Impact of COVID-19 on healthcare waste generation: Correlations and trends from a tertiary hospital of a developed country

Published version:

DOI:10.1177/0734242X221074195

(Article begins on next page)

NOTE

This is a non-final version of a paper published in final form on *Waste Management and Research*:

Garlasco J, Canepari A, Giacobone G, Funicelli G, Kozel D, Bernini L, Cotroneo A. **Impact of COVID-19 on healthcare waste generation: correlations and trends from a tertiary hospital of a developed country**. *Waste Manag Res*. 2022 Jan 28:734242X221074195. doi: 10.1177/0734242X221074195

The paper has been accepted for publication and the article is available at the following link: http://doi.org/10.1177/0734242X221074195

Jacopo Garlasco, M.D.[a]; Alessandro Canepari, M.D.[b]; Gilda Giacobone[c]; Gemma Funicelli, M.D.[b]; Daniela Kozel, M.D.[b]; Luciano Bernini, M.D.[b]; Alida Cotroneo, M.D.[b]

[a] Department of Public Health Sciences and Paediatrics, University of Turin, Turin, Italy
[b] Medical Direction Department, “SS. Antonio e Biagio e Cesare Arrigo” Hospital, Alessandria, Italy
[c] Logistics and Purveying Office, “SS. Antonio e Biagio e Cesare Arrigo” Hospital, Alessandria, Italy

Impact of COVID-19 on healthcare waste generation: correlations and trends from a tertiary hospital of a developed country

Abstract

The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented an emergency not only from a clinical point of view, but also for the environment due to the largely increased waste disposal. This study aimed at estimating, in the context of current trends, the increase in healthcare waste (HW) generation during the outbreak, based on data from a tertiary hospital. From the purveying office statements of “SS Antonio e Biagio e Cesare Arrigo” Hospital of Alessandria (Italy), monthly HW generation data from January 2015 to March 2021 were retrospectively retrieved. Trends and COVID’s impact were evaluated by Interrupted-Time Series design with linear regression models. Locally Weighted Scatterplot Smoothing was used to model the relation between infectious HW generation and proportion of COVID-related bed days. HW generation rose from 35.9±3.8 tonnes month^{-1} (2.4±0.2 kg per patient-day, kg PD^{-1}) in 2015-2019, to 46.3±6.0 tonnes month^{-1} (3.3±0.7 kg PD^{-1}) during the outbreak. The increasing trend was not appreciably modified as for its slope (p=0.363), while a significant level change was found between baseline and outbreak (+0.72 kg PD^{-1}, p<0.001). The proportion of COVID-related bed days non-linearly affected the infectious HW generated per patient-day, with steeper increases for proportions above 20%. The study showed a significant rise in HW generation in 2020-2021, reasonably due to the COVID outbreak; in addition, the generally increasing trend was not affected. Therefore, urgent measures are needed to conciliate safety requirements with HW generation issues.

Keywords: Healthcare waste, Waste generation, Infectious waste, COVID-19 outbreak, Hospitalisation days, Trend analyses

Jacopo Garlasco, M.D.[a]; Alessandro Canepari, M.D.[b]; Gilda Giacobone[c]; Gemma Funicelli, M.D.[b]; Daniela Kozel, M.D.[b]; Luciano Bernini, M.D.[b]; Alida Cotroneo, M.D.[b]

[a] Department of Public Health Sciences and Paediatrics, University of Turin, Turin, Italy
[b] Medical Direction Department, "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria, Italy
[c] Logistics and Purveying Office, "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria, Italy

Impact of COVID-19 on healthcare waste generation: correlations and trends from a tertiary hospital of a developed country

Introduction

The increase in hospital waste generation has represented an emerging issue over the last few decades, both in developing and developed countries, as a product of population (Korkut, 2018) and income growths (Windfeld and Brooks, 2015), and therefore of the increase in health service provision. Moreover, the greater attention paid to the prevention of healthcare-associated infections has encouraged using disposable medical items, with consequently higher waste disposal (Hicks et al., 2021; Tsai, 2021).

The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented a disruptive event: more than 180 million people have been diagnosed with COVID-19 worldwide as of 1st July, and the number of confirmed cases is still increasing

(World Health Organization, 2021). Owing to the virus's infectiousness and the consequent magnitude of the phenomenon, COVID-19 has represented an emergency also from an environmental and operative perspective, since it has enhanced medical waste production due to use of personal protective equipment (PPE) (Liang et al., 2021) such as face masks, disposable gloves and gowns, overboots and single-use head coverings, mainly composed of plastic materials (Henneberry, 2020; Klemeš et al., 2020). The amounts of face masks disposed of during the pandemic, for instance, have been estimated to be at least 42 million per week in the United Kingdom and 214 million per week in the United States (Selvaranjan et al., 2021).

The impact of the pandemic on healthcare waste production has been widely acknowledged as alarming (De Aguiar Hugo and Da Silva Lima, 2021; Sarkodie and Owusu, 2021): beside the broad usage of the already mentioned PPE, the pandemic expanded the need for several items, such as respirators and other life-support devices, individual safety appliances and other disposable plastic-based tools (Rupani et al., 2020), such as gauzes, bandages, plasters, laboratory plates and vials.

As a result, waste production boomed all over the world after the COVID-19 outbreak, especially in the most densely populated areas: for example, China recorded noticeable increases in medical waste from baseline (4902.8 tonnes day^{-1}) to post-outbreak levels (6606.8 tonnes day^{-1}) (Ma et al., 2020), while waste in the United States is estimated to have increased from 5 million tons (i.e. 4.5 million tonnes) per year to 2.5 million tons (i.e. 2.3 million tonnes) per month (Ilyas et al., 2020) and South Korea saw its daily generated medical waste increasing from less than 10 tonnes before the pandemic to a peak of 50 tonnes in April 2020 (United Nations Economic and Social Commission for Asia and the Pacific, 2020).

Following the classification reported in the Supplementary Material (see §1, *Nomenclature caveats*), in order to provide nomenclature consistency throughout the paper, the term *healthcare waste* (HW) will be used to indicate all monitored hazardous waste (i.e. toxic, chemical, infectious waste), without including municipal-like waste (not included in the hospital's routine surveillance: see Materials and Methods below), while the term *infectious healthcare waste* (IHW) will be used to specifically address waste at high biological and infectious risk (a subset of HW).

Many studies have been conducted to quantify the impact of the pandemic on medical waste production by healthcare facilities (Kalantary et al., 2021; Ma et al., 2020; Wang et al., 2021). However, to our knowledge, no analyses of such impact of COVID-19 have been performed in the context of HW generation trends yet.

Hence, this study aimed at estimating the increase in HW production during the COVID-19 outbreak and performing an analysis of the impact of the pandemic in the context of current trends, based on a 6-year data framework from a tertiary-care hospital of a developed country.

Materials and methods

Data collection

Data on waste generation were retrospectively retrieved from the statements of the purveying office of “SS. Antonio e Biagio e Cesare Arrigo” Hospital of Alessandria (Italy), a hub hospital providing care to a 600,000-inhabitant area: monthly data were collected between January 2015 and March 2021. These statements included the net weight and the respective category of HW (see Supplementary Material, §1, for detailed explanation) generated, on aggregate, by the whole facility, including all hospital wards and departments.

This precise routine monitoring of waste generation included HW only, i.e. all waste with a different stream and management compared to regular municipal waste: hence, all that concerned the hospital’s municipal-like waste (e.g. paper, plastic, wood, iron, glass etc., whose disposal happened after no contact with patients) was not included in this analysis due to the absence of reliable data.

Data concerning the total number of hospitalisation days and the number of those related to COVID-19 were extracted by the Accounting and Management Department of the hospital. All these data were collected in an aggregate form only, without any chance of identification of any individual, which ensured conformity of the study with the Italian (Law 2003/196) and European (Regulation EC/2016/679) regulatory framework for data protection and privacy. Thus, a final Microsoft Excel database was built, including all the information required for statistical analyses.

Endpoints

The primary outcomes identified for the analyses were the amounts of HW generated each month by the hospital (taking into account both the total amount and IHW only), considered firstly in absolute form and secondly in relation to patient-days. The relative COVID-related hospital load was quantified through the percentage of hospitalisation days due to positive patients out of the total.

Statistical analysis

Segmented linear regression models were built following the Interrupted Time Series (ITS) method (Bernal et al., 2017), in order to detect trends and level changes in HW generation after the COVID outbreak, by allowing also for the presence of an interaction term to quantify the possible slope change (see

Supplementary Material for detail about statistical design, model building and diagnostics).

Correlation between the amounts of HW generated (in relation to bed-days) and the fraction of bed-days that could be ascribed to COVID-19 was investigated through Pearson's correlation coefficient. Moreover, starting from the available data, the Locally Weighted Scatterplot Smoothing (LOESS) regression (Wilcox, 2017) was used to attempt to estimate the general trend of HW generation in relation to the percentage of bed-days related to COVID-19.

The same analyses were also performed by considering the subset of HW that was classified as IHW, so as to detect possible differences in trends and impact of COVID-19 between various waste categories.

In all cases the significance level was set at $\alpha=0.05$. The statistical software R (version 4.0.5) was used for all computation and plotting (R Core Team, 2020): in particular, the "rms" (Harrell Jr, 2021) and "lmtest" (Zeileis and Hothorn, 2002) packages were used to build the models and to perform relevant diagnostics.

Results

Descriptive statistics

Seventy-five monthly observations were available for the analysis, all including data regarding both bed-days and HW generation. Descriptive statistics for the hospital's bed occupancy and waste generation are reported in the Supplementary Material. The proportion of COVID-related bed-days varied according to the epidemic waves, ranging from 3-10% in lower-incidence months (from June to October 2020, and in February-March 2021) to 16-34% in acute phases (in March-April 2020, and from November 2020 to January 2021), when most of the hospital's activity was related to emergency treatments.

Trend analyses

Considering the whole pre-COVID period (from January 2015 to January 2020), an overall increasing trend was detected for the total generation of HW, with an average increase in the total amount of monthly HW by 1.5 tonnes year^{-1} ($p < 0.0001$). The occurrence of the COVID-19 outbreak caused a level change in total HW production, with an increase by 6.1 tonnes month^{-1} compared to the baseline level ($p = 0.0001$), but the slope of the rising trend was not apparently modified by the pandemic (Likelihood Ratio Test, LRT: $p = 0.3628$, Fig. 1). IHW was responsible for the greatest part of the increasing trend (+1.23 tonnes month^{-1} per year, $p = 0.0002$), and its level change after the COVID outbreak was even higher compared to that of the total amount of monitored HW (+6.3 tonnes month^{-1}, $p < 0.0001$; the trend is shown in Fig. 2a).

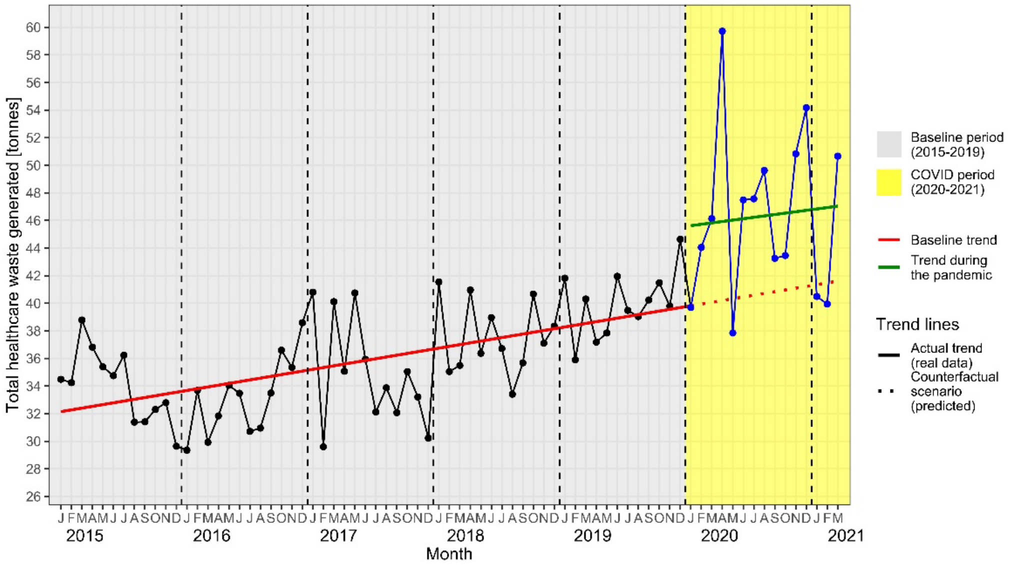

Fig. 1. HW generation trend in "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria, 2015-2021. All healthcare waste is included, as defined in the Introduction.

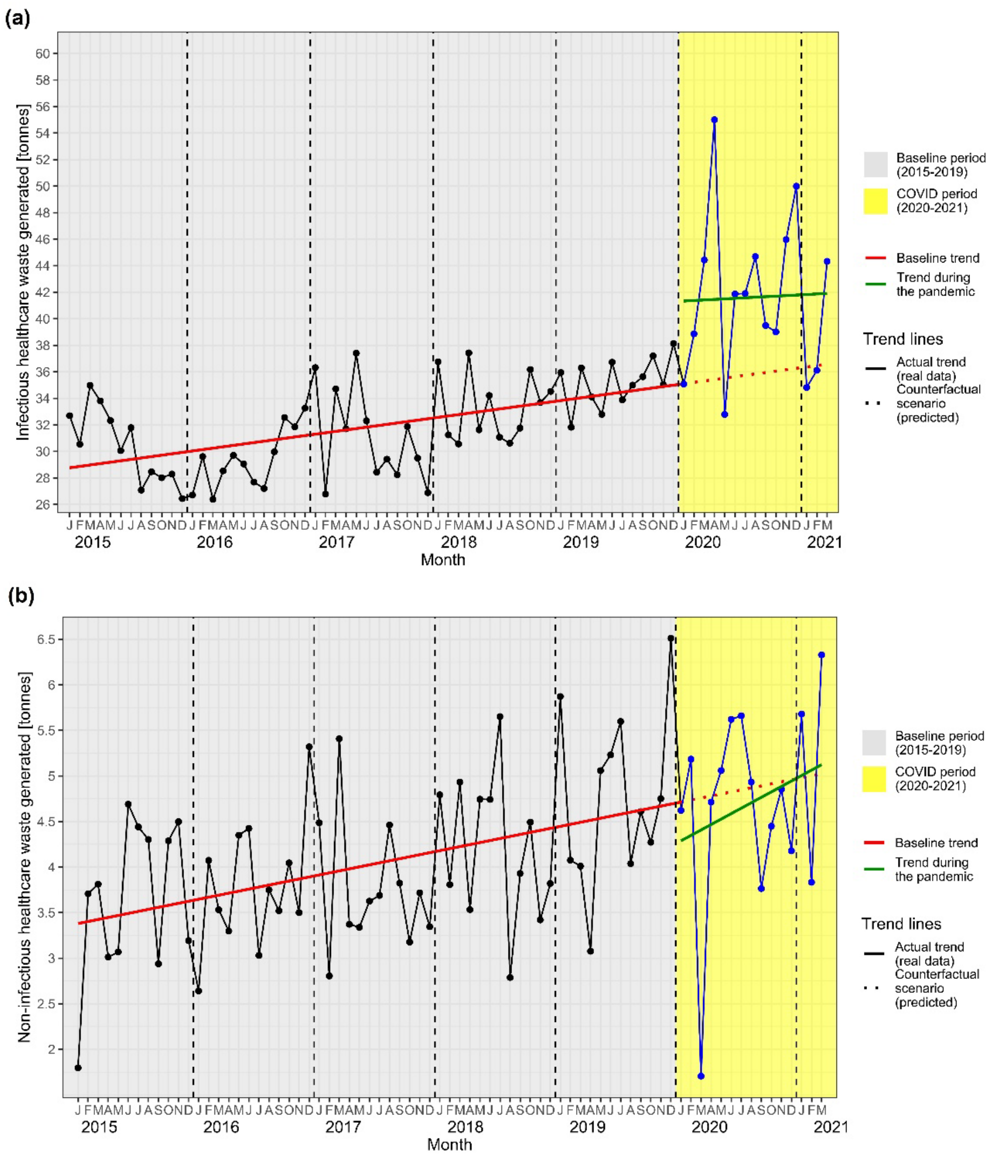

Fig. 2. IHW and non-infectious HW generation trends in "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria, 2015-2021. Plot (a) includes infectious waste only, as specified in the Supplementary File, while (b) includes non-infectious (toxic and chemical) waste products.

This was compensated by a slight decrease (-0.19 tonnes month^{-1}), though not statistically significant ($p = 0.5848$), in the production of other kinds of HW in the COVID period compared to baseline. However, even this waste category showed an increasing trend over time (+274 kg month^{-1} every year) and, after a trough in the most acute phases of the pandemic (March-April 2020), monthly generation rapidly tended to rise back to levels forecast by the pre-COVID trend (Fig. 2b).

These absolute figures corresponded to a rise in the total HW produced per patient-day (+0.72 kg PD^{-1} in the pandemic compared to baseline, $p < 0.0001$), of which almost the totality was represented by IHW (+0.7 kg PD^{-1}, $p < 0.0001$). Even in relation to bed days, the rising trend was not significantly affected by the outbreak (LRT: $p = 0.532$) since, both in the pre-COVID and the COVID period, HW generation appeared to grow by around 0.08 kg PD^{-1} per year ($p = 0.0072$). Full detail of the coefficients of all models is reported in Table 1, while trends for HW and IHW generation are depicted in the Supplementary Material (Fig. S1 and S2, respectively).

Table 1. Model coefficients of ITS regression analyses. For all outcomes (first column), the model without interaction (no slope change) was chosen, according to the criteria specified in the Supplementary Files (see §2): the second column shows the *p*-values yielded by the corresponding LRTs (comparing models with/without interaction). The following columns represent the trend coefficients (β_1 = monthly increase, β_{12} = annual increase) and the estimated COVID-related level change (β_{COVID}), along with respective *p*-values.

Outcome [unit]	LRT *p*-value (interaction)	Trend coefficients and level change [95% CI]	p-value
Total monthly HW [tonnes month^{-1}]	0.3628 (interaction removed)	β_1 = +0.125 [+0.071; +0.179] β_{12} = +1.502 [+0.854; +2.150]	**< 0.0001***
		β_{COVID} = +6.129 [+3.128; +9.129]	**0.0001***
Total HW per patient-day [kg PD^{-1}]	0.532 (interaction removed)	β_1 = +0.006 [+0.002; +0.011] β_{12} = +0.076 [+0.021; +0.131]	**0.0072***
		β_{COVID} = +0.723 [+0.468; +0.978]	**< 0.0001***
Monthly infectious HW [tonnes month^{-1}]	0.2457 (interaction removed)	β_1 = +0.102 [+0.051; +0.154] β_{12} = +1.229 [+0.609; +1.849]	**0.0002***
		β_{COVID} = +6.319 [+3.448; +9.189]	**< 0.0001***
Infectious HW per patient-day [kg PD^{-1}]	0.326 (interaction removed)	β_1 = +0.005 [+0.001; +0.009] β_{12} = +0.061 [+0.008; +0.114]	**0.0254***
		β_{COVID} = +0.700 [+0.452; +0.949]	**< 0.0001***
Monthly non-infectious HW [tonnes month^{-1}]	0.3883 (interaction removed)	β_1 = +0.023 [+0.010; +0.035] β_{12} = +0.274 [+0.124; +0.423]	**0.0005***
		β_{COVID} = –0.190 [–0.881; +0.500]	0.5848

Correlation between COVID-related load and amount of IHW

The amount of IHW generated per patient-day was positively correlated with the proportion of hospital load ascribable to COVID-19 disease (Pearson's $r = 0.687$, $p = 0.0046$). Moreover, with acceptable goodness of fit (Residual Standard Error: RSE = 0.4533), the LOESS smoothing suggested for the non-linearity of this association, with a greater increase of HW generation when the proportion of COVID-related hospitalisation days exceeded 20% (Fig. 3).

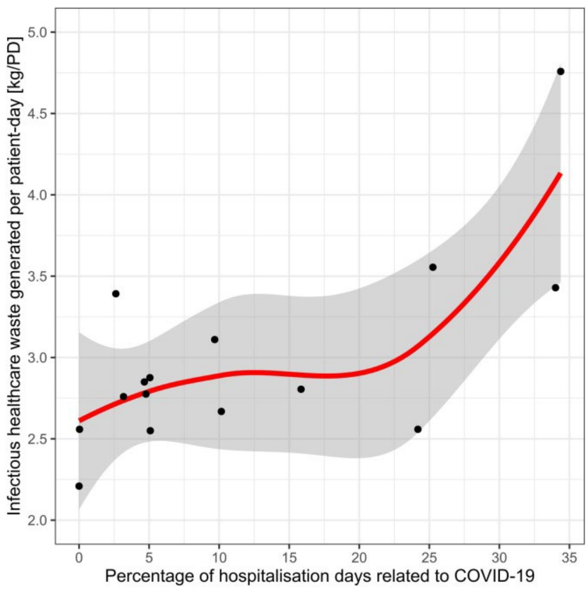

Fig. 3. Correlation between COVID-related hospital load and IHW generation per patient-day. For each month, the relative weight of COVID-19 is expressed as percentage of hospitalisation days ascribable to COVID-positive patients out of the total. The trend identified by the LOESS regression is shown by the red line (and its 95% confidence interval, shaded area).

Discussion

The first result emerging from trend analyses was a general increase in HW production over time. Even in the pre-COVID era, the amounts of HW tended to grow over time (+1.5 tonnes month^{-1} every year, Fig. 1): this was consistent with rising trends found in previous analyses of HW generation, where growths up to +36.6% have been recorded over a 4-year time span (Maamari et al., 2015). Moreover, also considering data in relation to patient-days, the growth estimated by the model (+0.076 kg PD^{-1} every year, Fig. S1) was absolutely comparable to the results obtained before the pandemic, when a 1.25-kg PD^{-1} increase over 17 years (i.e. averagely around +0.074 kg PD^{-1} every year) was demonstrated (Korkut, 2018).

The SARS-CoV-2 outbreak disruptively enhanced this process, first of all because of the systematic introduction of PPE for healthcare workers (Hantoko et al., 2021). In our experience, median hospital waste production rose from 2.4 (pre-COVID) to 3.3 kg PD^{-1} (during COVID), with a relative increase (approximately +38%) that was consistent with data obtained for medical waste both in similar contexts (e.g. France and the Netherlands) (Wei and Manyu, 2021) and in different geographical areas such as China (Ma et al., 2020; Wang et al., 2021). Furthermore, the absolute increase (+0.8 kg PD^{-1}) was aligned with results reported for medical waste generation in hospital settings: recent studies reported increases up to +3.5 kg PD^{-1} in hospital waste (Kalantary et al., 2021; Zambrano-Monserrate et al., 2020), of which 15-25% is estimated to be represented by IHW (Voudrias and Graikos, 2014; World Health Organization, 2018).

Beside the need to wear PPE for all healthcare and administrative personnel (Nzediegwu and Chang, 2020; Sangkham, 2020), patients' stay itself entailed a higher amount of IHW generated in hospitals: for example, needles and swabs used for routine diagnostics, discarded diapers or disposable cutlery used by COVID-positive patients for everyday meals (Das et al., 2021). Due to the persistence of coronaviruses in the common environment (Kampf et al., 2020), all these kinds of waste were considered as potential vehicles of SARS-CoV-2 transmission (Torkashvand et al., 2021) and therefore treated as hazardous waste according to international guidelines (European Commission, 2020; World Health Organization and United Nations Children's Fund, 2020), even though more recent research has shown that the virus is unlikely to be effectively transmitted through contaminated surfaces or waste (De-La-Torre et al., 2021; Delfino Barboza et al., 2021).

Almost all the increase of HW generated per patient-day (+0.7 out of +0.72 kg PD^{-1}) was represented by biologically hazardous waste. In fact, during the pandemic, the percentage of medical waste that could be ascribed to infectious sanitary waste rose up to 89% in some settings (Kalantary et al., 2021), which was definitely outstanding considering that, before the pandemic, the same proportion did not usually exceed 51-63% in industrialised and developing countries respectively (Aghapour et al., 2013; Diaz et al., 2008).

The absolute increase in IHW even exceeded the overall HW increase, while the production of non-infectious waste tended to be reduced during the pandemic. This was linked to the decrease in routine medical services provided by the hospital, similarly to what happened in most hospitals during the re-organisation of their healthcare activities (Panteli, 2020): all diagnostic and therapeutic procedures not strictly related to SARS-CoV-2 management were reduced to a minimum (Amador et al., 2021; Rodríguez-Leor et al., 2020) and, consequently, also the related use of reagents and cytotoxic liquids remarkably dropped. However, after a trough in non-infectious HW production in the very first months of the pandemic, this apparent decrease was rapidly followed by a rebound (Fig. 2b), plausibly due to the attempt to restart services previously suspended owing to COVID-19 (Webb et al., 2020). Moreover, infectious and non-infectious HW generation trends might have been also affected by the fact that, in an initial stage, the potential transmission of the virus through waste was still unclear, and thus some items could have been precautionarily classified as hazardous rather than non-hazardous.

The exceptionality of the COVID-related production of IHW is still more evident since IHW generation followed a non-linear pattern according to the relative COVID-related occupancy (Fig. 3). Studies conducted before the pandemic had generally found linear correlations between bed occupancy and daily produced waste at a given time point (Maamari et al., 2015; Sanida et al., 2010): on the contrary, in our experience, higher rates of COVID-positive patients seemed to shove the amount of IHW, particularly when more than 20% of all hospitalisation days were related to COVID. This was probably due to the saturation of the hospital's capacity to provide health care, and to the subsequent adoption of emergency solutions (e.g. patient allocation to other wards and, consequently, further safety measures and disposable items required), which resulted into even higher HW production.

However, the most significant (and worrying) output of this analysis is the apparently unmodified rising trend: this means that the increase in HW is currently being confirmed and COVID-19 has simply shifted HW generation to still higher levels. Such considerations acquire greater relevance as future scenarios are uncertain (Skegg et al., 2021) and the occurrence of variants possibly escaping vaccine-induced immunity (Centers for Disease Control and Prevention, 2021; Kustin et al., 2021) is suggestive of an extension of the COVID period, with potentially unbearable environmental impacts (Wei et al., 2021). In fact, the demand for PPE is estimated to rise at a 6-9% rate up to 2025, even though higher increases are not to be ruled out due to variants' potential impact (International Finance Corporation - World Bank Group, 2020).

This study has some limitations. First of all, HW data could be only collected on a monthly basis, with the possibility of a slight time lag (1-5 days) between waste generation, collection and recording; however, these possible fluctuations are likely to be only small and not systematic. Secondly, data were available in an aggregate form only, as this surveillance is not routinely performed at a ward level, which made it impossible to perform between-ward comparisons and correlations that might have offered further research ideas. Eventually, as explained above, our data did not include monitoring of municipal-like waste produced by the hospital, which accounts for an allegedly high proportion of the waste generated by the hospital. Further investigation would be needed by including also this category of waste: nevertheless, our analysis already provides an interesting insight of current trends in HW generation, particularly concerning hazardous medical waste, which is the category of medical waste requiring the most challenging and expensive management (Mol and Caldas, 2020; Windfeld and Brooks, 2015).

Conclusions

Waste generation in healthcare settings has represented an increasingly critical issue in the last decades: the COVID-19 pandemic has still enhanced this unenviable rising trends, by requiring additional precautions in clinical care at the expense of a sudden steep increase in HW generation and, consequently, of high environmental costs (Patrício Silva et al., 2020).

This study confirms that, in addition to the already critical burst due to COVID-19, the trend is still heading towards an increase in HW generation, which urges that measures be taken to conciliate patient safety requirements with the need to lower the impact of HW. As the definition and management of infectious waste widely differ between diverse contexts (Mühlich et al., 2003), it would be interesting to perform a similar surveillance in some other facilities both in the same geographical region (Italy) and in different countries, to spot possible differences between various hospitals and to achieve a global perception of hospital waste generation dynamics before and after the outbreak.

Other

Acknowledgements

We gratefully thank Roberta Bellini, Corrado Gualco and Cristian Zanelli (Accounting and Management Department, "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria) for providing aggregate data on hospitalisation days, both related and not related to COVID-19.

Funding: None

Data Statement

All data collected and analysed for this study, and the relevant computing code, are available upon request to the Corresponding Author of this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aghapour P, Nabizadeh R, Nouri J, Monavari M and Yaghmaeian K (2013) Analysis of hospital waste using a healthcare waste management index. *Toxicological & Environmental Chemistry* 95(4): 579–589. https://doi.org/10.1080/02772248.2013.802792

Amador M, Matias-Guiu X, Sancho-Pardo G, Contreras Martinez J, de la Torre-Montero JC, Peñuelas Saiz A, Garrido P, García-Sanz R, Rodríguez-Lescure Á, and Paz-Ares L (2021) Impact of the COVID-19 pandemic on the care of cancer patients in Spain. *ESMO Open* 6: 100157. https://doi.org/10.1016/j.esmoop.2021.100157

Bernal JL, Cummins S and Gasparrini A (2017) Interrupted time series regression for the evaluation of public health interventions: A tutorial. *International Journal of Epidemiology* 46(1): 348–355. https://doi.org/10.1093/ije/dyw098

Centers for Disease Control and Prevention (2021) COVID-19 Vaccine Breakthrough Infections Reported to CDC. *Morbidity and Mortality Weekly Report*. Available at: https://www.cdc.gov/mmwr/volumes/70/wr/mm7021e3.htm (accessed 25 July 2021)

Das AK, Islam N, Billah M and Sarker A (2021) COVID-19 pandemic and healthcare solid waste management strategy – A mini-review. *Science of the Total Environment* 778: 146220. https://doi.org/10.1016/j.scitotenv.2021.146220

De Aguiar Hugo A and Da Silva Lima R (2021) Healthcare waste management assessment: Challenges for hospitals in COVID-19 pandemic times. *Waste Management & Research* 39(1): Supplement 56-63. https://doi.org/10.1177/0734242X211010362

De-La-Torre GE, Pizarro-Ortega CI, Dioses-Salinas DC, Ammendolia J, Okoffo ED (2021) Investigating the current status of COVID-19 related plastics and their potential impact on human health. *Current Opinion in Toxicology* 27: 47–53. https://doi.org/10.1016/j.cotox.2021.08.002

Delfino Barboza S, Torres KJ, Vipond J, Lee J, Hallborg O, Guillaumie L, Radu R, Zaller N, Luby S, Fuller T, Sattler B, English P, Klimen SL, Bergen M, Lee K *et al* (2021) Health Expert Statement Addressing Safety of Reusables and COVID-19. Available at: https://www.greenpeace.org/usa/wp-content/uploads/2020/06/Health-Expert-Statement_125-experts.pdf (accessed 26 December 2021)

Diaz LF, Eggerth LL, Enkhtsetseg SH and Savage GM (2008) Characteristics of healthcare wastes. *Waste Management* 28(7): 1219–1226. https://doi.org/10.1016/j.wasman.2007.04.010

European Commission (2020) Waste management in the context of the coronavirus crisis. Available at: https://ec.europa.eu/info/sites/default/files/waste_management_guidance_dg-env.pdf (accessed 25 July 2021).

Greenberg RS and Kleinbaum DG (1985) Mathematical Modeling Strategies for the Analysis of Epidemiologic Research. *Annual Review of Public Health* 6(1): 223–245. https://doi.org/10.1146/annurev.pu.06.050185.001255

Hantoko D, Li X, Pariatamby A, Yoshikawa K, Horttanainen M and Yan M (2021) Challenges and practices on waste management and disposal during COVID-19 pandemic. *Journal of Environmental Management* 286: 112140. https://doi.org/10.1016/j.jenvman.2021.112140

Harrell Jr FE (2021) rms: Regression Modeling Strategies. *R Package version 6.2-0*. Available at: https://cran.r-project.org/web/packages/rms/rms.pdf (accessed 25 July 2021).

Henneberry B (2020) How Surgical Masks Are Made. *THOMASnet*. Available at: https://www.thomasnet.com/articles/other/how-surgical-masks-are-made (accessed 25 July 2021).

Hicks A, Temizel-Sekeryan S, Kontar W, Ghamkhar R and Rodríguez Morris M (2021) Personal respiratory protection and resiliency in a pandemic, the evolving disposable versus reusable debate and its effect on waste generation. *Resources, Conservation and Recycling* 168: 105262. https://doi.org/10.1016/j.resconrec.2020.105262

Ilyas S, Srivastava RR and Kim H (2020) Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Science of the Total Environment* 749: 141652. https://doi.org/10.1016/j.scitotenv.2020.141652

International Finance Corporation - World Bank Group (2020) Covid-19 – PPE demand & supply perspectives: Final Report. *Foreign, Commonwealth and Development Office*. Available at: https://www.ifc.org/wps/wcm/connect/1d32e536-76cc-4023-9430-1333d6b92cc6/210402_FCDO_GlobalPPE_Final+report_v14updated_gja.pdf?MOD=AJPERES&CVID=nyiUnTU (accessed 25 July 2021)

Kalantary RR, Jamshidi A, Golbini Mofrad MM, Jonidi Jafari A, Heidari N, Fallahizadeh S, Hesami Arani M and Torkashvand J (2021) Effect of COVID-19 pandemic on medical waste management: a case study. *Journal of Environmental Health Science and Engineering* 19: 831–836. https://doi.org/10.1007/s40201-021-00650-9

Kampf G, Todt D, Pfaender S, and Steinmann E (2020) Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *Journal of Hospital Infection* 104(3): 246–251. https://doi.org/10.1016/j.jhin.2020.01.022

Klemeš JJ, Fan YV, Tan RR and Jiang P (2020) Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renewable and Sustainable Energy Reviews* 127: 109883. https://doi.org/10.1016/j.rser.2020.109883

Korkut EN (2018) Estimations and analysis of medical waste amounts in the city of Istanbul and proposing a new approach for the estimation of future medical waste amounts. *Waste Management* 81: 168–176. https://doi.org/10.1016/j.wasman.2018.10.004

Kustin T, Harel N, Finkel U, Perchik S, Harari S, Tahor M, Caspi I, Levy R, Leshchinsky M, Ken Dror S, Bergerzon G, Gadban H, Gadban F, Eliassian E, Shimron O, Saleh L, Ben-Zvi H, Keren Taraday E, Amichay D, Ben-Dor A, Sagas D, Strauss M, Shemer Avni Y, Huppert A, Kepten E, Balicer RD, Netzer D, Ben-Shachar S and Stern A (2021) Evidence for increased breakthrough rates of SARS-CoV-2 variants of concern in BNT162b2-mRNA-vaccinated individuals. *Nature Medicine*. Epub ahead of print 14 June 2021. DOI: 10.1038/s41591-021-01413-7

Liang Y, Song Q, Wu N, Li J, Zhong Y and Zeng W (2021). Repercussions of COVID-19 pandemic on solid waste generation and management strategies. *Frontiers of Environmental Science and Engineering* 15(6): 115–132. https://doi.org/10.1007/s11783-021-1407-5

Ma Y, Lin X, Wu A, Huang Q, Li X and Yan J (2020) Suggested guidelines for emergency treatment of medical waste during COVID-19: Chinese experience. *Waste Disposal & Sustainable Energy* 2(2): 81–84. https://doi.org/10.1007/s42768-020-00039-8

Maamari O, Brandam C, Lteif R and Salameh D (2015) Health Care Waste generation rates and patterns: The case of Lebanon. *Waste Management* 43: 550–554. https://doi.org/10.1016/j.wasman.2015.05.005

Mol MPG and Caldas S (2020) Can the human coronavirus epidemic also spread through solid waste? *Waste Management & Research* 38(5): 485–486. https://doi.org/10.1177/0734242X20918312

Mühlich M, Scherrer M and Daschner FD (2003) Comparison of infectious waste management in European hospitals. *Journal of Hospital Infection* 55(4): 260–268. https://doi.org/10.1016/j.jhin.2003.08.017

Nzediegwu C and Chang SX (2020) Improper solid waste management increases potential for COVID-19 spread in developing countries. *Resources, Conservation and Recycling* 161: 104947. https://doi.org/10.1016/j.resconrec.2020.104947

Panteli D (2020) How are countries reorganizing non-COVID-19 health service delivery? *The COVID-19 Health Systems Response Monitor (HSRM)*. Available at: https://analysis.covid19healthsystem.org/index.php/2020/05/06/how-are-countries-reorganizing-non-covid-19-health-care-service-delivery (accessed 25 July 2021).

Patrício Silva AL, Prata JC, Walker TR, Campos D, Duarte AC, Soares AMVM, Barcelò D and Rocha-Santos T (2020). Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. *Science of the Total Environment* 742: 140565. https://doi.org/10.1016/j.scitotenv.2020.140565

R Core Team (2020) R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. Available at: https://www.r-project.org (accessed 25 July 2021).

Rodríguez-Leor O, Cid-Álvarez B, Ojeda S, Martín-Moreiras J, Ramón Rumoroso J, López-Palop R, Serrador A, Cequier Á, Romaguera R, Cruz I, de Prado AP and Moreno R (2020) Impact of the COVID-19 pandemic on interventional cardiology activity in Spain. *REC: Interventional Cardiology* 2: 82–89. https://doi.org/10.24875/RECICE.M20000123

Rupani PF, Nilashi M, Abumalloh RA, Asadi S, Samad S and Wang S (2020) Coronavirus pandemic (COVID-19) and its natural environmental impacts. *International Journal of Environmental Science and Technology* 17(11): 4655–4666. https://doi.org/10.1007/s13762-020-02910-x

Rutala WA and Mayhall CG (1992) Medical waste. *Infection Control & Hospital Epidemiology* 13(1): 38–48. https://doi.org/10.1086/646421

Sangkham S (2020) Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia. *Case Studies in Chemical and Environmental Engineering* 2: 100052. https://doi.org/10.1016/j.cscee.2020.100052

Sanida G, Karagiannidis A, Mavidou F, Vartzopoulos D, Moussiopoulos N and Chatzopoulos S (2010) Assessing generated quantities of infectious medical wastes: A case study for a health region administration in Central Macedonia, Greece. *Waste Management* 30: 532–538. https://doi.org/10.1016/j.wasman.2008.11.019

Sarkodie SA and Owusu PA (2021) Impact of COVID-19 pandemic on waste management. *Environment, Development and Sustainability* 23(5): 7951–7960. https://doi.org/10.1007/s10668-020-00956-y

Selvaranjan K, Navaratnam S, Rajeev P, Ravintherakumaran N (2021) Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions. *Environmental Challenges* 3: 100039. https://doi.org/10.1016/j.envc.2021.100039

Skegg D, Gluckman P, Boulton G, Hackmann H, Karim SSA, Piot P and Woopen C (2021) Future scenarios for the COVID-19 pandemic. *Lancet* 397(10276): 777–778. https://doi.org/10.1016/S0140-6736(21)00424-4

Torkashvand J, Jonidi Jafari A, Godini K, Kazemi Zahra, Kazemi Zohre and Farzadkia M (2021) Municipal solid waste management during COVID-19 pandemic: a comparison between the current activities and guidelines. *Journal of Environmental Health Science and Engineering* 19(1): 173–179. https://doi.org/10.1007/s40201-020-00591-9

Tsai W-T (2021) Analysis of medical waste management and impact analysis of COVID-19 on its generation in Taiwan. *Waste Management & Research* 39(1): Supplement 27–33. https://doi.org/10.1177/0734242X21996803

United Nations Economic and Social Commission for Asia and the Pacific (2020) The safe waste treatment for COVID-19 - Lessons from the Republic of Korea. *ESCAP Report.* Available at: https://www.unescap.org/sites/default/d8files/knowledge-products/200514%20waste%20management%20for%20COVID-

19%28edited%29%20FINAL.pdf (accessed 25 July 2021)

Voudrias E and Graikos A (2014) Infectious Medical Waste Management System at the Regional Level. *Journal of Hazardous, Toxic, and Radioactive Waste* 18(4): 1–9. https://doi.org/10.1061/(asce)hz.2153-5515.0000225

Wang J, Chen Zhuqi, Lang X, Wang S, Yang L, Wu X, Zhou X and Chen Zhulei (2021) Quantitative evaluation of infectious health care wastes from numbers of confirmed, suspected and out-patients during COVID-19 pandemic: A case study of Wuhan. *Waste Management* 126: 323–330. https://doi.org/10.1016/j.wasman.2021.03.026

Webb E, Hernández-Quevedo C, Scarpetti G, Edwards N, Reed S, Gandré C, Or Z, Cascini F, Winkelmann J, Kroneman M, De Jong J, Bernal-Delgado E, Angulo-Pueyo E, Estupiñán-Romero F, Rajan S and Chandran S (2020) Restarting More Routine Hospital Activities During Covid-19: Approaches From Six Countries. *Eurohealth* 26(2): 68–73. https://apps.who.int/iris/bitstream/handle/10665/336300/Eurohealth-26-2-68-72-eng.pdf

Wei G and Manyu L (2021) The Hidden Risks of Medical Waste and the COVID-19 Pandemic. *Waste360*. Available at: https://www.waste360.com/medical-waste/hidden-risks-medical-waste-and-covid-19-pandemic (accessed 25 July 2021)

Wei Y, Cui M, Ye Z and Guo Q (2021) Environmental challenges from the increasing medical waste since SARS outbreak. *Journal of Cleaner Production* 291: 125246. https://doi.org/10.1016/j.jclepro.2020.125246

Wilcox R (2017) The regression smoother LOWESS: A confidence band that allows heteroscedasticity and has some specified simultaneous probability coverage. *Journal of Modern Applied Statistical Methods* 16(2): 29–38. https://doi.org/10.22237/jmasm/1509494580

Windfeld ES and Brooks MSL (2015) Medical waste management - A review. *Journal of Environmental Management* 163: 98–108. https://doi.org/10.1016/j.jenvman.2015.08.013

World Health Organization (2021) WHO Coronavirus (COVID-19) Dashboard. Available at: https://covid19.who.int (accessed 02 July 2021)

World Health Organization (2018) Health-care waste. *Fact Sheets*. Available at: https://www.who.int/news-room/fact-sheets/detail/health-care-waste (accessed 25 July 2021)

World Health Organization and United Nations Children's Fund (2020) Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19: Interim guidance WHO Publication Office. Available at: https://www.who.int/publications/i/item/water-sanitation-hygiene-and-waste-management-for-the-covid-19-virus-interim-guidance (accessed 25 July 2021).

Zambrano-Monserrate MA, Ruano MA and Sanchez-Alcalde L (2020) Indirect effects of

COVID-19 on the environment. *Science of the Total Environment* 728: 138813. https://doi.org/10.1016/j.scitotenv.2020.138813

Zeileis A and Hothorn T (2002) Diagnostic Checking in Regression Relationships. *R News* 2: 7–10. https://cran.r-project.org/web/packages/lmtest/vignettes/lmtest-intro.pdf