



Capacity assessment to secure COVID-19 waste treatment in Vietnam

Trang D T Nguyen^{1,2} · Kosuke Kawai³ · Toyohiko Nakakubo¹

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Abstract

The accelerated generation of COVID-19 waste under the Delta-fuelled outbreak placed a sudden burden on waste disposal in Vietnam. To secure the treatment of COVID-19 waste amid the pandemic uncertainty, treatment capacity was assessed by determining treatment occupancy rate—the ratio of estimated demand to calculated capacity—both nationally and in Ho Chi Minh City. At the general occupancy rate for COVID-19 waste treatment of 7.4%, the country was capable of handling COVID-19 waste, with a capacity to treat 62 191 t month⁻¹. However, Ho Chi Minh City became overwhelmed, indicated by a treatment occupancy rate of up to 780% during the Delta outbreak, as the unanticipated growth of demand for COVID-19 waste treatment caused waste to back up. The assessment results, in addition to current legislation, support collaboration in waste treatment as a solution to using existing resources to address the acute shortage of treatment capacity, so as to secure COVID-19 waste treatment. The findings could be used by other developing countries to tackle the waste problem in the pandemic era.

Keywords COVID-19 · Medical waste · Treatment capacity · Capacity assessment · Developing country

Abbreviations

CITENCO	HCMC Urban Environment Company Limited
COVID-19	Coronavirus disease 2019
DOH	Department of Health
DONRE	Department of Natural Resources and Environment
HCMC	Ho Chi Minh City
HMW	Hazardous medical waste
JSC	Joint Stock Company
MOH	Ministry of Health
MONRE	Ministry of Natural Resources and Environment
NSC	National Steering Committee
PC	People's Committee
PPE	Personal Protective Equipment

URENCO	Urban Environment Company
VEA	Vietnam Environment Administration
WHO	World Health Organization

Introduction

The global pandemic of coronavirus disease 2019 (COVID-19) has remarkably pressurized waste management systems in developing countries with improper waste disposal infrastructure [1–3]; those were not designed to operate under a pandemic [4–7]. With relevant to inadequate practices for waste management due to technical and financial constraints in those nations [2, 8], typical issues caused by COVID including sudden and large increase in waste generation, shortage of waste handlers and lack of adequate safety at work [1, 2, 7, 9] have led to further disruptions in waste collection, transportation, recycling and final disposal [1, 2, 10]. Following transportation, waste disposal was the next stage in the waste management system to be overwhelmed during the COVID-19 pandemic [10], owing to a sudden growth in waste treatment demand [4, 11, 12]. Insufficient treatment capacity restricted the safe disposal of COVID-19 waste [4, 7, 11, 12] in a number of developing countries using the recommended incineration of COVID-19 waste [1, 2, 7]. For instance, in Indonesia,

✉ Trang D T Nguyen
nguyen.thi.doan.trang@ocha.ac.jp

¹ Ochanomizu University, 2-1-1 Otsuka, Bunkyo, Tokyo 112-8610, Japan

² Ho Chi Minh City University of Natural Resources and Environment, 236B Le Van Sy Street, Ward 1, Tan Binh District, Ho Chi Minh City, Vietnam

³ National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan

where incinerators for onsite medical waste treatment were available in only 87 out of 2820 hospitals nationwide [Aqil and Dipa, 2020, as cited in 5] critical concern was raised over the leakage of COVID-derived infectious waste to waterways [5]. In Bangladesh, along with restricted waste collection, the demand for medical waste treatment outstripped capacity, contributing to the universal spread of single-use plastic items on roadsides, in drains and in open spaces [13]. In India, where the Delta variant drove a huge production of biomedical waste, upgrading treatment capacity was proposed [14, 15] in the context where the legally restricted method of deep burial was adopted for biomedical waste treatment because of the lack of incineration capacity [15]. Securing the treatment of COVID-19 waste was needed in developing countries to halt the infection's spread through virus-laden waste [2, 3, 16], while keeping the existing waste systems from collapsing under the pandemic crisis [1].

In Vietnam, incineration was regulated for safe disposal of “potentially SARS-CoV-2 contaminated waste” (COVID-19 waste) following Decision 3455/QD-BCDQG *Guidance on waste management and sterilization for COVID-19 prevention and control*, National Steering Committee, August 5, 2020 (Decision 3455). Since the onset of pandemic, Vietnam has experienced 4 waves of infections. Over the first 3 waves, the country had achieved its initial success in controlling the infections despite the presence of several variants of coronavirus (Alpha, lineage B.1.1.7, first identified in the UK; Beta, B.1.352, South Africa) [17, 18]. The fourth wave began in April 2021

witnessed a far higher infections fuelled by the highly contagious Delta variant (B.1.167.2, India) [19]. Over the first three waves of infections, from April 2020 to March 2021, the country had the capacity to safely dispose of about 1486 t of COVID-19 waste [20]. However, since April 2021, under the fourth wave of infections driven by the highly contagious Delta variant, the nation suffered a much greater burden of COVID-19 waste disposal as infections soared to much higher levels than ever before (Fig. 1), increasing the demand for waste treatment. Understanding the current performance of COVID-19 waste treatment in Vietnam thus became essential to securing treatment of pandemic-induced waste under the complicated progression of COVID.

Ho Chi Minh City (HCMC), the largest city in Vietnam, was hit hardest under the Delta outbreak [18]. As of October 31, 2021, according to the WHO Representative Office for Vietnam and the Ministry of Health (MOH), HCMC remained the epidemic center, with a cumulative number of 432 132 cases, approximately 47% of the national tally of 921 122 cases [21]. To bring the outbreak under control, a lockdown was imposed for nearly 3 months through the end of September 2021, in conjunction with the adoption of several anti-virus measures in HCMC. Assessment of the COVID-19 waste treatment capacity in HCMC in the context of its specified measures for pandemic control (Fig. 2) should contribute to the overall understanding of the nation's performance in COVID-19 waste disposal and of further responses aimed at securing COVID-19 waste treatment.

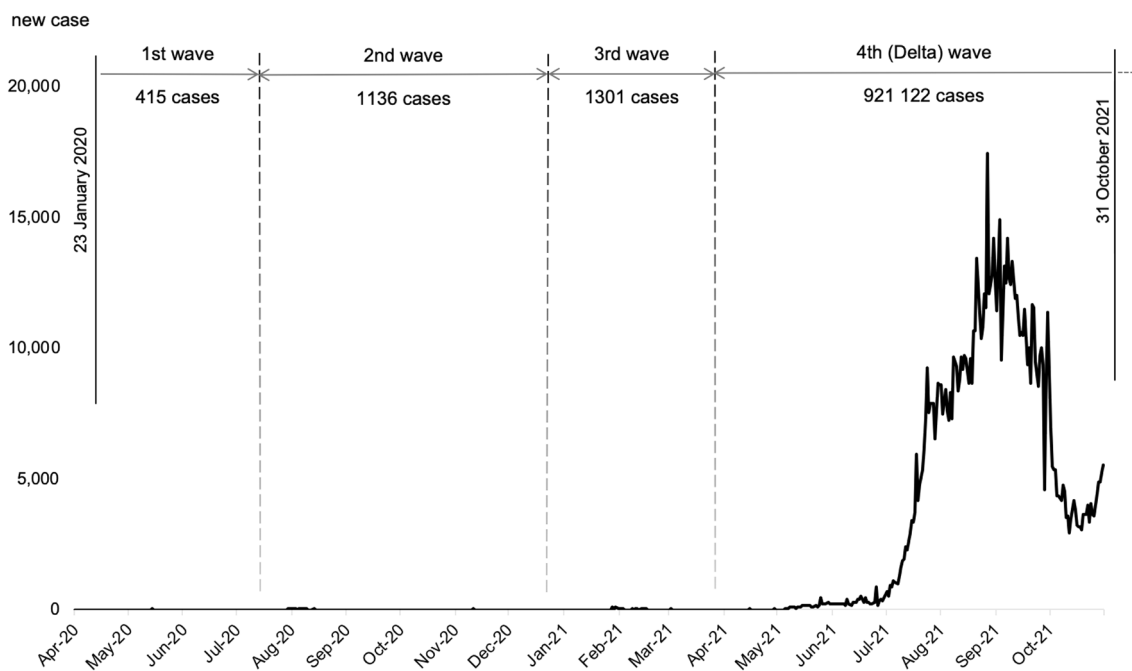


Fig. 1 Pandemic curve in Vietnam from April 2020 to October 2021

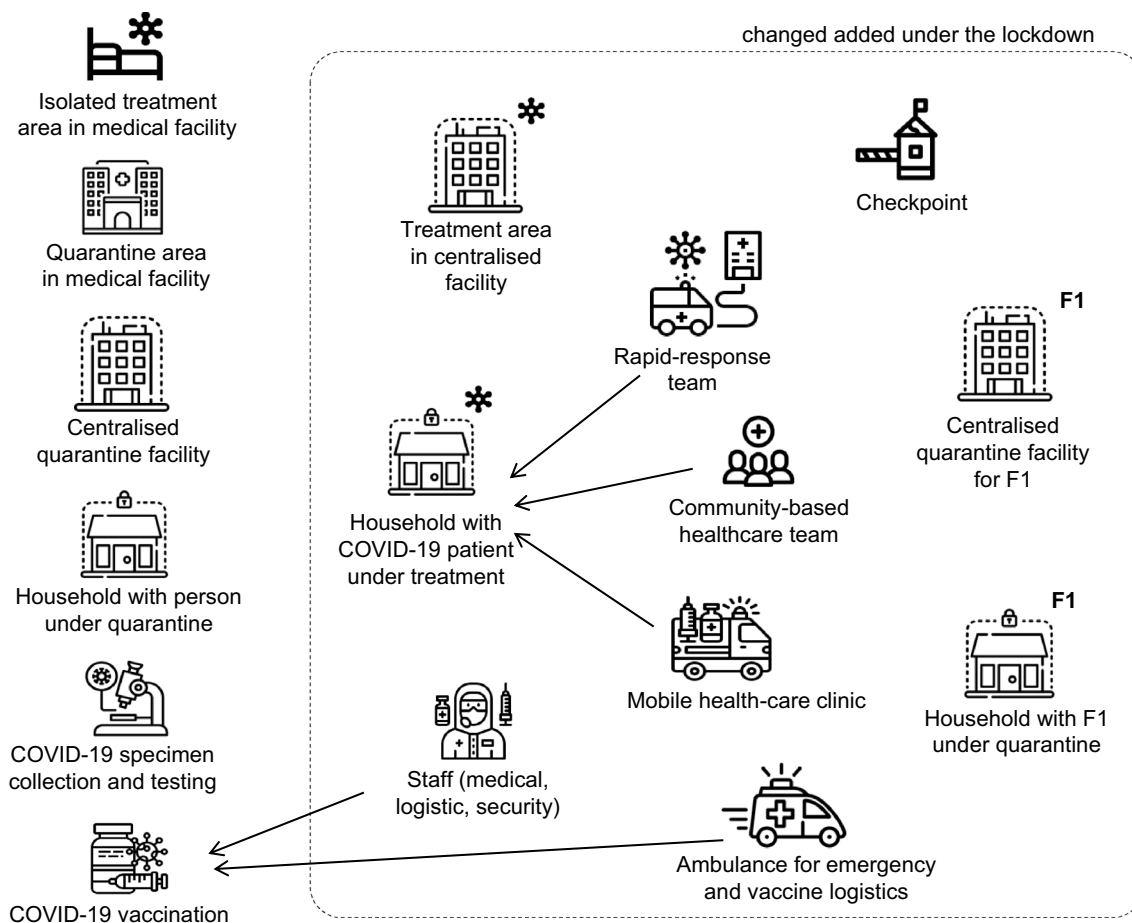


Fig. 2 Sources of COVID-19 waste generation in the context of specified anti-virus measures adopted in Ho Chi Minh City (April–October 2021)

Here the capacity for treatment of COVID-19 waste was accessed both nationwide and in HCMC, a center of the Delta outbreak, by determining the treatment occupancy rate, the ratio of estimated demand to calculated waste treatment capacity. The findings could support further responses to secure the safe disposal of COVID-19 waste in Vietnam, especially in the face of a likely outbreak fuelled by Omicron, a variant of concern that was “[...] highly transmissible and is rapidly replacing Delta as the dominant SARS-CoV-2 variant [...]” [22] and was confirmed to be present in the country in late December 2021 [18]. Other developing countries could refer to the findings for tackling the waste problem under the unpredictable progression of COVID.

COVID-19 waste treatment in Vietnam

COVID-19 waste was specified to be incinerated within a day of generation, preferably onsite (Decision 3455). Medical facilities were required to treat COVID-19 waste

produced within their boundaries in their incinerators or to engage a contractor to take it to a licensed waste incinerator in a centralized treatment complex. The state-run Urban Environment Company (URENCO), under the direction of the Provincial People’s Committee (PC), was made responsible for the collection and treatment of COVID-19 waste by other sources (e.g., centralized quarantine facilities), using its existing system of medical waste management. Private companies licensed to treat hazardous medical waste (HMW) were encouraged to join URENCO for COVID-19 waste treatment (Decision 3455). In addition, Decision 3455 authorized cross-provincial collaboration for COVID-19 waste treatment to balance differences in treatment capacity among provinces. Neither system was in use by April 2021—before the Delta outbreak—probably because enough treatment capacity was still available. However, as COVID-19 waste generation accelerated under the Delta outbreak, the Ministry of Natural Resources and Environment (MONRE) adopted a list of 80 industrial waste treatment facilities throughout the country authorized for COVID-19 waste treatment following Legal document 2743/

BTNMT-TCMT *Strengthening the collaboration of medical waste induced by COVID-19 pandemic*, May 21, 2021 (Legal document 2743), and Legal document 2854/BTNMT-TCMT *Addition of licensed facilities for hazardous medical waste treatment*, May 26, 2021 (Legal document 2854), in an attempt to enforce the correct treatment of COVID-19 waste. Such legislation was expected to support the PC in assigning suitable facilities to join URENCO and to facilitate cross-provincial collaboration for COVID-19 waste treatment.

The HCMC Urban Environment Company Limited (CITENCO), a state-run company, was responsible for COVID-19 waste treatment in HCMC from the beginning of the pandemic using its treatment capacity of 42 t day⁻¹. To deal with a far greater demand under the outbreak, on behalf of the PC, the Department of Natural Resources and Environment of HCMC (DONRE HCMC) officially invited private waste treatment providers to join CITENCO. Only Viet Uc Environment Joint Stock Company (JSC) accepted. Three more companies accepted a later invitation issued to companies that treat not only industrial hazardous waste but also municipal solid waste, using incinerators located in waste treatment complexes. The final collaboration of CITENCO, Viet Uc Environment JSC, Moc An Chau Logistics Corporation and Green Sai Gon Company (though not Tam Sinh Nghia Company) has enhanced the capacity for COVID-19 waste treatment in HCMC as of December 2021.

Materials and methods

Treatment capacity was assessed by determining the treatment occupancy rate of COVID-19 waste, defined as the ratio of estimated treatment demand to the calculated capacity. Treatment capacity nationwide was assessed monthly, both before and during the Delta outbreak, from April 2020 to March 2021 and from April to October 2021. In HCMC, the rate of COVID-19 waste treatment occupancy was determined on daily basis during the outbreak time, from April to October 2021, for treatment capacity assessment of the city.

Sources of data and information

For the estimation of COVID-19 waste treatment demand (waste generation), daily national data were acquired from the COVID-19 Information Portal of MOH (<https://covid19.gov.vn/>), covering new cases, recovered cases and numbers of quarantined persons by quarantine place (medical facility, centralized facility and households), from April 1, 2020, to October 31, 2021. The cumulative total of real-time reverse-transcription polymerase chain reaction (qRT-PCR) tests performed and, since March

8, 2021, of COVID-19 vaccine shots administered were also acquired. The HCMC Center for Disease Control (<https://covid19.hochiminhcity.gov.vn/>) provided similar data for HCMC, along with daily numbers of COVID-19 patients under treatment and F1 under quarantine, available from 10 August for those in households and from 12 August for those in centralized facilities. Other data were also obtained from official sources (number of traffic checkpoints, Department of Transportation; number of mobile clinics and rapid-response teams, Department of Health). Furthermore, policy and legal documents on COVID-19 response, nationally and in HCMC, were thoroughly reviewed to update sources of COVID-19 waste and, accordingly, the rates of waste generation.

Calculation of the national capacity of COVID-19 waste treatment was based on a list of facilities recommended for COVID-19 waste treatment (Legal documents 2743, 2854) and the national set of licenses for hazardous waste treatment from the Vietnam Environment Administration (VEA) under MONRE ([http://vea.gov.vn/detail?\\$id=910](http://vea.gov.vn/detail?$id=910)). The capacity of COVID-19 waste disposal in HCMC was obtained from DONRE HCMC and CITENCO.

Environmental reports, plans for waste management and official data sources such as the Center for Environmental Information and Data (under VEA, <http://ceid.gov.vn/>) were reviewed for the volume of waste generated (demand) and treatment performance (capacity) before the pandemic and for figures forecast in planning for future expansion.

Updates on sources and rates of COVID-19 waste generation

Sources and rates of COVID-19 waste generation, which influence the estimation of waste treatment demand, were ascertained from the anti-virus measures adopted. This added five more sources of COVID-19 waste (Treat_C, isolated treatment area; Treat_{HH}, household with COVID-19 patient under treatment; Q_{C-F1} , centralized quarantine facility for direct contact with infected person (F1); Q_{HH-F1} , household with F1 under quarantine; and Checkpoint, 24/7 checkpoint under lockdown) and rates of generation in HCMC. The rate of COVID-19 waste generation was updated for Vaccination, a source of COVID-19 waste identified before the Delta outbreak, following the recent release of relevant legislation. Types of COVID-19 waste typically included personal protective equipment (PPE), mask (medical, respirator), gloves (medical, sterile, latex heavy duty), tissues and disinfecting wipes, shoes cover, face shield, disposed vaccine vials and auto-disable syringes. Supplementary Table S1 presents the stated supply of anti-virus resources and equipment in relation to the updated availability of legal documents.

Estimation of treatment demand

Demand for COVID-19 waste treatment was taken as the volume of COVID-19 waste generated, estimated from the stated supply of pandemic resources (e.g., medicines, chemicals) and equipment (e.g., medical, personal protective) as proposed for Vietnam [20], using the sources and rates of COVID-19 waste generation updated here. National demand for treatment of non-COVID medical hazardous waste for 2020 and 2021 was based on the reported annual rate of increase of generation of 7.6% [23]. That in HCMC was calculated using the reported value in 2020 and the annual rates of increase of medical care beds of 6.1% and of medical waste generation of 2% in 2017–2019 and 4.5% in 2021–2024 [24].

Calculation of treatment capacity

Capacity for treatment by incineration at designated facilities was taken as capacity for COVID-19 waste treatment (Fig. 3) in respect of the regulation on safe disposal of COVID-19 waste (Decision 3455) and was calculated from the database of national treatment facilities established in this study.

The national database was built from raw and scattered information extracted from the set of licensed facilities for hazardous waste treatment at the VEA and a list of facilities recommended by MONRE to accept COVID-19 waste. All license records were reviewed to avoid duplication (e.g., different versions of a license granted to one service provider) and to exclude any expired licenses. Facility homepages or records by Provincial Department of Natural Resources and Environment administrating the facility's service were referred to for missing information. All data were then compiled and consolidated into a database of national hazardous waste treatment facilities,

consisting of basic information (e.g., license number, validity, location), treatment specification (e.g., capacity by treatment method, technical standards of treatment), and other (e.g., equipment specifications). To calculate COVID-19 waste treatment capacity, treatment capacity of designated facilities in line with treatment methods (incineration, non-incineration) and other parameters were extracted from the database. The incineration capacity of all facilities was then totaled to give the national COVID-19 waste treatment capacity. The capacity for non-COVID waste treatment was obtained from the total of the facilities' non-incineration treatment capacities. In HCMC, the capacity for COVID-19 waste treatment was directly obtained by totaling the incineration capacity of CITENCO and the private companies. Intermediate and final results of capacity assessment—estimation of treatment demand, calculation of treatment capacity, and determination of treatment occupancy rate—are presented separately for the nation and HCMC in Results and Discussion section.

Conditions for calculation

The estimates are considered to be reliable on account of the ready availability of clear COVID-19 data from the authorities and the actual quantities of resources and equipment supplied to combat the pandemic. Changes in regulations during the assessment, however, would have influenced the data. In the absence of waste collection rates, all waste generated was assumed to be eventually collected for treatment. The final calculation of national capacity covered 65 facilities out of 80 recommended by MONRE, with the exception of 12 facilities owing to data unavailability and 3 more without incineration capability.

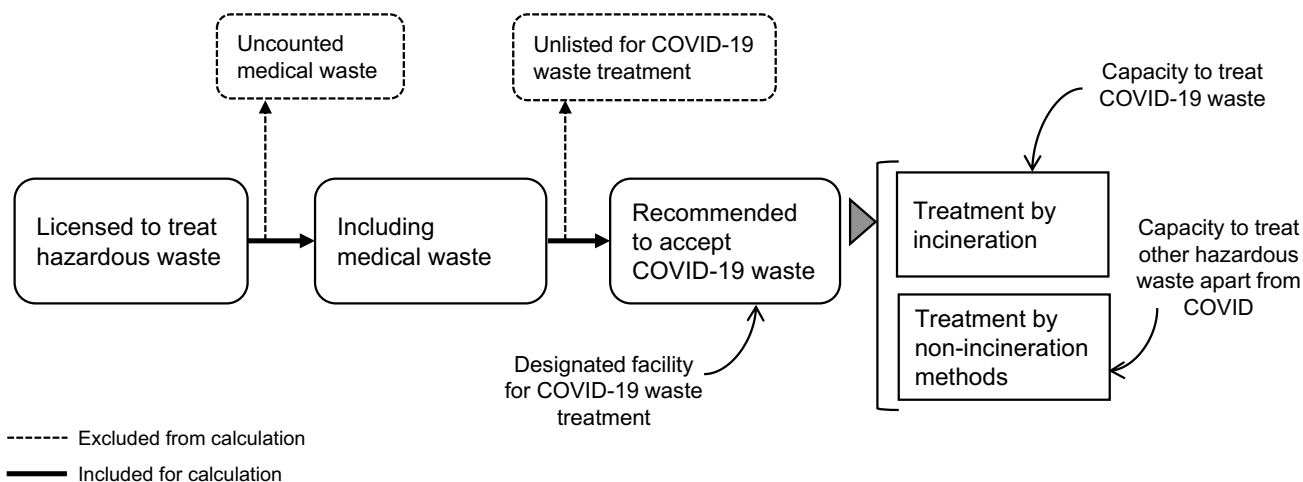


Fig. 3 Determination process of eligible facilities for COVID-19 waste treatment

Table 1 Updated sources and rates of COVID-19 waste generation

Source	Rate of waste generation	Unit
Treat _{ISOL}	4.64	kg bed ⁻¹ day ⁻¹
Treat _C	3.09	kg bed ⁻¹ day ⁻¹
Treat _{HH}	1.94	kg bed ⁻¹ day ⁻¹
Q _{MED}	3.86	kg bed ⁻¹ day ⁻¹
Q _C	46.43	g bed ⁻¹ day ⁻¹
Q _{C-F1}	47.35	g bed ⁻¹ day ⁻¹
Q _{HH}	24.62	g bed ⁻¹ day ⁻¹
Q _{HH-F1}	24.62	g bed ⁻¹ day ⁻¹
Testing	50	g test ⁻¹
Vaccination	29.89	g shot ⁻¹
Checkpoint	1.06	kg point ⁻¹ day ⁻¹

Results and discussion

Updates on sources and rates of COVID-19 waste generation

Of the updated sources and rates of COVID-19 waste generation as of October 2021 (Table 1), estimates of national treatment demand were based on sources identified as Treat_{ISOL}, isolated treatment area; Q_{MED}, quarantine area in a medical facility; Q_C, centralized quarantine facility; Testing, COVID-19 specimen collection and testing; and Vaccination, COVID-19 vaccination. Updated estimates of HCMC treatment demand were based on the same sources and five more (Treat_C, treatment area in centralized facility; Treat_{HH}, household with COVID-19 patient under treatment; Q_{C-F1}, centralized quarantine facility for F1; Q_{HH-F1}, household with F1 under quarantine; and Checkpoint, 24/7 checkpoint under lockdown). Number of generating units by sources of COVID-19 waste for estimating treatment demand of the country and of HCMC is presented in Supplementary Tables S2 and S3, respectively.

Assessment of national treatment capacity

Nationally, an estimated 94415 *t* of COVID-19 waste was generated as of October 31, 2021, 19 months since COVID was declared a national pandemic (Table 2). The production of COVID-19 waste rocketed up under the 4th wave fuelled by the Delta variant, from a mere 124 *t* in previous phases to 13 276 *t* per month on average. Demand peaked in September 2021 at around 38 590 *t*, 1078 times the lowest value of 35.8 *t* in June 2020 and 7.8 times the average of 4969.2 *t* per month (Fig. 4).

The estimated monthly demand for non-COVID medical waste treatment was 1955.6 *t* in 2020 and 2104.3 *t* in 2021, based on a reported volume of 21 810 *t* in 2019 [25] and an annual rate of increase of 7.6% [23]. Such estimates are

Table 2 Estimated national demand for COVID-19 waste treatment by source

Estimated demand	1st, 2nd, 3rd waves	4th wave (Delta)	Total
By waste source			
Treat _{ISOL}	292.2	70 186.8	70 479.0
Q _{MED}	804.3	16 175.1	16 979.4
Q _C	248.8	2 845.5	3 094.3
Testing	140.0	1 269.2	1 409.2
Vaccination	1.5	2 451.7	2 453.2
Total (<i>t</i>)	1486.8	92 928.3	94 415.1
(<i>t</i> month ⁻¹)	123.9	13 275.5	4 969.2

considered reliable given the upward trend observed before the pandemic [26] and the predicted further increase to 33 577 *t* in 2025 (Decision 170/QD-TTg, Master planning of hazardous medical waste treatment system to 2025, by the Prime Minister, February 8, 2012).

Within the 65 designated facilities resulted after Fig. 3, an estimated monthly capacity of 67 160 *t* was available to treat COVID-19 waste, accounting for around 22.3% of the total national capacity of more than 301 000 *t* (Table 3). The balance is available for other, non-COVID hazardous waste. Supplementary Table S4 presents treatment capacity of 65 designated facilities for COVID-19 waste treatment.

The estimated rate of COVID-19 waste treatment averaged 7.4% of the national capacity, but ranged greatly from < 0.1 to 57.5% with demand (Fig. 4). A national capacity of 62 191 *t* per month was accordingly available for treatment of COVID-19 waste, ranging from 28 570 to 67 124 *t* per month (Fig. 5b, c). The nation was thus likely capable of handling COVID-19 waste treatment using its current capacity. In addition, demand for non-COVID waste treatment could be met with an enormous capacity of 235 432 *t* per month, which also covered hazardous waste from the industrial and agricultural sectors.

The demand for COVID-19 medical waste treatment was only 1.6% of the capacity for all types of hazardous waste, and that for non-COVID waste treatment was only 0.7% (Fig. 5a). In the most critical situation when the treatment demand hits its peak (38 590 *t*, 12.8%; Fig. 5c), the country was still capable of handling COVID-19 waste treatment, with an available capacity of 28 570 *t* left. However, provinces with limited waste disposal capacity could face difficulties if demand surged.

Cross-province collaboration in COVID-19 waste treatment offers promise in overcoming local shortages of treatment capacity. This strategy is compatible with the suggestion for developing countries to use current resources to maximize treatment capacity under a pandemic [1, 2, 7]. The treatment facility database established here supports municipalities with information on potential providers

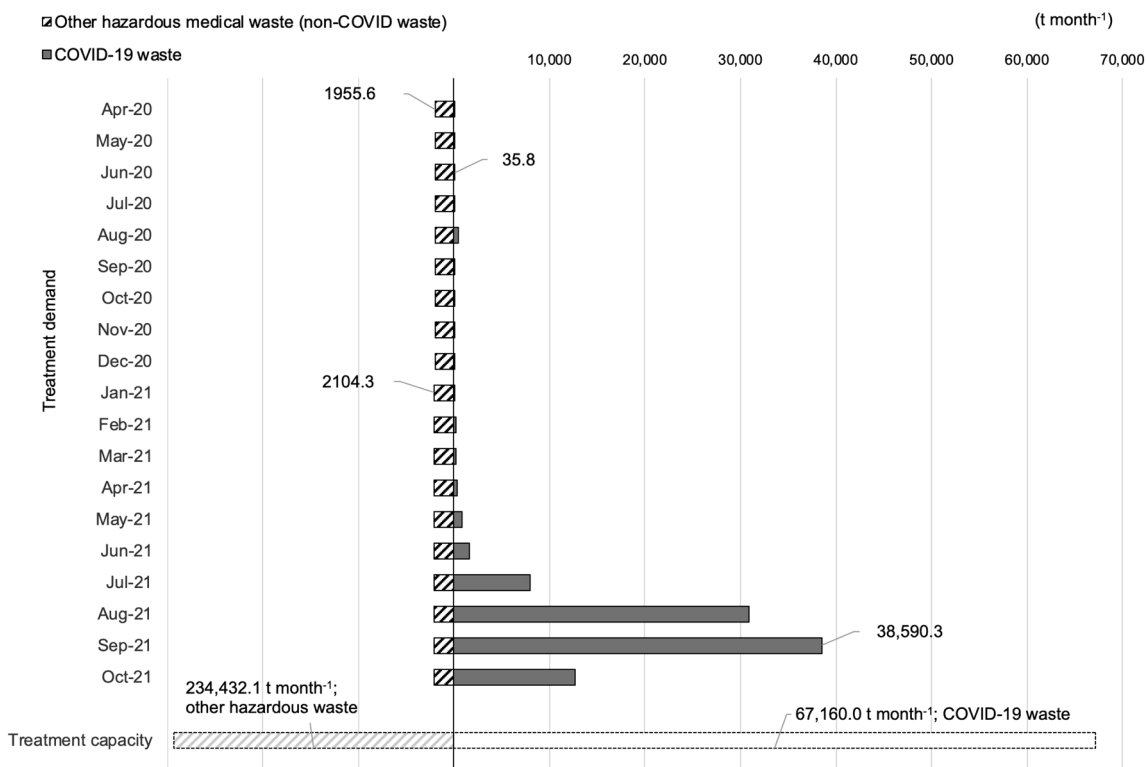


Fig. 4 Monthly distribution of treatment demand in comparison with capacity of COVID-19 waste and non-COVID waste (April 2020–October 2021)

Table 3 National capacity for hazardous waste treatment

Type of waste	Calculated treatment capacity		
	$t\text{ month}^{-1}$	$t\text{ day}^{-1}$	%
COVID-19 waste	67 160.0	2 208.0	22.3
Other hazardous waste	234 423.1	7 707.1	77.7
Total	301 583.1	9 915.1	100.0

of COVID-19 waste treatment. Information sharing is necessary for optimal and flexible allocation of treatment capacity among provinces. Adequate sanitary and anti-virus measures are also required for safe transportation of a large amount of infectious waste across provinces.

Assessment of treatment capacity in Ho Chi Minh City

The estimated demand for COVID-19 waste treatment in HCMC was about 28 552 t over the assessment time, equivalent to an average of 133.4 t per day (Table 4). $Treat_{HH}$ (households with COVID-19 patients under treatment), a newly identified source of COVID-19 waste, contributed the second largest share among the total (7479.4 t , 26.2%) despite the availability only 3 months of data on it out of the

entire calculation time of 7 months. The daily demand for COVID-19 waste treatment also fluctuated widely, from 3.0 $t\text{ day}^{-1}$ on April 1–13, 2021, to 504.9 t per day on September 6, 2021 (Fig. 6a).

Treatment capacity in HCMC was 69 $t\text{ day}^{-1}$ for hazardous medical waste (COVID-19 waste and non-COVID waste) as of October 2021 (Table 5) and could be expanded to 159 $t\text{ day}^{-1}$ from 2022 [27] through the collaboration of CITENCO with private companies. Use of Tam Sinh Nghia Company’s incinerators, those were designed to treat municipal solid waste, remained undecided.

The treatment occupancy rate in HCMC averaged 193.3% over the calculation time. It began to exceed 100% around 2 months after the outbreak began (Fig. 6b). A drop from 396 to 290% was achieved in July 2021 following an expansion of treatment capacity from 42 to 69 t through waste treatment collaboration. In particular, when it peaked at 780% on September 6, 2021, 435.9 t per day of COVID-19 waste stayed untreated, posing a risk of infection spread through virus-laden waste. Temporary storage of COVID-19 waste in medical facilities should be given priority over regular hazardous medical waste as an adaptive measure, although capacity might not be sufficient.

In the absence of a pandemic, treatment of regular hazardous medical waste would have been attainable

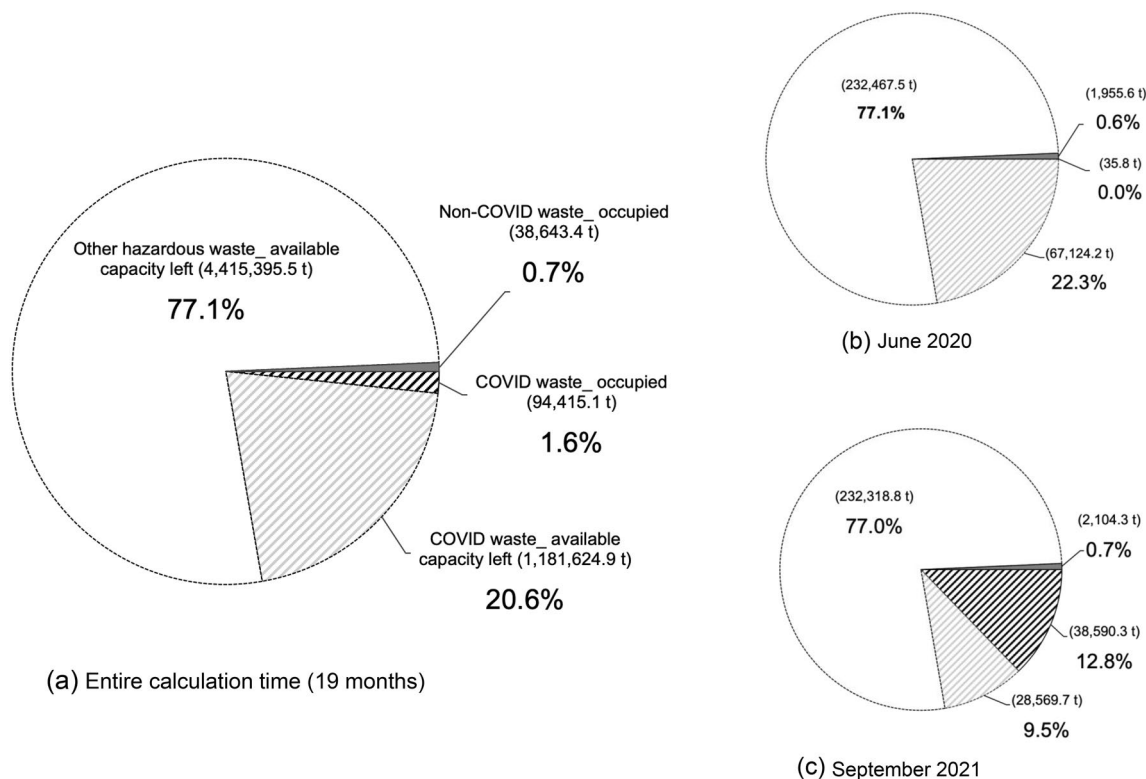


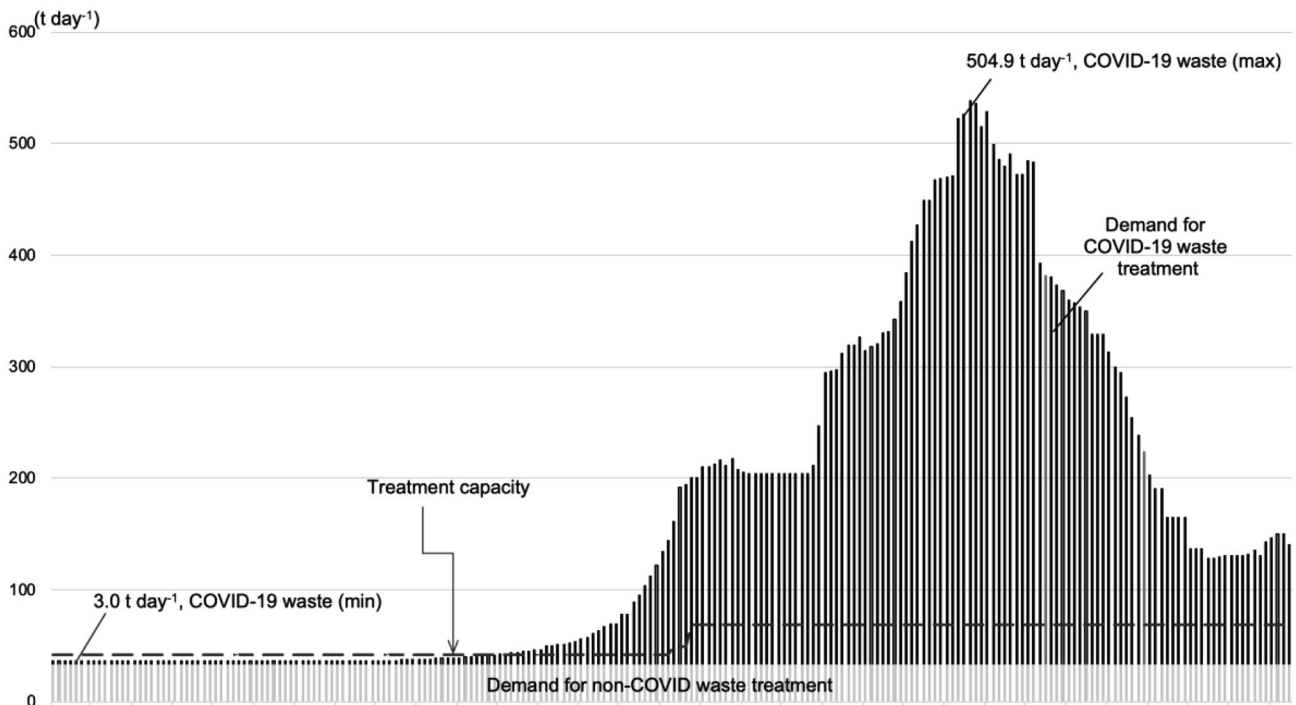
Fig. 5 Ratios of waste treatment occupancy nationwide: **a** over the entire calculation time, and when monthly demand for treatment was **b** lowest and **c** highest

Table 4 Estimated demand for COVID-19 waste treatment in Ho Chi Minh City (April–October 2021)

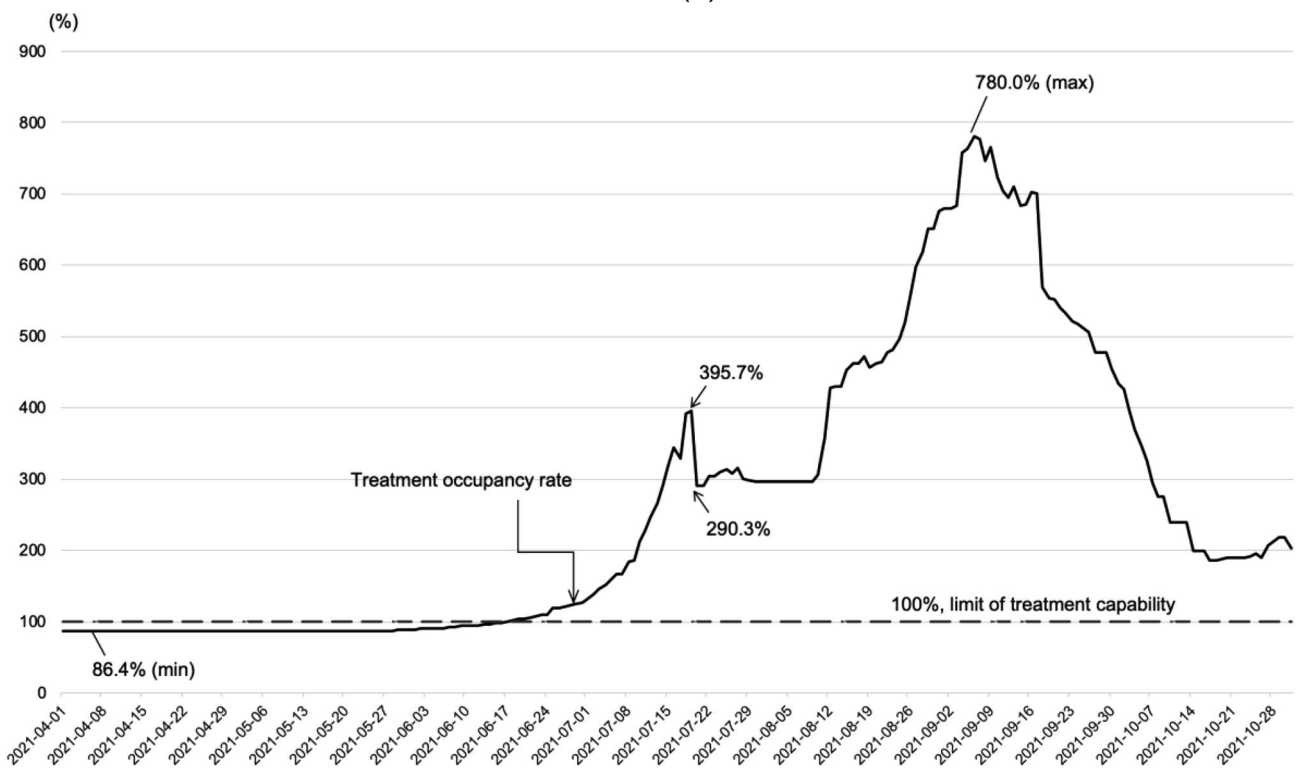
Source	Treatment demand	
	t (7 months) ⁻¹	%
Treat _{ISOL}	16498.4	57.8
Q_C	43.1	0.2
Testing	149.2	0.5
Vaccination	452.5	1.6
Treat _C	3851.8	13.5
Treat _{HH}	7479.4	26.2
Q_{C-FI}	7.9	0.0
Q_{HH-FI}	33.1	0.1
Checkpoint	36.8	0.1
Total	28552.2	100.0

(Fig. 6a, Fig. 7). But the generation of enormous amounts of COVID-19 waste under the Delta outbreak obviously caused the existing disposal infrastructure, which was not designed to operate under a pandemic crisis, to lag behind demand. Treatment capacity of 1021 t day⁻¹ planned for 2025 [28] offers a solution to the shortage of treatment capacity, but only if it can be brought forward, with consideration of the restrictions for pandemic control.

The collaboration between CITENCO and private waste treatment providers in HCMC provides practical experience in overcoming the acute shortage of COVID-19 waste treatment capacity during an outbreak. The suitability of providers to treat COVID-19 waste (treatment method and capacity, location of incinerator, capability of adopting infection control measures) was considered first by the authorities, followed by an onsite inspection. Provincial authorities could also suggest local treatment providers those were licensed by DONRE and thus not included in the list by MONRE to participate in COVID-19 waste treatment. For instance, Moc An Chau Logistics Corporation and Green Sai Gon Company had practically involved in COVID-19 waste treatment in HCMC along with those listed by MONRE (CITENCO, Viet Uc Environment JSC), according to DONRE HCMC in its *Report on environment and natural resources governance in 2021 and vision, solutions for 2022* [27]. Social responsibility, not business profit, can be seen as motivating the private service providers to join CITENCO, since they were not legally required to offer such public service. The participation of private companies should be promoted further by easing the constraints behind some rejections (e.g., inadequate anti-virus equipment, need for COVID-19 vaccination of their personnel) to enable better use of local resources to secure COVID-19 waste treatment.



(a)



(b)

Fig. 6 Daily distribution of: **a** hazardous medical waste treatment demand and capacity, and **b** according rate of treatment capacity in Ho Chi Minh City under Delta outbreak (April–October 2021)

Table 5 Capacity for hazardous medical waste treatment in Ho Chi Minh City (April–October 2021)

Treatment service provider	Capacity (t day ⁻¹)
HCMC Urban Environment Company Limited (CITENCO)	42
Viet Uc Environment Joint Stock Company	7
Moc An Chau Logistics Corporation	10
Green Sai Gon Company	10
Total	69

Challenges and recommendations

As for private waste treatment providers, typical issues including shortage of labors due to infections or isolation, inadequate PPE for waste handlers and lack of anti-virus

measures for safety during handling infectious waste appeared to restrict their involvement in COVID-19 waste treatment along with the state-run company. Practical supports by authority such as vaccination prioritized for waste handlers from private treatment companies, and PPE supplied for handling infectious waste could help addressing their difficulties and thus enhance the collaboration for securing COVID-19 waste treatment. Local authority played an important role in facilitating a collaboration in waste treatment to secure COVID-19 waste treatment in its administrative area. Regarding regional collaboration, information sharing among relevant provinces was necessitated for an optimal and efficient collaboration in COVID-19 waste treatment. Also, proper measures for infection prevention should be maintained during transportation of a large volume of infectious waste crossing provincial boundaries.

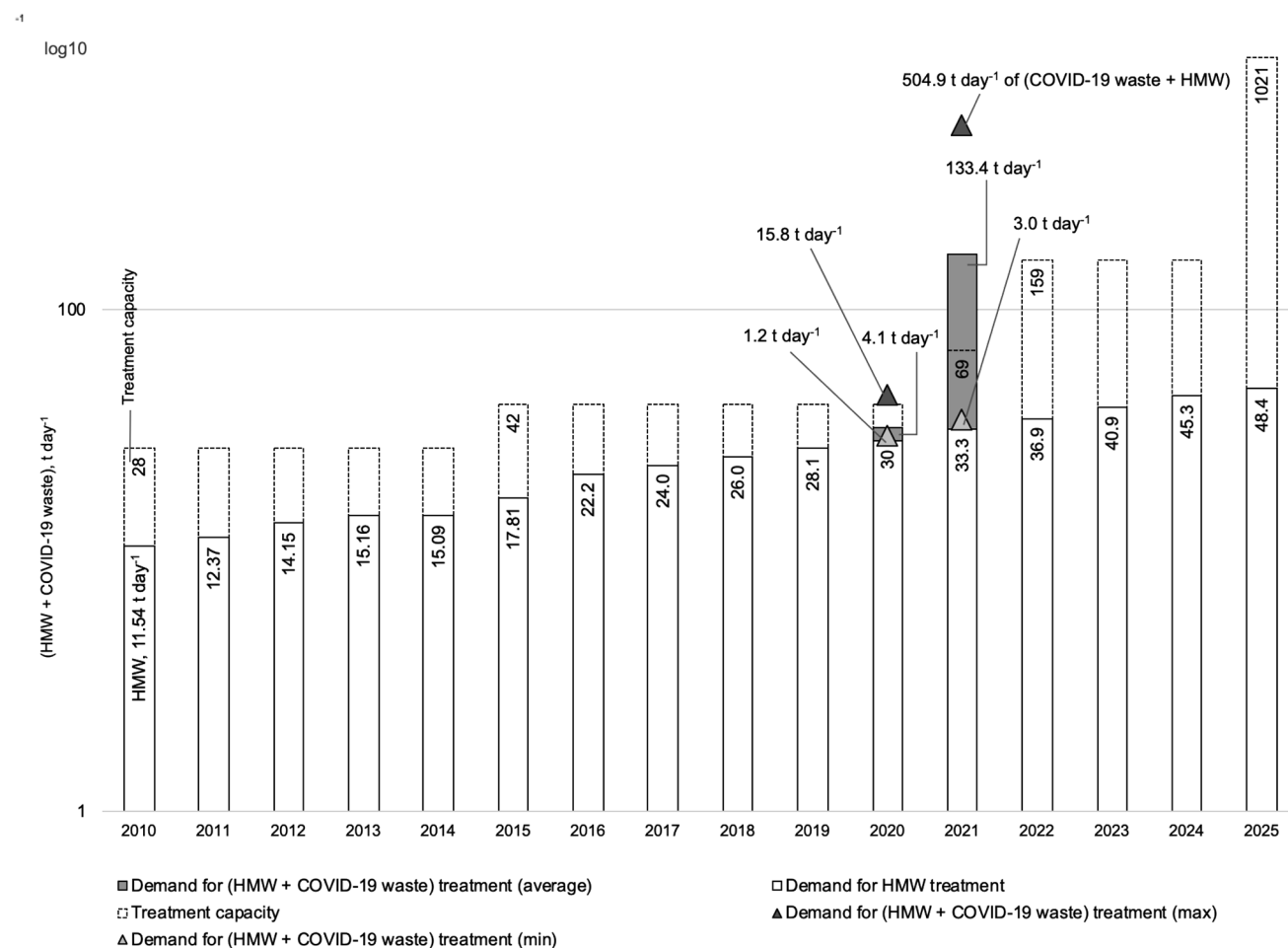


Fig. 7 Waste treatment occupancy in Ho Chi Minh City before the pandemic (2010–2019), during the pandemic (2020–2021) and under the planned expansion (2022–2025)

Conclusion

Treatment capacity was assessed by determining the treatment occupancy rate—the ratio of estimated demand to the calculated capacity for COVID-19 waste treatment—nationally and in HCMC. With a COVID-19 waste treatment occupancy rate of only 7.4% on average (and a range of <0.1–57.5%), Vietnam had the capacity to handle COVID-19 waste, with a spare readiness of 62 191 t per month. Cross-provincial collaboration to maximize treatment capacity by using existing resources offers promise to balance local deficiencies of treatment capacity due to unpredictable surges of demand. Information on potential providers of COVID-19 waste treatment can be obtained from the national database established here. An optimal allocation of treatment capacity requires adequate anti-virus measures for safe transportation of large amounts of infectious waste and information sharing among localities.

In HCMC, treatment capacity during the Delta outbreak was overwhelmed, at a treatment occupancy rate of 193.3%. At the highest rate of 780%, 435.9 t of COVID-19 waste went untreated daily, posing a risk of infection spread. Collaboration between CITENCO and private service providers improved the City's capacity for COVID-19 waste treatment, reducing the treatment occupancy rate from 395.7 to 290.3%.

The generation of huge amounts of COVID-19 waste under the Delta outbreak caused the pre-pandemic disposal infrastructure to lag behind demand. The temporary storage of COVID-19 waste in medical facilities should be given priority over HMW as an adaptive measure during a waste disposal backlog. Practical aid should support the participation of private companies in pandemic waste treatment to achieve better use of existing local resources. The planning of new treatment facilities should be brought forward, since the end of the pandemic is still not in sight. The findings of this study could provide other developing countries with information and evidence to use in tackling waste under a pandemic.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10163-022-01529-z>.

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