhan (0.56 kg/(bed/day)). In all places, GRMW increased during the pandemic, and the most dramatic increase was observed in King Abdullah University Hospital in Jordan where the increased percentage was 1262%. On the other hand, one of the lowest increased percentages was observed in China by 23% after Tehran and Iran, suggesting that the larger place often results in a lower GRMW during a pandemic (Fig. 3). Fig. 3 presents strong descending trends of GRMW in all places based on the population,

Table 1. Tonnage and Generation Rates of Medical Waste per Day and Patients in Asia Before the COVID-19 Pandemic

Location	Period	Tons/day BC	kg/(bed/day) BC	kg/(day/ patient) BC	No. of Beds	No. of Patients	References
KAUH, Jordan, Asia	February–August 2004	0.087	0.29	0.36	300	242	(14)
Jordan, Asia	2003	9.4	0.96	-	9743	-	(15)
Wuhan, China, Asia	Before the pandemic	50	0.56	-	90 000	-	(16)
China, Asia	Before the pandemic	4903	0.71	-	6 870 000	-	(11, 17)
Malaysia, Asia	Before the pandemic	90	1.55	-	58 000	-	(18)
Aradkuh, Tehran, Iran, Asia	Before the pandemic	87.4	3.38	-	25 866	-	(19, 20, 21)
Iran, Asia	2016	354.3	2.98	-	118 894	-	(19, 20)
DMCH, Bangladesh, Asia	2006	3.27	1.93	0.63	1700	5200	(22)
BMCH, Bangladesh, Asia	2006	0.67	2.24	0.64	300	1050	(22)
GH, Bangladesh, Asia	2006	0.94	1.6	0.41	591	2289	(22)

Note. COVID-19: Coronavirus disease 2019; BC: Before COVID-19; KAUH: King Abdullah University Hospital; DMCH: Dhaka Medical College Hospital; BMCH: Bangladesh Medical College Hospital; GH: General hospitals.

Table 2. Tonnage and Generation Rates of Medical Waste per Day and Patients in Asia during the COVID-19 Pandemic

Location	Period	Tons/day BC	Kg/(bed/day) DC	Kg/day/ patient) DC	No. of Beds	COVID-19 Cases	References
KAUH, Jordan, Asia	March-20	0.395	3.95	14.16	100	28	(23, 24)
Wuhan, China, Asia	Until March 2020	265	2.94	-	90 000	50 333	(16)
China, Asia	Until March 21, 2020	6067	0.87	-	6 960 000	82 100	(11, 17, 25)
Malaysia, Asia	Until March 2020	115	1.98	-	58 000	3483	(18, 25, 26)
Aradkuh, Tehran, Iran, Asia	March 20	110	3.8	-	29 254	~8369	(20, 21, 25)
Iran, Asia	April 22	444.8	3.3	-	134 193	-	(27)
Dhaka, Bangladesh, Asia	April 31, 2020	206	4.8	-	42 571	~5701	(28, 29, 30)
Bangladesh, Asia	April 20	483.3	3.4	-	141 903	7628	(25, 28)

Note. COVID-19: Coronavirus disease 2019; BC: Before COVID-19; DC: During COVID-19; KAUH: King Abdullah University Hospital; DMCH: Dhaka Medical College Hospital; BMCH: Bangladesh Medical College Hospital; GH: General hospitals.

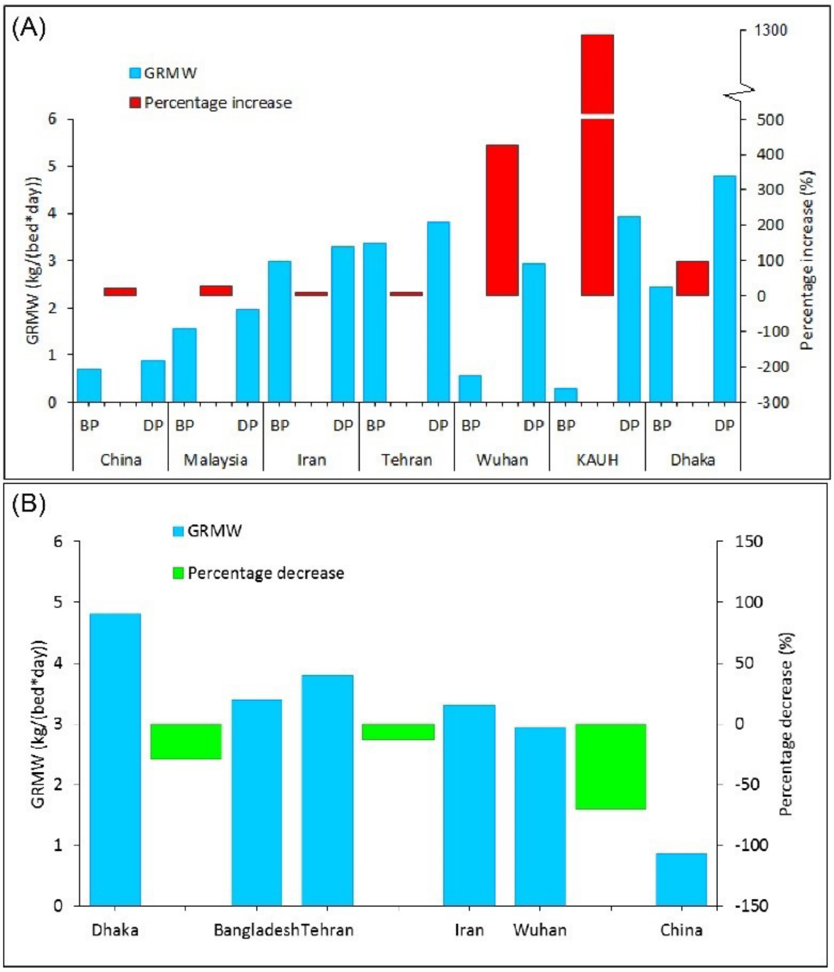

Fig. 2. Percentage Increase of GRMW before the Pandemic in Asia (A) and GRMW in Countries and Their Mega Cities during the Pandemic (V). *Note.* GRMW: Generation rate of medical waste; BP: Before the pandemic: DP: During the pandemic

number of hospital beds, and accumulated COVID-19 cases during the pandemic. Although these trends were descending before the pandemic, no strong R^2 (~0.03) was observed between GRMW and population or the number of hospital beds.

The statistical analysis of medical waste before and during the pandemic is presented in Table 3 and Fig. 4. Based on the analysis of variance, the *F*-value was greater than 4 only between GRMW before and during the pandemic; however, the corresponding *P* value was insignificant. Likewise, the total generation of medical waste per day did not display any significant difference before and during the pandemic. The difference in GRMW between megacities and their countries was similarly insignificant during the pandemic in Asia. These results are also graphically presented in Fig. 4 by box plots.

3.2. Disinfecting Methods of Medical Wastes During the Coronavirus Disease 2019 Pandemic

3.2.1. Autoclaving

Autoclave includes the disinfection of wastes by exposing them to direct steam at temperature, pressure, and contact time around 121-134°C, 15 Psi, and 30-60 minutes, respectively. Each cycle of autoclaving is completed with 200 to 10 000 L of waste. Sharp tools, reusable instruments, bedding wastes, and personal protective equipment are often persuaded to use autoclaves. This method is not recommended for the disinfection of chemical, radioactive, volatile, and semi-volatile wastes. Autoclave does not reduce the volume of the wastes, so complementary treatment of the autoclaved wastes is required. It is difficult to kill all microorganisms for large quantities of the wastes as well as large wastes (2, 31, 32).

3.2.2. Microwaves

Wastes are irradiated by electromagnetic waves from microwaves with length waves between 200-300 nm. Each cycle with 30-500 liters of waste is completed in 30-60 minutes. The wastes should have enough water to complete the thermal process. This method is also applied to the same wastes that are disinfected by autoclave. The microwave process heats the waste from inside to outside, and it is not economical to treat large quantities of waste with microwaves (2,33).

3.2.3. Chemical Disinfecting

Chemical disinfection, sodium hypochlorite, calcium hypochlorite, dioxide chloride, proxy acid, ozone, dry lime, and iron catalyzers are frequently used with crushed wastes. The wastes are crushed due to the increase in

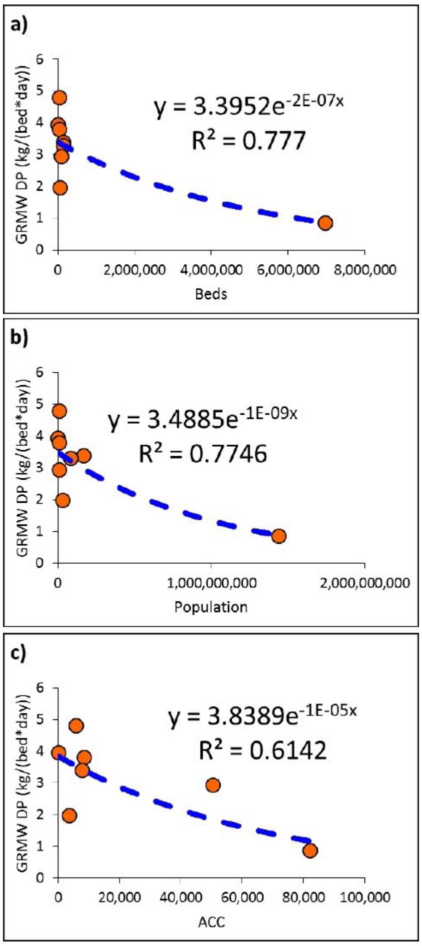

Fig. 3. The Trend of GRMW based on the Hospital Beds (a), Population (b), and ACC (c) during the COVID-19 Pandemic. *Note*. GRMW: Generation rate of medical waste; ACC: Accumulated confirmed cases; COVID-19: Coronavirus disease 2019

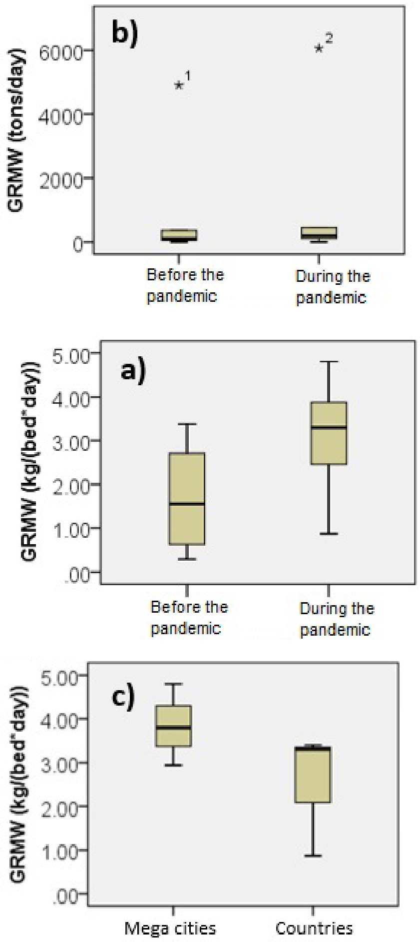

Fig. 4. Box Plots of GRMW Before and During the Pandemic (a, b) and of the GRMW Between Countries and Their Mega Cities during the Pandemic (c). *Note*. GRMW: Generation rate of medical waste

Table 3. ANOVA for the GRMW before and during the Pandemic and for the GRMW Between Countries and Their Mega Cities During the Pandemic

Different Scenarios of Medical Waste Generation	F	*P* Value
GRMW before and during the pandemic	4.12	0.065
TGMW before and during the pandemic	0.04	0.846
Engaged mega cities versus their countries	1.8	0.251

Note. ANOVA: One-way analysis of variance; GRMW: Generation rate of medical waste; TGMW: Total generation of medical waste.

contact surface and mixed with chemical disinfectants. Therefore, microorganisms are killed after an effective contact time. This method is rapid and stable for disinfecting a wide range of wastes although residual of the process, costs, and well-trained experts are considered disadvantages of this technology (34).

3.2.4. Landfilling

Landfilling is the easiest method for disposing the waste with low costs. The potential of public health and environmental issues will rise if the technology utilizes an open dump approach (35, 36). Stabilized and degraded solid wastes, leachate, and gas (i.e., CO_2, H_2S, CH_4, and the like) are the final productions of landfilling even though air, soil, and water are contaminated. Therefore, landfilling of medical wastes is not recommended and correct. The disposal of medical wastes in landfills should be prohibited in many countries unless the medical waste is disinfected from all hazardous microorganisms so that exposure to them does not cause any health and environmental issues (1,37).

3.2.5. Incineration

Incineration technology applies dry oxidation at temperatures higher than 850°C for the treatment of the wastes. The capacity and cycling time of the incinerations range between 15-2000 kg/h and 6-8 hours. Due to the high temperature of the process, infectious wastes are effectively treated. The unreusable and unrecyclable wastes are the input of the incinerations before being disposed in landfills. This method considerably decreases the volume of the wastes and turns them into ash and gas. In addition to the advantages of incinerators, they also led to many human and environmental concerns since they release heavy metals, dioxin, furan, hydrogen chloride, and the like into the atmosphere (38, 39). In general, the most used technologies were autoclaves and microwaves for disinfecting the medical wastes in Asia. Over 80% of infectious wastes were disinfected by

Table 4. Frequency Percentage of the Used Disinfecting Methods in Different Countries

Countries	Autoclave	Microwave	Chemical Disinfecting	Landfilling	Incinerators
India	43	39	10	6	2
Malaysia	41	38	8	7	6
China	38	37	12	10	3
Australia	43	32	11	7	7
Bangladesh	31	27	16	18	8

Note. Source: [9].

autoclave and microwave in India, while at the worst case, the percentage use of autoclave and microwave was about 60% in Bangladesh (Table 4). Moreover, the incinerators were used less frequently in Asia, and their frequency percentage was around 5%.

4. Conclusion

In this study, the relationship between COVID-19 incidences and medical wastes as well as recommended disinfecting methods were reviewed and analyzed. It was found that GRMW increased in all hospitals, cities, and countries during the pandemic period in Asia. According to the results of the ANOVA test, this increase was almost significant because the F-value was greater than 4, while the *P* value was not lower than 0.05. When considering the whole country, its GRMW is lower compared to the most engaged city. Furthermore, an increase in hospital beds, population, and accumulated confirmed cases of COVID-19 led to a decrease in GRMW. Autoclaves and microwaves were considered the most popular techniques for disinfecting medical wastes, while the least popular methods were chemical disinfecting, landfilling, and incinerators.

The investigation of the same study is recommended for other continents as future works. Comparing the results of such studies in different continents may reveal interesting features. Since medical wastes are produced differently from patient to patient, the evaluation of GRMW as unit of kg/patient/day is also suggested.

Acknowledgments

The authors thank Ahvaz Jundishapur University of Medical Sciences and Mizan Online News Agency for educational support and information about medical waste.

Authors' Contribution

Conceptualization: Heydar Maleki, Nematollah Jafarzadeh.
Data curation: Heydar Maleki.
Investigation: Heydar Maleki, Nematollah Jafarzadeh.
Methodology: Heydar Maleki.
Project administration: Nematollah Jafarzadeh.
Resources: Heydar Maleki.
Software: Heydar Maleki.
Writing–original draft: Heydar Maleki.
Writing–review & editing: Heydar Maleki, Nematollah Jafarzadeh.

Competing Interests

The authors declare that they do not have any conflict of interests.

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval

Not applicable.

Funding

This study is part of personal research, and no funding was provided.

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