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Environmental Implications of COVID-19 Medical Waste: Public Perception in Eastern Saudi Arabia

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ABSTRACT

The novel coronavirus primarily spreads through airborne droplets and contaminated surfaces. To limit transmission, the widespread use of face masks and gloves has become a daily practice, resulting in a significant rise in environmental waste. Improper disposal of these items in public spaces may further facilitate virus transmission. Despite this growing concern, studies exploring public perceptions of managing pandemic-related masks and gloves remain scarce. This study investigates public awareness, attitudes, and practices concerning the disposal of gloves and masks during the COVID-19 pandemic in Saudi Arabia. The results indicate that 74% of participants are knowledgeable about correct disposal practices, and 76% demonstrate positive attitudes toward waste management. Gender was significantly associated with adherence to biomedical waste regulations ($r = 0.169$, $p = 0.0001$) and with recognizing community responsibility in proper COVID-19 waste disposal ($r = 0.158$, $p = 0.0001$). Most participants were aware of existing regulations governing biomedical waste collection and disposal. Furthermore, public perception of the effectiveness of municipal measures to prevent virus spread showed a significant positive correlation with awareness levels ($r = 0.279$, $p = 0.0001$). Overall, the findings emphasize that proper management of infectious waste is essential to safeguard communities from the risks associated with improper disposal during the COVID-19 pandemic.

Keywords: Community perception, Public perception, Medical waste management, Environmental impact, Novel coronavirus outbreaks, Masks and gloves generated during the novel corona virus pandemic

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Introduction

Over the past twenty years, research has demonstrated that Coronaviruses (CoVs) are capable of infecting not only humans but also various mammals [1, 2]. In humans, CoVs can affect multiple organ systems, including the respiratory, gastrointestinal, hepatic, and central nervous systems [3]. On 11 March 2020, the World Health Organization (WHO) declared COVID-19 a global pandemic after the virus spread rapidly across multiple countries, including the Kingdom of Saudi Arabia (KSA). By 30 September 2021, WHO reported 233,201,667 confirmed COVID-19 cases and 4,772,958 deaths across 216 countries. In KSA, 543,028 infections and 8,709 deaths had been recorded.

Because contaminated hands can transfer the virus to the eyes, nose, and mouth [4], the use of personal protective equipment (PPE), such as gloves and masks, became a global necessity. In Saudi Arabia, a study of 4,305 participants indicated that 86.4% followed proper mask-wearing protocols and demonstrated appropriate behaviors, with 98.3% consistently wearing masks to reduce virus transmission [5]. According to population projections from the General Authority for Statistics, approximately 33,250,000 masks are used daily in KSA, assuming around 95% of the population wears them.

The environmental impact of PPE has raised concerns worldwide. Research indicates that the surge in production, consumption, and improper disposal of PPE has negatively affected ecosystems [6]. For instance, Wuhan, China,

saw medical waste (MW) treatment needs increase by 215 tons/day during the pandemic, exceeding a pre-pandemic capacity of 260 tons/day. Barcelona, Spain, reported a 350% rise in MW (1,200 tons vs. 275 tons normally), while Thailand's daily MW increased from 1,500 to 6,300 tons. In the UK, MW disposal rose by 300%, and France and the Netherlands experienced 10% and 5% increases, respectively [7-9]. In South Korea, the daily production of COVID-19-related MW escalated from approximately 295 tons in early February–March 2020 to 20 tons per day in April [10].

This rise in MW heightens the risk of virus transmission, particularly when waste management is inadequate [11-13]. Workers handling waste, including cleaners and municipal staff, are particularly vulnerable to infection [14]. Such concerns underscore the urgent need for effective MW management practices [15-17], and several studies have proposed strategies for COVID-19 waste handling [7, 13, 18, 19].

Although public knowledge, attitudes, and practices (AAP) regarding MW management have been emphasized before the pandemic, few studies have focused specifically on PPE disposal during COVID-19. For example, a survey of 1,303 residents in Bangladesh revealed that masks and gloves were the most commonly used PPE, yet only about half (49.35%) disposed of them in dedicated bins at home or in communal areas (54.56% and 75.6%, respectively) [20]. Similarly, in Nepal, a survey of 512 households indicated that 62.3% were dissatisfied with the existing municipal waste system [21].

While hospitals are recognized as significant generators of MW, waste produced by the public is often neglected. Unlike hospitals, where infectious waste is carefully handled, PPE used by the public is generally disposed of in household bins and becomes part of municipal waste. Municipal waste encompasses all household-generated waste, whereas medical waste includes healthcare-related materials such as syringes, human tissues, chemicals, disposable devices, radioactive waste, and biological fluids [22, 23]. Improper disposal of either type can threaten human health and the environment, affecting soil, water, air, and landscapes.

In the study area, municipalities do not provide specific collection or disposal methods for masks and gloves. Consequently, infectious waste from public use often ends up in landfills mixed with general municipal waste. Conversely, waste from medical personnel and COVID-19 patients is treated as infectious waste and is either incinerated, autoclaved, or safely landfilled. Given the lack of research on public AAP regarding COVID-19 waste management (COVWM), it is critical to assess public perceptions and behaviors. Encouraging social and ethical responsibility in collecting, storing, managing, and disposing of COVID-19 waste is essential to reduce viral transmission and environmental hazards.

In KSA, licensed companies such as the Saudi Gulf Company for Environmental Protection (SEPCO), Enjaz Company, and Saad Trading and Construction handle MW transport, treatment, and disposal. Incineration, autoclaving, and landfill are the standard disposal methods. A prior study in Eastern Province hospitals and healthcare centers reported MW generation rates of 640.74 ± 0.59 tons/year for hospitals and 0.598 ± 0.119 tons/year for healthcare centers, with per-bed and per-patient generation rates of 0.51 kg/bed/day and 1.66 kg/patient/day, respectively [24].

During lockdown periods, public behaviors regarding mask and glove disposal varied considerably. Therefore, this study aims to evaluate AAP toward gloves and masks discarded in the environment during the COVID-19 pandemic in Eastern Province, KSA **(Figure 1**). It also examines the relationship between public perception and attitudes toward contagious waste management. This research focuses on the general community rather than healthcare or municipal workers, with separate studies on these groups currently in progress by our team.

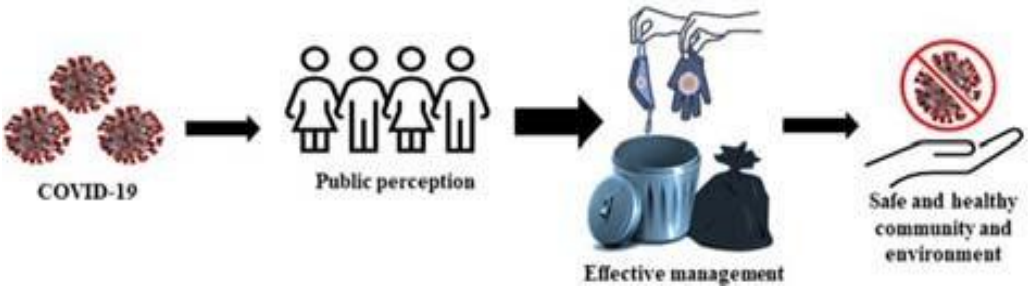


Figure 1. presents a visual summary of how the public perceives the waste generated during the COVID-19 pandemic.

The remainder of this paper is structured as follows: Section 2 describes the methodology adopted for the study, while Section 3 presents and discusses the findings. Section 4 offers the final conclusions. The study was conducted in the Eastern Province of KSA between 15 July 2020 and 17 August 2020.

Materials and Methods

Design of study

A cross-sectional survey was carried out among 572 individuals from the general population in the Eastern Province of KSA. Since numerous international studies have demonstrated a link between public perception, attitudes, and the management of infectious waste, this research aims to determine whether a similar relationship exists in the Eastern Province during the COVID-19 pandemic. Data were collected over a one-week period, from 24 June to 1 July 2020, using a structured questionnaire distributed through online channels, including various social media platforms.

The survey was developed with reference to previous literature and national and international guidelines, notably the WHO recommendations for medical waste management [4, 18, 25-27]. It was administered electronically via QuestionPro®, offering both Arabic and English versions to accommodate the region's linguistically diverse population.

The questionnaire consisted of two main sections: the first gathered socio-demographic data such as age, gender, marital status, education level, and occupation; the second addressed participants' awareness, attitudes, and practices (AAP) regarding COVID-19-related waste (COVW). Collected responses were analyzed using the Statistical Package for the Social Sciences (SPSS®) version 25 (IBM®, Armonk, NY, USA).

Statistical analysis

SPSS was employed to process and interpret the dataset, enabling the identification of patterns and variations within the responses. Descriptive statistics—including mean, median, standard deviation, variance, skewness, and kurtosis—were generated from the questionnaire data. Furthermore, a Pearson correlation matrix was produced to examine associations between variables, using a two-tailed significance test to evaluate the survey outcomes.

Ethical approval

The authors did not conduct any direct human subject research for this study. All individuals who took part in the survey provided their consent prior to contributing their responses.

Results and Discussion

At the time this manuscript was submitted, no prior research had examined the public's awareness, attitudes, and practices (AAP) related to COVID-19-generated waste (COVW), despite the crucial role that proper disposal of items such as masks, gloves, and disposable tissues plays in limiting viral transmission. Evaluating AAP can also greatly assist authorities in managing the sudden surge in waste produced through widespread community use of protective equipment, enabling the development of safer and more effective emergency waste-handling guidelines.

Table 1 presents the sociodemographic characteristics of all 572 respondents, representing a full 100% response rate, which is adequate to meet the objectives of the study.

Table 1. Demographic profile of participants (N = 572).

Characteristic	Category	Frequency (N)	Percentage (%)
Age (years)	<18	5	0.87
	18–24	144	25.17
	25–34	134	23.43
	35–44	134	23.43
	45–54	90	15.73
	55–64	60	10.49
	>65	5	0.87
Gender	Male	258	45.03

	Female	314	54.97
Marital Status	Single	202	35.25
	Married	342	59.86
	Divorced	15	2.62
	Widowed	6	1.05
	Prefer not to say	7	1.22
Educational Level	High School	76	13.26
	Diploma	40	6.98
	Bachelor	352	61.61
	Master	67	11.69
	Doctorate	37	6.46
Profession	Education	110	19.2
	Engineering	193	33.68
	Banking	5	0.87
	Health Worker	28	4.89
	Medical Doctor	6	1.05
	Management	95	16.58
	Others	135	23.73

1Mean age in years ±SD = 36.123 ± 1.357.

Awareness of the participants regarding COVID-19 wastes

Participants' awareness was evaluated across six indicators (AW1–AW6), summarized in **Table 2**. For AW1, which addresses the definition of biomedical waste, both the mean and median were found to be 2. The distribution showed a Skewness of 0 and an elevated Kurtosis value of 29.10, suggesting that responses were highly concentrated around specific answer choices and followed a near-normal pattern. A large majority—510 participants (97%)—correctly identified biomedical waste as material produced through hospital-related activities such as diagnosis, treatment, and preventive procedures. In contrast, 9 respondents (2%) associated biomedical waste with household refuse, and 8 individuals (2%) indicated that they did not know the correct definition.

Table 2. Awareness about COVID-19 wastes management (N = 572).

Awareness Item	Mean	Median	SD	Variance	Skewness	Kurtosis	25th Percentile	50th Percentile	75th Percentile
AW1: Definition of medical waste	2.00	2.00	0.177	0.031	0.000	29.097	2	2	2
AW2: Regulations for medical waste collection and disposal	1.72	1.00	0.913	0.833	0.573	-1.557	1	1	3
AW3: Applicability of MW management rules and COVID-19 waste technologies in healthcare	3.58	4.00	0.916	0.839	-0.499	0.303	3	4	4
AW4: Procedures for COVID-19 waste disposal	3.49	4.00	1.086	1.180	-0.611	-0.123	3	4	4
AW5: Appropriate biomedical waste disposal methods	2.00	2.00	0.221	0.049	0.277	17.619	2	2	2
AW6: Proper methods for disposing COVID-19 waste	1.33	1.00	0.606	0.367	1.684	1.646	1	1	2

A comparable pattern was observed for AW5, which assessed knowledge about the proper disposal of biomedical waste. Most participants, 501 (95%), indicated that biomedical waste should be collected in designated bins and handed over to certified hazardous waste management companies or specialists. A small proportion, 12 participants (2%), believed that biomedical waste could be treated as municipal waste and sent to landfills, while

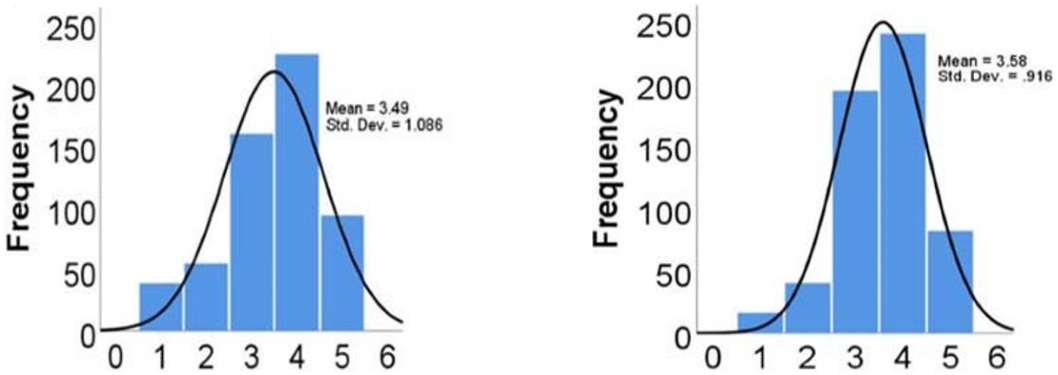
14 participants (3%) were unsure of the correct disposal method. These findings demonstrate a high level of public awareness regarding biomedical waste and its proper handling.

These results contrast with studies conducted in Kathmandu, Nepal, where 26.3% of respondents lacked sufficient knowledge about healthcare waste [26], and with the findings of Sidhu and Kaur (2016) [28], who reported below-average awareness of biomedical waste management. One likely explanation for this discrepancy is the higher educational level of participants in the present study compared to those in the previous studies.

Regarding awareness of established, accessible, and published regulations for the collection and disposal of general biomedical waste (AW2), the 75th percentile of responses fell below "do not know" (answer 3), while the 25th and 5th percentiles were below answer 1. This indicates a tendency for participants' answers to shift toward uncertainty. Specifically, 212 participants (32%) were unaware of whether regulations exist in their region, 315 (59%) acknowledged that well-known regulations are in place, and 45 participants (9%) believed that no such regulations exist.

For COVID-19-specific waste management (AW3 and AW4), only 74 participants (14%) strongly agreed that hospitals and medical centers in the region are equipped with the necessary guidelines, technologies, and information to handle COVID-19 waste (AW3). Meanwhile, 223 participants (42%) agreed, and 177 (34%) remained neutral. Regarding awareness of procedures for discarding used gloves, masks, and disposable handkerchiefs during the pandemic (AW4), only 16% strongly agreed, 39% agreed, 29% were neutral, 9% disagreed, and 7% strongly disagreed.

The distributions of responses for AW3 and AW4 are illustrated in **Figures 2a and 2b**, respectively. Both histograms show similar trends, with mean values of 3.49 (AW4) and 3.58 (AW3), and slightly right-skewed distributions, reflected in skewness values of 0.61 and 0.49.



a) b)

Figure 2. illustrates participants' perceptions regarding COVID-19 waste management.

Figure 2a shows the distribution of responses about the procedures followed to dispose of COVID-19 wastes, with a mean of 3.49, median of 4, and skewness of -0.611. **Figure 2b** depicts the distribution of perceptions concerning the applicability of medical waste management rules, guidelines, and technologies for COVID-19 waste in hospitals and medical centers, with a mean of 3.58, median of 4.00, and skewness of -0.499.

Regarding the proper disposal of used masks, gloves, and disposable handkerchiefs during the COVID-19 pandemic (AW6), 388 participants (74%) reported that these items should be collected separately in dedicated containers and treated as medical waste. Meanwhile, 100 participants (19%) preferred disposal in municipal waste bins, and 39 respondents (7%) were unsure about the correct method. **Figure 3** illustrates the distribution of responses for AW6, showing a left-skewed trend toward separating COVID-19-related waste into dedicated containers for biomedical waste management.

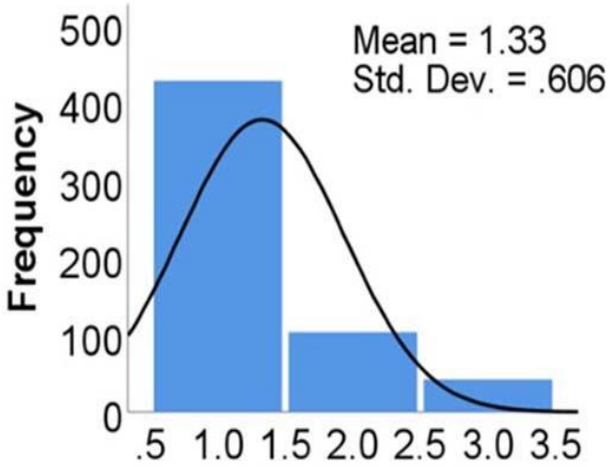


Figure 3. illustrates participants' responses regarding the correct disposal of used masks, gloves, and disposable tissues generated during the COVID-19 pandemic, showing a mean of 1.33, median of 1.00, and a positively skewed distribution (skewness = 1.684). The findings suggest that the majority of respondents perceive such waste as medical waste, which likely contributes to the overall high level of awareness about COVID-19 waste management (COVWM). This aligns with WHO recommendations stating that community-used masks in areas affected by COVID-19 should be handled as infectious waste.

In contrast, earlier studies conducted before the pandemic highlighted considerable knowledge gaps among nursing and healthcare personnel regarding medical waste regulations [25, 29, 30], including insufficient understanding of proper storage, segregation, and management practices [25, 31].

The attitude of the participants toward COVID-19 wastes

In this study, participants generally exhibited a positive attitude toward COVID-19 waste management (COVWM). When evaluating attitudes regarding the classification of COVID-19-related waste (AT1), **Table 3** indicates that the 25th, 50th, and 75th percentiles all correspond to answer 1, reflecting the view that gloves, masks, and disposable handkerchiefs generated during the pandemic should be treated as medical waste. A smaller proportion of participants—64 individuals (13%)—categorized COVW as municipal waste, while 61 participants (12%) were unsure of the correct classification.

Table 3. Attitude towards COVID-19 wastes management (N = 572).

Attitude Item	Mean	Median	SD	Variance	Skewness	Kurtosis	25th Percentile	50th Percentile	75th Percentile
AT1: Classification of COVID-19 waste	1.34	1.00	0.667	0.445	1.725	1.443	1	1	1
AT2: Sufficiency and effectiveness of municipal COVID-19 waste management measures	3.48	4.00	1.122	1.259	-0.462	-0.592	3	4	4
AT3: Inappropriate disposal of COVID-19 waste	3.47	4.00	1.180	1.393	-0.511	-0.706	3	4	4
AT4: Importance of attending specialized training on COVID-19 waste management	1.88	2.00	0.894	0.799	0.228	-1.713	1	2	3
AT5: Experience and training level of healthcare workers managing medical waste	3.53	4.00	0.947	0.896	-0.464	0.319	3	4	4
AT6: Viewing effective disposal of COVID-19 waste as a collective community responsibility	4.46	5.00	0.794	0.630	-1.949	4.843	4	5	5

The participants' perspectives on the adequacy and effectiveness of municipal COVID-19 waste management (COVWM) measures (AT2) revealed a varied distribution: 107 individuals (19%) strongly agreed, 214 (38%) agreed, 129 (22%) were neutral, 91 (16%) disagreed, and 31 (5%) strongly disagreed that the measures implemented by municipalities to safeguard public health during the pandemic were sufficient and effective.

Regarding the improper disposal of COVID-19-related waste (AT3), 225 participants (39%) agreed, 110 (19%) strongly agreed, 99 (17%) were unsure, 99 (18%) disagreed, and 39 (7%) strongly disagreed that they had observed people discarding used gloves and masks inappropriately in the environment.

As shown in **Table 3**, the responses for AT2 and AT3 followed a similar trend, with mean values of 3.48 and 3.47, and variance values of 1.259 and 1.393, respectively. Both distributions were right-skewed, indicating that a significant proportion of participants expressed concern about the improper disposal of COVW. Previous research on general medical waste management (MWM) often reported a positive attitude among participants, who recognized poor waste management as a serious public health issue [25, 31, 32]. However, more recent studies revealed either negative [26] or unfavorable [33] attitudes toward MWM.

A lower level of acceptance was observed regarding the importance of attending specialized training on COVWM (AT4), with only 243 participants (46%) expressing willingness to participate in such courses. Similarly, attitudes toward the training and competence of personnel managing medical waste in hospitals and medical centers (AT5) were moderate: 15% strongly agreed, 36% agreed, 39% were unsure, 6% disagreed, and 4% strongly disagreed. This may reflect the belief of 56% of participants that information on COVWM can be accessed through news outlets and online resources.

Conversely, one of the most positive findings was participants' attitude toward the collective responsibility of the community for effective COVW disposal (AT6). Here, 59% strongly agreed and 32% agreed that safe disposal of used masks, gloves, and disposable handkerchiefs is a shared duty. **Figure 4** illustrates that the distribution of responses for AT6 is right-skewed, with the 50th and 75th percentiles below 5, indicating that most participants strongly supported community involvement in proper waste disposal. This favorable attitude correlates significantly with the high level of awareness among respondents regarding the environmental and health risks associated with improper disposal of COVID-19 waste.

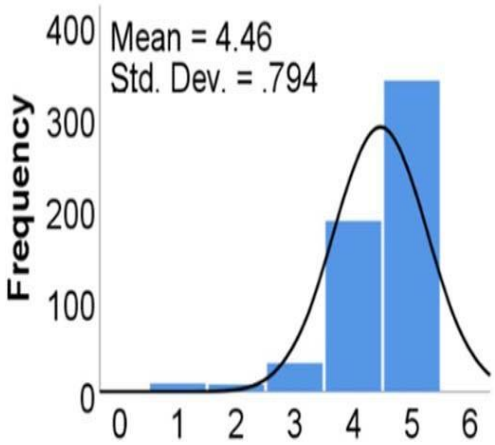


Figure 4. illustrates the distribution of community attitudes toward viewing the proper disposal of COVID-19-related waste (COVW) as a collective responsibility. The responses were predominantly right-skewed, indicating strong agreement among participants. The mean response was 4.46, the median was 5.00, and the skewness was -1.949, reflecting a general consensus on the importance of shared responsibility in managing pandemic-related waste.

The practice of the participants regarding COVID-19 wastes

Table 4 presents the results of participants' practices concerning COVID-19 waste management (COVWM). For PR1, most respondents (402 participants, 76%) reported disposing of used gloves, masks, or disposable handkerchiefs in cars or household trash bins. Regarding PR2, which assessed the use of a designated or special garbage bag for COVID-19 waste, only 22% of participants strongly agreed (option 5) that they regularly followed this practice. Additional responses included 35% agreeing (option 4), 12% remaining neutral (option 3), 20% disagreeing (option 2), and 11% strongly disagreeing (option 1). These results suggest that while many participants are aware of WHO (2020) [4] guidelines recommending that COVID-19-related waste be collected in secure, closed black bags prior to final municipal disposal, there remains a gap in consistent application.

A less desirable behavior was observed in PR1, as 76% of participants reported discarding gloves or masks in cars or household bins. This behavior was significantly correlated ($r = 0.258$, $p = 0.000$) with PR3, where 44% of

respondents indicated that they generally did not encounter dedicated disposal sites for masks and gloves while outside their homes during permitted outings.

Regarding attendance at specialized COVWM training (PR4), responses displayed a strong positive skewness of 2.73, indicating that most participants had not attended such training. Only 51 participants (10%) reported having received formal training on COVID-19 waste management.

Table 4. Practice regarding COVID-19 wastes management (N = 572).

Practice Item	Mean	Median	SD	Variance	Skewness	Kurtosis	25th Percentile	50th Percentile	75th Percentile
PR1: Disposal of COVID-19 waste in cars or household bins	1.24	1.00	0.430	0.185	1.193	-0.578	1	1	1
PR2: Disposal of COVID-19 waste in a dedicated garbage bag	3.36	4.00	1.320	1.741	-0.390	-1.105	2	4	4
PR3: Disposal of COVID-19 waste in public dedicated containers	2.78	3.00	1.255	1.575	0.100	-1.080	2	3	4
PR4: Attendance of specialized training for COVID-19 waste management	1.90	2.00	0.297	0.088	-2.713	5.380	2	2	2

Correlation analysis between AAP of participants regarding COVID-19 wastes

Table 5 summarizes the correlation analysis between community awareness, attitudes, and practices (AAP) regarding the disposal of used face masks, gloves, and disposable handkerchiefs during the COVID-19 pandemic. The findings indicate a statistically significant relationship ($r = 0.293$, $p < 0.0001$) between participants' knowledge of medical waste collection and disposal regulations (AW2) and their perception of the training and competency of healthcare personnel responsible for managing medical waste in hospitals and medical centers (AT5) in the region. Pearson's correlation test was applied to all variables using a two-tailed significance level of 0.05. Several other variable pairs also showed significant correlations at the 0.01 level, as detailed in **Table 5**.

Table 5. Two-tailed Pearson Correlation between public attitude, awareness and practices.

		AW1	AW2	AW3	AW4	AW5	AW6	AT1	AT2	AT3	AT4	AT5	AT6	PR1	PR2	PR3	PR4
AW1	*r*	1	-0.032	.097*	-0.027	.089*	-0.016	-0.030	0.070	0.033	0.055	-0.042	0.050	-0.046	0.067	-0.016	-0.033
	p		0.439	0.020	0.516	0.033	0.698	0.480	0.093	0.425	0.188	0.320	0.235	0.273	0.108	0.708	0.429
AW2	*r*	-0.032	1	-.092*	-.093*	0.065	.125**	0.076	-0.049	-0.046	.107*	-.189**	0.019	-0.064	-0.058	-0.046	.100*
	p	0.439		0.028	0.026	0.118	0.003	0.069	0.248	0.271	0.011	0.000	0.642	0.125	0.163	0.274	0.017
AW3	*r*	.097*	-.092*	1	.210**	0.033	-0.046	-.085*	.279**	.154**	-0.014	.293**	.096*	0.057	.140**	.196**	-.106*
	p	0.020	0.028		0.000	0.429	0.274	0.043	0.000	0.000	0.733	0.000	0.022	0.176	0.001	0.000	0.011
AW4	*r*	-0.027	-.093*	.210**	1	0.015	-.123**	-.127**	.214**	.331**	-0.023	.113**	.104*	.242**	.438**	.187**	-.149**

	p	0.516	0.026	0.000		0.725	0.003	0.002	0.000	0.000	0.585	0.007	0.012	0.000	0.000	0.000	0.000
AW5	*r*	.089*	0.065	0.033	0.015	1	-0.022	-0.008	0.057	-0.060	-0.016	-0.009	-0.039	0.009	0.002	0.015	-0.048
	p	0.033	0.118	0.429	0.725		0.607	0.848	0.176	0.153	0.709	0.831	0.350	0.822	0.968	0.713	0.252
AW6	*r*	-0.016	.125**	-0.046	-.123**	-0.022	1	.328**	0.015	-0.032	.141**	-0.021	-0.045	-.099*	-.103*	0.024	.100*
	p	0.698	0.003	0.274	0.003	0.607		0.000	0.722	0.443	0.001	0.617	0.278	0.018	0.013	0.566	0.017
AT1	*r*	-0.030	0.076	-.085*	-.127**	-0.008	.328**	1	0.048	-0.005	.083*	-0.068	-.088*	-0.033	-0.037	0.029	.115**
	p	0.480	0.069	0.043	0.002	0.848	0.000		0.254	0.899	0.046	0.103	0.035	0.432	0.373	0.485	0.006
AT2	*r*	0.070	-0.049	.279**	.214**	0.057	0.015	0.048	1	.101*	0.061	.143**	.095*	0.067	.203**	.321**	0.079
	p	0.093	0.248	0.000	0.000	0.176	0.722	0.254		0.015	0.146	0.001	0.024	0.110	0.000	0.000	0.060
AT3	*r*	0.033	-0.046	.154**	.331**	-0.060	-0.032	-0.005	.101*	1	-0.075	.107*	.132**	.120**	.281**	.203**	-.153**
	p	0.425	0.271	0.000	0.000	0.153	0.443	0.899	0.015		0.074	0.010	0.002	0.004	0.000	0.000	0.000
AT4	*r*	0.055	.107*	-0.014	-0.023	-0.016	.141**	.083*	0.061	-0.075	1	0.048	-0.046	0.014	0.002	0.021	.188**
	p	0.188	0.011	0.733	0.585	0.709	0.001	0.046	0.146	0.074		0.250	0.275	0.732	0.957	0.613	0.000
AT5	*r*	-0.042	-.189**	.293**	.113**	-0.009	-0.021	-0.068	.143**	.107*	0.048	1	0.017	0.053	.109**	.110**	0.025
	p	0.320	0.000	0.000	0.007	0.831	0.617	0.103	0.001	0.010	0.250		0.678	0.209	0.009	0.008	0.557
AT6	*r*	0.050	0.019	.096*	.104*	-0.039	-0.045	-.088*	.095*	.132**	-0.046	0.017	1	0.053	.198**	0.050	0.021
	p	0.235	0.642	0.022	0.012	0.350	0.278	0.035	0.024	0.002	0.275	0.678		0.209	0.000	0.228	0.615
PR1	*r*	-0.046	-0.064	0.057	.242**	0.009	-.099*	-0.033	0.067	.120**	0.014	0.053	0.053	1	.239**	.169**	-.141**

	p	0.273	0.125	0.176	0.000	0.822	0.018	0.432	0.110	0.004	0.732	0.209	0.209		0.000	0.000	0.001
PR2	*r*	0.067	-0.058	.140**	.438**	0.002	-.103*	-0.037	.203**	.281**	0.002	.109**	.198**	.239**	1	.258**	-0.072
	p	0.108	0.163	0.001	0.000	0.968	0.013	0.373	0.000	0.000	0.957	0.009	0.000	0.000		0.000	0.087
PR3	*r*	-0.016	-0.046	.196**	.187**	0.015	0.024	0.029	.321**	.203**	0.021	.110**	0.050	.169**	.258**	1	-0.039
	p	0.708	0.274	0.000	0.000	0.713	0.566	0.485	0.000	0.000	0.613	0.008	0.228	0.000	0.000		0.356
PR4	*r*	-0.033	.100*	-.106*	-.149**	-0.048	.100*	.115**	0.079	-.153**	.188**	0.025	0.021	-.141**	-0.072	-0.039	1
	p	0.429	0.017	0.011	0.000	0.252	0.017	0.006	0.060	0.000	0.000	0.557	0.615	0.001	0.087	0.356	

Correlation is statistically meaningful at the 5% level (two-tailed). ** Correlation is statistically meaningful at the 1% level (two-tailed). refers to the Pearson correlation value, and p indicates the probability value for the two-tailed test.

These findings indicate that the public demonstrates a strong understanding of the procedures for disposing of COVID-19-related waste (COVW) and generally follows proper disposal practices. Public awareness regarding the implementation of medical waste management (MWM) rules, guidelines, and technologies for COVW in hospitals and medical centers was found to have a very strong correlation with multiple attitudes and practices. These include perceptions of the adequacy and effectiveness of municipal COVWM measures to limit COVID-19 spread, concerns about improper disposal of COVW, evaluations of the training and competence of healthcare personnel handling medical waste, and actual disposal practices such as using dedicated garbage bags or public containers for COVW.

A significant positive correlation ($r = 0.279$, $p < 0.0001$) was also observed between public awareness of hospital and municipal measures (AW3) and participants' attitudes (AT2) toward the sufficiency and effectiveness of these interventions in mitigating virus transmission.

Furthermore, knowledge of proper COVW disposal procedures was strongly associated with participants' perceptions of municipal COVWM effectiveness, their attitudes toward improper disposal, and their disposal behaviors—including discarding waste in household bins or cars, using dedicated garbage bags, and utilizing public collection containers. This awareness also strongly influenced participants' interest in attending specialized COVWM training. Similarly, understanding the correct disposal methods for used masks, gloves, and handkerchiefs was closely linked to participants' attitudes and practices, including recognizing these items as medical waste and collecting them in designated containers.

In addition, the public's attitudes regarding the adequacy and effectiveness of municipal COVWM measures were highly correlated with proper disposal practices, such as using special garbage bags and public collection containers. Attitudes toward the improper disposal of masks and gloves in the environment also had a notable impact on participants' actual disposal behaviors and their willingness to participate in specialized COVWM training programs.

Correlation analysis between AAP and participants' characteristics

A multi-correlation analysis **(Table 6)** was conducted to examine the relationships between participants' demographic characteristics—such as gender, education level, and profession—and their awareness, attitudes, and practices (AAP) regarding COVID-19 waste management.

Table 6. Correlation of participants' gender, education level, and profession with their awareness, attitudes, and practices regarding COVID-19 waste management.

Study Domain	Item	Correlation with Gender (r)	p-value	Correlation with Education Level (r)	p-value	Correlation with Profession (r)	p-value	Interpretation
Awareness	AW1	0.04	0.344	-0.06	0.151	0.106*	0.011	Weak positive with profession
	AW2	0.169**	0.0001	-0.166**	0.0001	0.078	0.062	Positive correlation with gender, negative with education
	AW3	-0.055	0.191	-0.042	0.322	0.071	0.091	Not significant
	AW4	-0.019	0.647	-0.028	0.505	0.047	0.265	Not significant
	AW5	0.062	0.139	-0.015	0.727	0.001	0.975	Not significant
	AW6	0.158**	0.0001	-0.177**	0.0001	0.135**	0.001	Positive with gender and profession, negative with education
Attitude	AT1	0.081	0.053	-0.116**	0.005	0.099*	0.018	Weak positive with profession, negative with education
	AT2	0.108**	0.01	-0.174**	0.0001	0.101*	0.016	Positive with gender and profession, negative with education
	AT3	-0.047	0.262	-0.036	0.384	0.076	0.071	Not significant
	AT4	0.084*	0.046	-0.069	0.098	0.110**	0.009	Positive with gender and profession
	AT5	0.018	0.672	0.002	0.956	0.003	0.949	Not significant
	AT6	0.01	0.806	0.024	0.572	-0.011	0.796	Not significant
Practice	PR1	-0.024	0.563	0.068	0.104	-0.023	0.591	Not significant
	PR2	0.069	0.101	-0.164**	0.0001	0.134**	0.001	Negative with education, positive with profession
	PR3	0.041	0.322	-0.138**	0.001	0.083*	0.047	Negative with education, positive with profession
	PR4	0.115**	0.006	-0.054	0.199	0.033	0.425	Positive with gender

Indicates a statistically significant correlation at the 5% level (two-tailed). ** Indicates a statistically significant correlation at the 1% level (two-tailed). N = 572; r represents the Pearson correlation coefficient; p denotes the two-tailed significance value.

Gender showed significant correlations with several awareness and attitude indicators. Specifically, gender was significantly associated with AW2 (r = 0.169, p = 0.0001) and AW6 (r = 0.158, p = 0.0001), suggesting that many participants were unaware of the existing regulations for biomedical waste collection and disposal in their region. Additionally, gender correlated with attitudes AT1 (r = 0.081, p = 0.053), AT2 (r = 0.108, p = 0.01), and AT4 (r = 0.084, p = 0.046), as well as with practice PR4 (r = 0.115, p = 0.006). Percentile analysis indicated that males predominantly occupied the 25th quartile, whereas females were represented in the 50th and 75th quartiles, highlighting that female participants were more likely to participate in specialized training on COVID-19 biomedical waste management.

A notable negative correlation was observed between education level (high school, diploma, bachelor's, master's, doctorate) and several awareness, attitude, and practice responses. For example, higher education levels were inversely associated with PR2 (r = -0.164, p = 0.0001) and PR3 (r = -0.138, p = 0.001), indicating that participants with higher educational attainment were less likely to dispose of masks and gloves in designated garbage bags or public containers during the COVID-19 pandemic. In other words, as education level increased, adherence to proper disposal practices decreased.

Participants' professions, including roles in education, engineering, banking, healthcare, or as medical doctors, were significantly correlated with certain awareness and attitude items. For instance, profession was associated with AW1 (r = 0.006, p = 0.011), suggesting that many participants lacked a precise understanding of the definition of biomedical waste. This underscores the need for targeted awareness campaigns. Profession also correlated with AT4 (r = 0.110, p = 0.009), indicating that most participants expressed willingness to attend training on COVID-19 biomedical waste management.

Limited research has explored public perception and attitudes toward PPE waste disposal. However, the findings of this study align with those reported in Bangladesh, where residents demonstrated generally adequate awareness, attitudes, and practices for proper PPE disposal [20]. Similar to our study, women exhibited better disposal practices than men. In contrast, the relationship between education and proper disposal observed in our study differed from previous findings, as higher education was associated with less compliant disposal behaviors, and profession did not consistently predict knowledge of biomedical waste.

These results also contrast with observations from Guyana and Nigeria [12], where PPE disposal practices were poor. In those countries, 60.9% of households in Guyana and 71.5% in Nigeria were found to dispose of PPE alongside general solid waste, highlighting widespread improper disposal. In comparison, participants in this study demonstrated higher levels of awareness and adherence to proper PPE disposal practices.

Conclusion

This study provides a novel assessment of community members' awareness, attitudes, and practices concerning the disposal of used face masks, gloves, and disposable handkerchiefs generated during the COVID-19 pandemic. Effective management of such potentially hazardous waste is critical to protecting the community from indirect exposure to the virus and minimizing environmental contamination from long-lasting, plastic-based, or infectious materials that could otherwise reach landfills or oceans. The findings indicate that a high level of public awareness is closely linked to positive attitudes, which in turn contribute to proper and environmentally responsible disposal practices during the pandemic. Encouragingly, the majority of participants viewed the safe disposal of COVID-19-related waste as a collective responsibility, reflecting a strong community-oriented mindset.

Nonetheless, some improper behaviors persist, such as discarding used masks and gloves in vehicles or household trash bins and inappropriate disposal in public areas, which participants themselves recognized as undesirable. Moreover, only a small proportion of respondents strongly agreed that COVID-19 waste in hospitals and medical centers is handled by trained personnel, highlighting an urgent need for community education and training programs focused on available policies, guidelines, and best practices for COVID-19 waste management.

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