
Estimation of Solid Medical Waste Production and Environmental Impact Analysis in the Context of COVID-19: A Case Study of Hubei Province in China

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Abstract

COVID-19 greatly challenges human beings in the health sector and leaves behind a large amount of medical waste that poses many potential threats to the environment. In this paper, we compiled relevant data released by official agencies and the media, and conducted data supplementation based on previous studies to calculate the net value of medical waste production in Hubei Province during COVID-19 with the help of a neural network model. Then, we reviewed the data related to the environmental impact of medical waste per unit and designed four scenarios to estimate the environmental impact of new medical waste generated during the epidemic. The results showed that at a medical waste generation rate of $0.5 \text{ kg}/(\text{bed} \cdot \text{d})$ COVID-19 resulted in a net increase in medical waste volume of about 3366.99 tons in Hubei Province. In the four scenario assumptions, if the medical waste brought by COVID-19 is completely incinerated, it will have a large impact on the air quality. If it is disposed by distillation sterilization, it will produce a large amount of wastewater and waste residue. Based on the results of the study, three policy recommendations are proposed in this paper: strict control of medical wastewater discharge, reduction and transformation of the emitted acidic gases, and attention to the emission of metallic nickel in exhaust gas and chloride in soil. These policy recommendations provide a scientific basis for controlling medical waste pollution.

Keywords: COVID-19; Medical waste; Environmental impact; China

1. Introduction

COVID-19 pandemic is threatening human health and has brought many indirect influences on the environment. Among them are ecological restoration due to restrictions on human activities and the increase in domestic solid waste and electricity consumption due to non-contact lifestyles[1,2]. In addition to domestic waste, the rapid consumption of masks, protective clothing, and large amounts of other medical supplies along with the global outbreak of COVID-19 has generated large amounts of infectious medical waste[3]. The disposal of these medical wastes can cause several environmental hazards, which mainly include pollution of the atmosphere, waters, and soil [4]. The impact of medical waste on human health and the ecological environment is further aggravated, as the excess low-risk medical waste is often disposed of at domestic waste standards, which is a result of people lacking anticipation or preparation for the epidemic. [5]

Along with the spread of epidemic, the medical waste, for its long-term strong infectivity, needs to be disposed of as soon as possible [6,7]. The incineration of medical waste produces a variety of harmful gases, and these gas mixtures can cause varying degrees of pollution to the air, water, and soil[8]. With the explosive increase in the number of confirmed cases, the risk of medical waste disposal and the environmental impact afterwards are then rapidly expanded[9]. Therefore, it is important to estimate the amount of new medical waste generated by the epidemic and the amount of pollutants it produces to provide perspectives and data to support environmental recovery in the post-epidemic era[10].

Current research related to medical waste focuses on the evaluation of medical waste disposal technologies, economic benefits of medical waste disposal, medical waste production and composition [11] management methods. The current literature on the environmental impact of COVID-19 focuses on environmental recovery from

reduced human activities, increased solid waste from non-contact lifestyles and how to dispose of plastic waste from the epidemic [12,13] etc. The above-mentioned literature illustrates that there are already many scholars who are concerned about the huge environmental impact that will be caused by the waste generated during the epidemic [14-16], but to our knowledge, only a few scholars have studied the quantification and environmental impact of medical waste [17,18]. The prerequisite for assessing the environmental impact of new medical waste from an epidemic is a reasonable estimate of medical waste production, and the current means of predicting or estimating medical waste production are mainly gray prediction models, field survey methods, simple linear regression methods, and empirical estimation methods, and each of these survey methods has many advantages and shortcomings. Therefore, how to estimate the amount of medical waste generated by COVID-19 and assess its environmental impact is an urgent issue to be addressed.

In this paper, we first obtained the annual medical waste production in Hubei Province by empirical estimation method and calculate the actual medical waste production in Hubei Province for each month by weight. Following that, we constructed a counterfactual framework of medical waste under conventional conditions by means of deep learning and compares it with the actual production of medical waste to calculate the amount of medical waste generated by COVID-19 in Hubei province. Finally, we quantified the specific environmental impact of the additional medical waste using the environmental impact data at the time of medical waste disposal [19]

2. Methods and data

2.1. Research Subjects and Scope

In China, Hubei province is the epicenter of Covid-19, and consequently the region producing the largest amount of medical waste[20]. Therefore, Hubei Province was chosen as the subject of the study (Figure 1). According to the epidemic data published

by Health Commission of Hubei Province, the epidemic in Hubei Province mainly occurred at the end of January and lasted to the end of April. Therefore, this paper focuses on the epidemic medical waste production in Hubei Province from late January to late April and its impact on the environment.

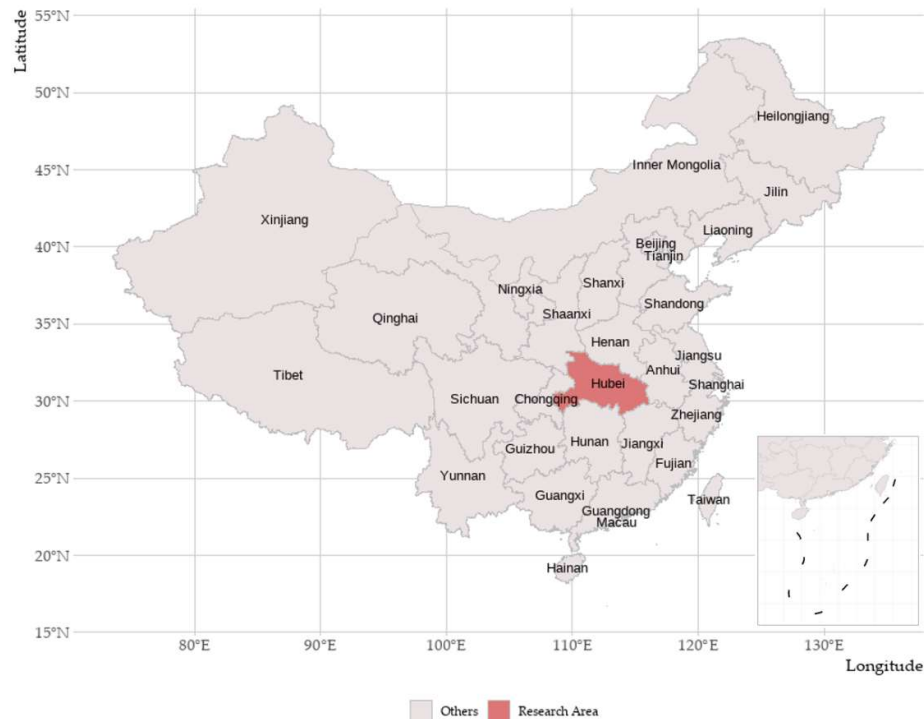


Figure 1 Map of Hubei Province

2.2. Calculation of annual production of medical waste

At present, the calculation methods of medical waste production mainly include field survey method and empirical estimation [21,22]. The field survey method mainly selects several representative medical institutions in a certain area by random sampling, and then investigates the medical waste production of these medical institutions to obtain the basic situation of medical waste production (Dehghani et al., 2019). However, this method is time-consuming, costs more and is not universally applicable. The empirical estimation method, on the other hand, uses an internationally-used empirical

formula to estimate the medical waste production by substituting the values of variables such as the number of visits, bed utilization rate, and number of beds [24,25]. Therefore, this paper implemented the empirical estimation method to calculate the annual medical waste production in Hubei Province from 2014 to 2019, which was used as the basis for predicting the medical waste production in each month of 2020.

There are many factors affecting the annual production of medical waste, among which the main ones are education level, living standard of residents, economic development level, number of beds in medical institutions, bed utilization rate, medical service level, and number of visits [26-29]. It was found that the number of beds in medical institutions, the bed utilization rate and the number of visits were the most important factors affecting annual production of medical waste[30]. Therefore, in this paper, the annual medical waste production in Hubei Province was calculated based on the number of beds, bed utilization rate, and number of visits in each year by applying the empirical formula Q , the calculation formula is as follows.

$$Q = 365BPM + NS \quad (1)$$

Medical waste in Hubei Province for the calendar year consists of two parts. One is the outpatient department medical waste, and the other is the inpatient department medical waste. In the formula B denotes the number of beds in all medical institutions in Hubei Province in a given year, and P denotes the bed utilization rate of that year, and M indicates the average daily amount of medical waste generated per unit bed. N denotes the number of visits to all medical institutions in Hubei Province in a given year, and S denotes the average amount of medical waste generated per unit visit per day.

2.3. Estimation of monthly production of medical waste

According to the purpose of this paper, it is necessary to calculate the monthly medical waste production in Hubei Province in previous years and then use it as a basis

to predict the monthly medical waste production under normal conditions in 2020. Although the number of beds, bed occupancy rate and number of visits to medical institutions in Hubei Province per month are not officially published, studies have shown that there is a highly positive linear relationship between the monthly medical waste production and the total number of visits to hospitals in Hubei Province [31]. Therefore, in this paper, the ratio of the total number of hospital visits per month to the total number of hospital visits in Hubei Province in that year is used as the weight, and then the calculated values of the above annual medical waste production are multiplied by the weights of the corresponding months to obtain the monthly medical waste production as q_i . The specific calculation formula is as follows.

$$q_i = Q \cdot \omega_i \quad (2)$$

$$\omega_i = \frac{n_i}{\sum_{i=1}^{12} n_i} \quad (3)$$

where ω_i is the ratio of the total number of hospital visits per month to the total number of hospital visits in Hubei Province in that year, and n_i is the total number of hospital visits in month i of a year in Hubei Province.

2.4. Counterfactual predictions for medical waste

Based on the time series data estimated in the previous section, this section constructs counterfactual forecasts for the year 2020 without the occurrence of the pandemic. For the prediction of time series data, there are multiple prediction models to choose from. Considering the limitation of sample size and the accuracy of prediction, this paper uses several models for prediction simulation and validates the set models by using various indicators. Finally, the Long short-term memory (LSTM) model is selected to predict the amount of medical waste generated from January to April 2020.

2.4.1. Long Short Term Memory Neural Network

LSTM is a special type of RNN network that solves the problem of long range dependencies in data by capturing multiple aspects of past information through multiple network layers. In econometrics, LSTM provides a new tool for dealing with time series data [32]. Currently, LSTM has been applied to prediction scenarios stock selection and forecasting [33] and solar activity prediction [34]. As a variant of recurrent neural network, LSTM has a neural network repetition chain structure. With a repetition unit of not only one but four internal network layers, LSTM is able to capture long short term memory.

LSTM is a network that solves the very streamlined form of the long dependency problem in RNN networks. In this network, a brief LSTM memory transfer is given by c^t , the h^t is completed, and its relation to the output result y^t which is expressed by the following equation.

$$c^t = z^f \odot c^{t-1} + z^i \odot z \quad (4)$$

where c^t represents the long-time part of the selective memory, the z^f serves as forget gate to control the previous state of c^{t-1} for forgetting, and z^i represents the memory gate that is retained, and z is the current information scaled by the tanh function.

$$h^t = z^o \odot \tanh(c^t) \quad (5)$$

h^t represents the short-time memory part from the current output of the gate z^o and the long-time memory of Hadamard Product after tanh activation.

$$y^t = \sigma(W'h^t) \quad (6)$$

y^t represents the final output result. And similar to RNN, the output result is often ultimately obtained by the difference between the weight matrix after Sigmoid

activation and h^t the variation of the obtained. To ensure the reliability of the prediction model selection in this paper, Seasonal-ARIMA, Prophet, is also used to compare with the LSTM time series prediction model, and its results are reported in the Appendix.

2.5. Scenario assumptions for environmental impact assessment

We will use a scenario-based approach to make assumptions about the composition and disposal of the estimated increase in medical waste due to COVID-19 outbreak. This will be used to conduct an environmental impact assessment. Epidemic medical waste differs from normal medical waste in two ways: 1. The nature of the waste differs: due to the infectious nature of COVID-19, the net value estimated above is considered to be infectious waste in this paper[35]. Due to the lack of relevant data, this paper uses the assessment data of typical medical waste as a substitute. Therefore, we used [19] proposed environmental assessment data for potentially infectious waste (see Table 5). 2. The waste disposal method is different. Due to the surge of medical waste, according to government information, almost all of the waste will be disposed of using the incineration method. Accordingly, the following scenario assumptions were made[36].

A. Business as usual (BAU)

In the BAU scenario, we consider the disposal of medical waste as a continuation of the previous approach: according to relevant reports, as of the end of December 2019, the centralized medical waste disposal in Hubei Province has been licensed with a total capacity of 63,000 tons/year, of which 61% of the capacity adopts high-temperature incineration treatment process and 39% of the capacity adopts autoclave steam sterilization treatment. Therefore, in this scenario this paper assumes that the epidemic in Hubei Province adds medical waste ($M = 0.5$) 61% is disposed of by high-temperature incineration and 39% by autoclaving.

B. Complete pyrolysis (CP)

In the CP scenario, we refer to the study by [18] In order to expand the waste disposal volume, it is assumed that Hubei Province will adopt complete pyrolysis for waste disposal. In this scenario, all medical waste will be disposed of by high-temperature pyrolysis.

C. More pyrolysis (MP)

In the scenario where pyrolysis is preferred, we assume that epidemic waste disposal is prioritized by disposal volume [37]. Due to the large amount of medical waste brought by the epidemic, the pressure of waste disposal is increased, which makes the proportion of pyrolysis waste increase. In this scenario, 80% of the waste will be pyrolyzed at high temperatures and the remaining 20% will be sterilized using autoclaving.

D. More Steam sterilization(MS)

In the scenario where steam disinfection is preferred, we assume that outbreak waste disposal is prioritized in terms of infection risk reduction and environmental protection. Steam disinfection method disinfects medical waste in the presence of infectious agents by degrading proteins and destroying microbial tissues. During this process, no harmful gases are released [38]. In the MS scenario, we increase the percentage of steam disinfection method in BAU so that 60% of medical waste is disinfected by steam disinfection method and 40% by pyrolysis method.

2.6. Related Data Sources

2.6.1. Annual production related data sources

In this paper, we obtained the statistics of the number of beds, bed utilization rate, and attendance of medical institutions in Hubei Province from 2008 to 2019 by

reviewing relevant information from the National Bureau of Statistics (as shown in Table 1 Indicators related to medical institutions in Hubei Province over the).

Table 1 Indicators related to medical institutions in Hubei Province over the years

Year	Bed amount/10000	Bed utilization rate %	Visits (Billion times)
2008	16.73	87.3	1.44
2009	18.72	92.7	2.18
2010	20.04	96.1	2.39
2011	22.40	98.7	2.68
2012	25.30	99.3	3.06
2013	28.82	96.5	3.21
2014	31.75	96.1	3.45
2015	34.31	92.4	3.48
2016	36.06	92.0	3.55
2017	37.62	92.7	3.56
2018	39.35	92.7	3.51
2019	40.33	92.3	3.54

Data source: National Bureau of Statistics

In calculating the annual production of medical waste, the daily production of medical waste per unit bed in equation (1) M and medical waste production per unit visit S are unknown. For the S , in this paper, we searched the relevant literature in China and abroad [39] and found that the daily medical waste generation per unit visit was 0.03-0.05 kg, and the value was positively correlated with the economic development level. Therefore, according to the level of economic development in China, this paper takes the average value of $0.04 \text{ kg}/(\text{visits} \cdot d)$. For the M , there are large differences among different countries and slight differences among different regions of the same country [40]. According to a study by domestic scholars [41-43], the medical waste generation rate in Gansu Province in 2010 was $0.59 - 0.79 \text{ kg}/(\text{bed} \cdot d)$, and the medical waste generation rate in 2014 in Enshi Prefecture, Hubei Province was about $0.37 \text{ kg}/(\text{bed} \cdot d)$, the average medical waste generation rate of the province in Hubei Province in July 2016 was about $0.5 \text{ kg}/(\text{bed} \cdot d)$. Given the development of economic conditions, infrastructure and medical services in Hubei Province in recent years, this paper sets the medical waste generation rate in Hubei Province at $0.5 \text{ kg}/(\text{bed} \cdot d)$. In the subsection of sensitivity analysis, this paper conducts a sensitivity analysis for the daily production of medical waste in hospital beds M . This indicator was subjected to sensitivity analysis.

2.6.2. Monthly production related data sources

In this paper, by reviewing the relevant data from the National Health and Wellness Commission of the People's Republic of China, we obtained all hospital visits per month in Hubei Province from 2014-2019 as shown in Figure 2.

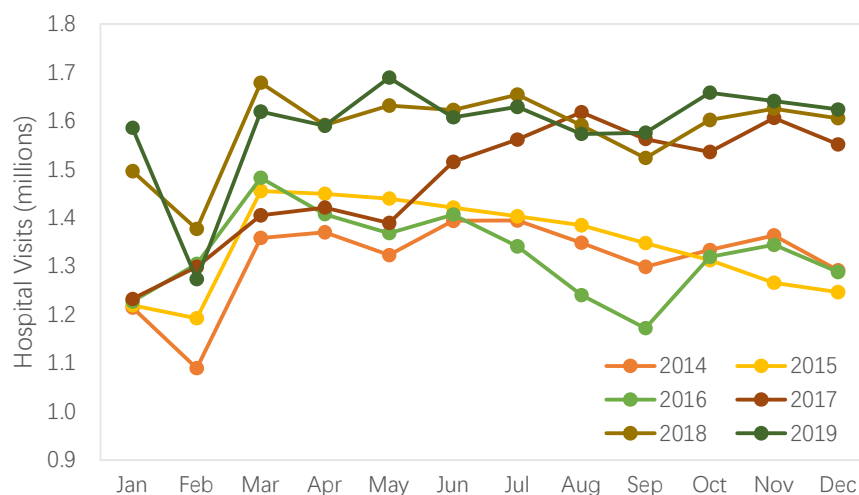


Figure 2 Hospital Visits by Month, Hubei Province, 2014-2019 (million visits)

The percentage of each month was calculated based on the total number of hospital visits in each month from 2014-2019 in Hubei Province, which is the weight of medical waste production in each month to the total medical waste production in that year.

2.6.3. Environmental impact-related data sources

According to domestic and international studies on medical waste disposal, different disposal methods may be suitable for different categories of medical waste, and the disposal technology for medical waste is mainly divided into two types, incineration and non-incineration. The latter one is the most common method of autoclaving [44].

Medical waste disposal produces a mixture of hazardous gases, including carbon monoxide, sulfur dioxide, nitrogen oxides, fluoride, various metals and their compounds, dioxins, and other volatile organic compounds [45]. Among them, mercury in exhaust gases not only pollutes the atmosphere, but also enters the water and soil with the air flow, thus degrading water sources and inhibiting plant growth. The toxicity of dioxins is much higher than that of other toxic gases, and dioxin concentrations in

flue gases from medical waste incineration are significantly higher than those from domestic waste incineration [46]. Sulfur dioxide in exhaust gases also contributes to atmospheric acidification, which in turn can lead to high-risk natural hazards such as acid rain [47]. Medical waste that is randomly put into rivers and lakes can easily lead to a decrease in lake size, changes in the acidity and alkalinity of water bodies, and the death of a large number of aquatic organisms [48]. The infiltration of many harmful substances into the soil may change the pH of the soil, make the soil lose its fertility, and even affect the survival of soil microorganisms and the growth of plants [7,49,50].

According to the research of domestic and foreign scholars, it was found that a variety of hazardous substances are produced after medical waste disposal, and the amount of production depends on the disposal technology used [51]. In this paper, the main hazardous substances produced by two common disposal technologies were obtained by reviewing the relevant literature [19]

3. Results and discussion

3.1. Estimated monthly production of medical waste

The monthly production of medical waste in Hubei Province was calculated based on the annual production of medical waste in Hubei Province and the weights of each month, so we first calculated the annual production of medical waste in Hubei Province from 2014 to 2019 by using Equation (1) and the relevant data collected above (as shown in Figure 3).

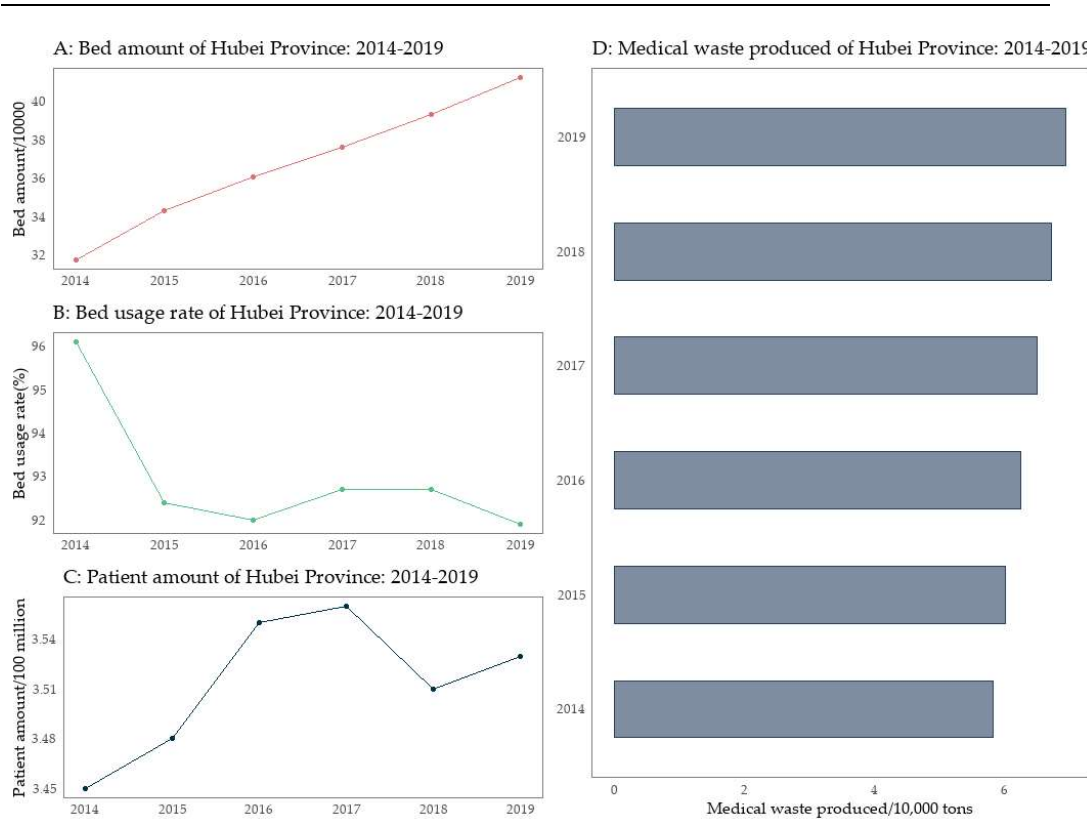


Figure 3 Annual production of medical waste in Hubei Province, 2008-2019

The Figure depicts the trend of medical waste, patient visits, bed utilization rate, and number of beds in Hubei province from 2008-2019. A represents the change in the number of hospital beds, where the bars represent the number of beds in tens of thousands, which can be seen to be increasing over time. B represents the annual bed utilization rate, which is shown to fluctuate in the graph. C depicts the trend of growth in the number of patient visits. D represents the estimated annual medical waste generated. It is initially recognized from the Figure, the number of consultations and the number of hospital beds in Hubei province show an increasing trend year by year, which is in line with previous studies [52], and such an increase may be caused by the increasing resident population and the growing industrialization, etc. [53-56]. In this paper, the above annual production data and the weights of each month of the corresponding year were used so as to calculate the monthly medical waste generation

in Hubei Province from 2014-2019 (as shown in Figure 4).

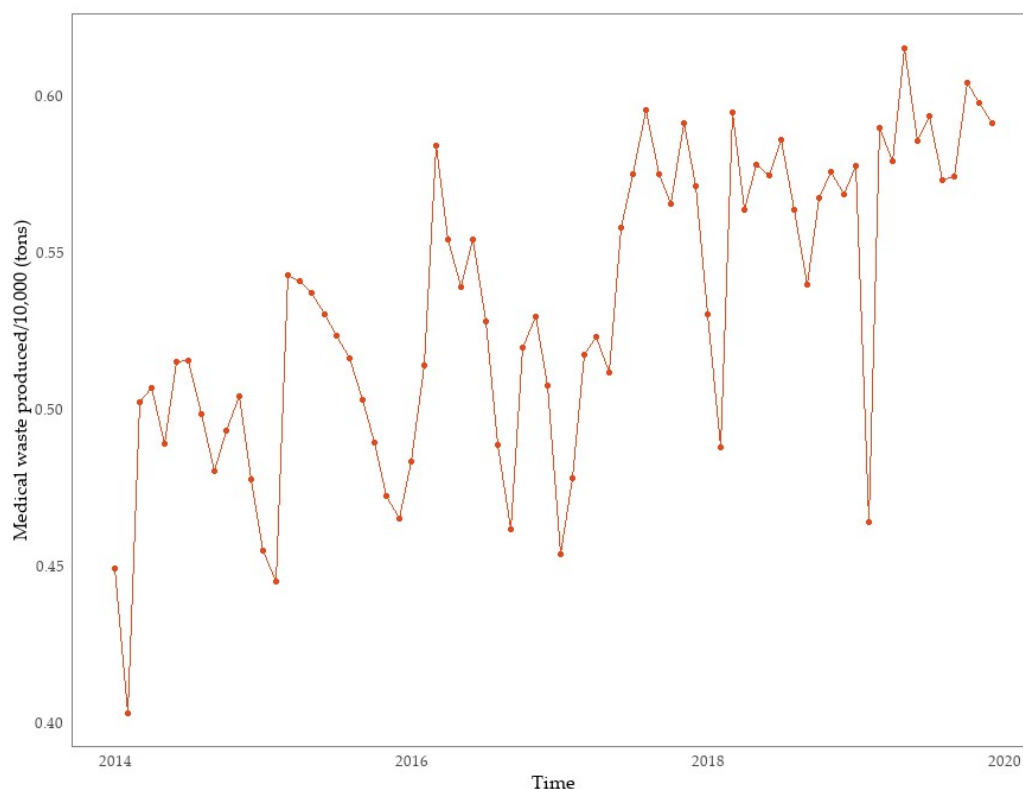


Figure 4 Monthly production of medical waste in Hubei Province, 2014-2019

From the results of the Figure 4, it can be seen that the lowest peak of monthly medical waste generation in Hubei Province mainly occurs in February each year, and the highest peak mainly occurs in March each year (sometimes in May-August). The main reasons for this pattern are as follows: (1) The Spring Festival usually falls in February. Generally speaking, most Chinese tend to avoid visiting medical institutions and other similar places during the most important traditional festival; (2) March is right after the Spring Festival, a time when more people are willing to go out, including visiting hospitals for diagnosis and treatment; (3) Hubei Province has a relatively developed tourism industry, and the May-August period is the first month after the Chinese New Year. (3) the tourism industry in Hubei Province is relatively developed, and May-August is the peak period for tourism, which increases the flow of people, and

possibly the number of patients.

3.2. Medical waste monthly production forecast

The LSTM Model was used to obtain the counterfactual prediction of the scenario where there were no COVID-19 epidemic in 2020. The medical waste generation rates of 0.6765, 0.5838, 0.6864 and 0.6777 tons from January to April 2020 were obtained for the case of medical waste generation rate of 0.5 kg/(bed·d).

3.3. New medical waste production from the outbreak

According to the epidemic data released by the Hubei Provincial Health and Wellness Commission, the epidemic in Hubei Province broke out on January 23, while it basically ended on April 28. According to the Hubei Provincial Department of Ecology and Environment, from January 23 to April 28, Hubei Province safely disposed of a total of 24,357.99 tons of medical waste. Therefore, it can be assumed that the medical waste generated during the epidemic in Hubei Province was 24,357.99 tons.

In order to calculate the additional medical waste production during the epidemic period compared to the normal period, this paper needs to first calculate the medical waste production under normal conditions in Hubei Province from January 23 to April 28, 2020. According to the medical service data published by the National Health and Wellness Commission of the People's Republic of China, under normal conditions, the number of hospital beds, bed occupancy rate, and the number of attendances on each date of the same month vary so little that it could be neglected. Therefore, under the empirical estimation method, this paper can assume that the daily medical waste production in Hubei Province is the same in each month under normal conditions. According to the predicted medical waste production in Hubei Province from January to April 2020 ($M = 0.5$), the medical waste production in Hubei Province from January 23 to April 28, 2020 under normal conditions can be calculated (as shown in

the Table 2).

Table 2 Predicted production of medical waste under conventional conditions in Hubei Province

Time	Medical waste(ton)
1/23-1/31	1964
2/1-2/29	5838
3/1-3/31	6864
4/1-4/28	6325
Sum	20991

Based on the actual production value of medical waste from the epidemic in Hubei Province and the total normal production from Table 2, we can obtain the net production value of new medical waste from the epidemic in Hubei Province of 3366.99 tons, which is 16.04% higher than that under the normal conditions in the same period. For the reader's reference, in the supporting information, this paper also predicts the medical waste generation on normal conditions based on $0.4 \text{ kg/ (bed} \cdot d)$ or $0.6 \text{ kg/ (bed} \cdot d)$.

3.4. Scenario Analysis

For the environmental impact of epidemic medical waste, this paper set four scenarios and calculated the impact situation of medical waste on environmental factors under various scenarios by adjusting the application ratio of two disposal technologies, and the results are shown in Figure 5 and Figure 6.

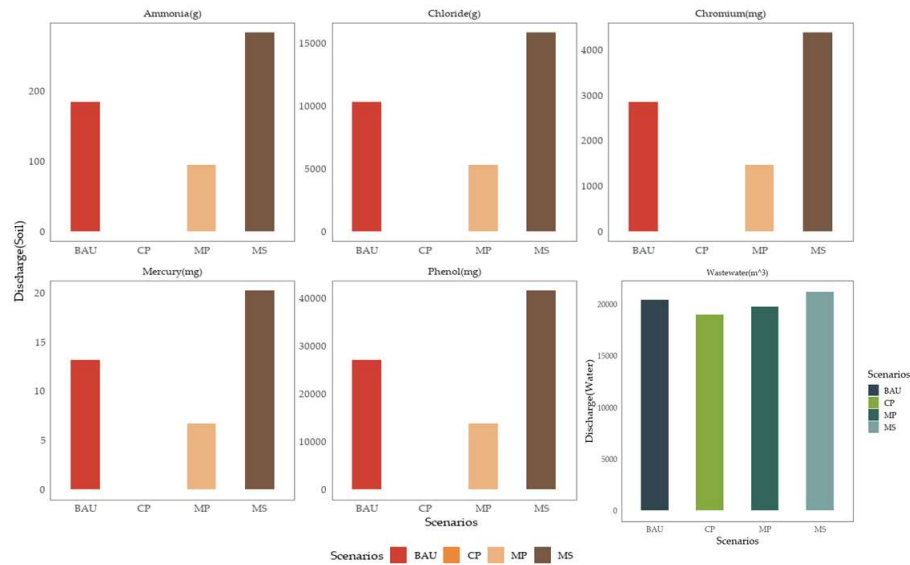


Figure 5 Wastewater and waste production under four scenarios

From Figure 5, it can be seen that the order of the magnitude of wastewater and sludge emissions under the four scenarios is $MS > BAU > MP > CP$, which means that the high-temperature incineration method can reduce the impact of medical waste disposal on the water and soil environments. Especially for the discharge of wastewater, which contains many harmful substances, such as chloride, fluoride, sulfur dioxide, mercury, and other heavy metals. And the amount of discharged wastewater is quite huge in all four scenario assumptions, so the government should manage wastewater generated during medical waste disposal. It should strictly control the discharge of such wastewater and the emission standards of the concentration of various chemical substances contained in it, and at the same time enhance the supervision and punishment of the medical waste disposal industry to ensure that the harm caused by wastewater to human health and ecological environment is minimized.

It can also be seen from Figure 5 that chloride emissions are the highest among the waste materials discharged into the soil, exceeding the sum of emissions of other harmful substances. Excessive chloride in the soil is likely to cause soil acidification,

salinization, and even soil erosion. Therefore, for countries and regions with serious epidemics, local governments should strengthen the control of chloride content from medical waste disposal, and take appropriate methods to collect and reuse the chloride to avoid environmental pollution caused by large amount of discharge into the soil.

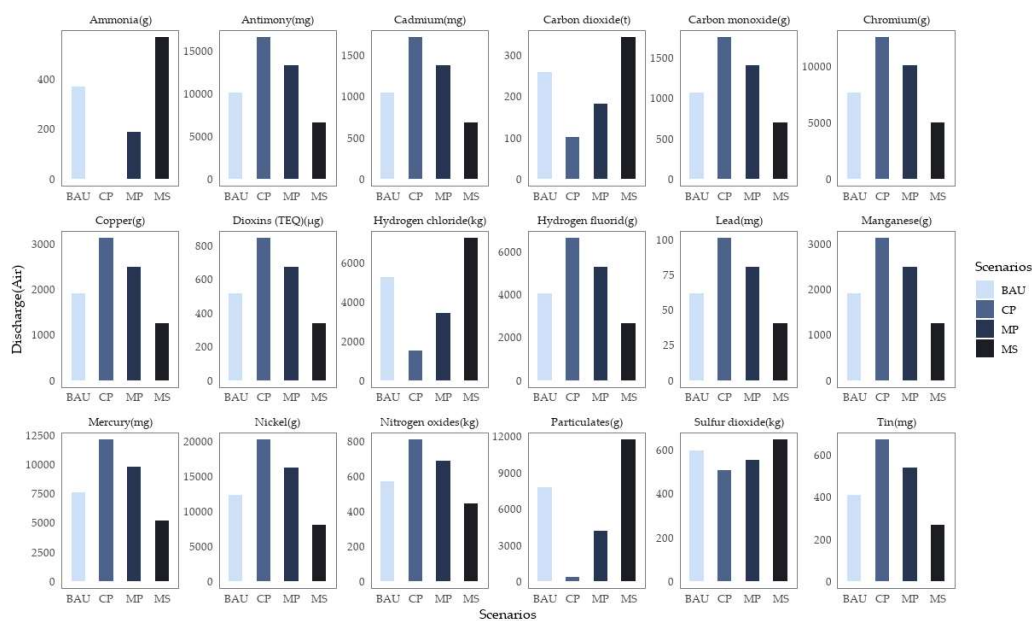


Figure 6 Exhaust gas production under the four scenarios

As can be seen from Figure 6, the order of magnitude of most of the exhaust gas emissions in the four scenario assumptions is: CP>MP>BAU>MS. Therefore, Steam sterilization method produces less exhaust gas than high-temperature incineration method, but produces more sulfur dioxide, hydrogen chloride, and carbon dioxide gases. Among the harmful exhaust gases emitted, hydrogen chloride gas has the highest emissions. Sulfur dioxide and hydrogen chloride are easily combined with water vapor when emitted directly into the atmosphere, thus forming acid rain. This can have an extremely negative impact on human health and the ecological environment. Moreover, carbon dioxide accumulates in the atmosphere, which tends to create a greenhouse effect. Therefore, countries with serious epidemics should monitor the concentration of acid gases generated by medical waste disposal in real time, and organize experts and

scholars to discuss and study this issue, and use cost-effective means to convert these acid gases into harmless gases.

In addition, the emissions contain many heavy metals, among which content of nickel was the most and content of lead the least according to Figure 6. Nickel and its compounds emitted into the atmosphere can easily form dust and affect the growth of plants when they land in the soil, and through certain chemical reactions, they can also produce various carcinogenic substances. Therefore, among the many metallic substances contained in exhaust gas, the government should pay special attention to the emission of nickel metal, improve relevant laws and regulations as soon as possible, and improve medical waste disposal technology. Especially for countries with serious epidemics, such as the United States, Brazil, and India, the government should take effective measures to reduce the large amount of nickel particles generated by medical waste disposal.

4. Conclusion

In this paper, we found that at a medical waste generation rate of 0.5 kg/(bed·d), COVID-19 resulted in a net increase in medical waste volume of about 3366.99 tons in Hubei Province. Moreover, the quantities of various waste gases, wastewater and sludge generated by the epidemic medical waste were calculated and compared separately in four scenario assumptions. The possible environmental impacts under different disposal methods were simulated to provide a reference for the disposal of medical waste during the epidemic. We combined the empirical estimation method with a neural network model to estimate the counterfactual data of medical waste during the epidemic in Hubei Province in 2020, which provides a new idea for estimating medical waste production in the future. In addition, we quantified the environmental impact of this medical waste, which provides a policy basis for how to dispose of medical waste in countries or regions with serious epidemics

5. Author Contributions

Conceptualization, Yifan Song and Jinquan Ye; Data curation, Yun Zhong; Formal analysis, Yifan Song and Jinquan Ye; Funding acquisition, Jinquan Ye and Yun Zhong; Investigation, Yifan Song; Methodology, Yifan Song and Jinquan Ye; Validation, Yurong Liu; Writing – original draft, Yifan Song, Jinquan Ye and Yun Zhong; Writing – review & editing, Yurong Liu.

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