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Quantitative evaluation of infectious health care wastes from numbers of confirmed, suspected and out-patients during COVID-19 pandemic: A case study of Wuhan

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ABSTRACT

The fight against coronavirus disease 2019 (COVID-19) is still running its courses. Proper management and disposal of health care wastes (HCWs) are critical to win the fight. To achieve aforementioned tasks, prediction of their production is highly desired. In this study, primary data of production of three kinds of HCWs collected from Wuhan, the first epidemic epicenter worldwide and a mega city with more than 10 million population who has went through a lockdown period of 78 days, were reported for their first time. HCWs were classified into routine HCWs, infectious HCWs (IHCWs) and infectious municipal solid wastes. Among them, infectious HCWs from designated hospitals for COVID-19 were recognized as the most dangerous one. A multiple linear regression (MLR) model was built to predict the production of IHCWs with high significance. Numbers of patients were demonstrated high correlations with the production of IHCWs in an order of confirmed patients > out-patients > suspected patients. By the MLR model, production rates of IHCWs by confirmed, suspected and out patients were determined as 3.2, 1.8 and 0.1 kg/patient, respectively. In addition, constant production of IHCWs during the pandemic period was determined as 13 tons/d. This is the first study on quantitative evaluation of infectious HCWs during COVID-19 pandemic. The achievements in this study have potentials to shed light on global efforts to the prediction, management and disposal of vast HCWs generated in the war against COVID-19.

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people through more widespread pathways (Randazzo et al., 2020). Thus, IHCWs are significantly infectious and dangerous, which should be strictly managed and disposed (Ilyas et al., 2020, Thakur, 2021).

To achieve aforementioned tasks, production data of IHCWs are necessary. The quantitative prediction approach of IHCWs was necessary to the arrangement of collection, transportation and disposal facilities. Unfortunately, little study has been reported concerning the quantitative prediction of IHCWs production during the pandemic (Kalina and Tilley, 2020). Abu-Qdaís et al., determined the production rate of medical wastes by COVID-19 patients as 14.16 kg/patient in a hospital in Jordan, however, too little samples were involved in the study (Abu-Qdaís et al., 2020). Some efforts have been paid on the description of the production of routine HCWs (Yu et al., 2020). Generally, the production of routine HCWs was calculated by HCWs production rates (kg/(bed x day)) and number of medical beds (Minoglou and Komilis, 2018). However, this approach is not competent to describe boosting yields of IHCWs during pandemic periods due to the vast consumption of medical resources and self-protective equipment by various categories of patients including confirmed, suspected and out ones (Britton et al., 2020, Yu et al., 2020, Zhang et al., 2020).

Hence, in this study, the production rates of IHCWs were determined based on practical data of their production. Multiple Linear Regression (MLR) is a statistical method to predict the outcome of a dependent variable by uses several independent variables, which has been widely employed in the fields of environment (Ozcelep et al., 2020, Hosseinazadeh et al., 2020). Especially, previous research suggested MLR model competent to forecast the production of RHOCWs (Golbaz et al., 2019, Al-Khatib et al., 2016). Based on aforementioned hypothetical theory to calculate the production of RHOCWs, MLR model was considered as the most suitable one to describe the production of IHCWs. In this study, the classification of HCWs and the production of three kinds HCWs during Wuhan's pandemic period were provided and discussed for their first time. Considering that Wuhan is the first epidemic epicenter of the world, it is very valuable to analyze the production data of HCWs during the pandemic period, to understand the relationship between the spread of the pandemic and the production of HCWs. Then, the linear correlation between the number of patients and IHCWs production, and also the MLR models to predict the production of IHCWs were investigated. By the prediction results, proper arrangement of disposal facilities for IHCWs can be achieved during the COVID-19 or even other coronavirus pandemic. The MLR model and also the experiments on emergency responses to boosting increased amounts of IHCW during pandemic periods in Wuhan have potential to shed light on global efforts to management and disposal of vast HCWs generated in the war against COVID-19.

2. Methodology

2.1. Study location and period

The study area is located in Wuhan (29°58’ N, 113°53’ E) which is the capital city of Hubei Province, China. It has an area of 8494 km² with 11.21 million inhabitants. The study period is from 21 February to 24 April 2020.

2.2. Data collection

2.2.1. Data on spread of pandemic

The data of pandemic including the number of confirmed patients (CP), suspected patients (SP) and out-patients (OP), where all patients in designated hospitals for COVID-19 involved, were collected from Wuhan Municipal Health Commission and provided in Fig. 1. All the three categories of patients came from designated hospitals for COVID-19, not only permanent but also temporary ones. In detail, confirmed patients meant patients with clinical symptom of COVID-19 who was diagnosed by Computerized Tomography and DNA reports. Suspected ones meant patients with clinical symptom who has not been diagnosed. Out-patients meant who received medical services from out-patient department of designated hospitals for COVID-19. Designated hospital meant the permanent/temporary hospitals only served for COVID-19 patients, and those patients can only get medical services from designated hospitals. Vice versa for undesignated hospitals.

The data of designated hospitals for COVID-19/undesignated ones, medical beds in designated/undesignated hospitals and out-patients suffered other diseases than COVID-19 were collected from Wuhan Municipal Health Commission.

2.2.2. Classification of HCWs during the pandemic period

A stricter classification standard of HCWs was carried out for the management of HCWs during the pandemic period in Wuhan (Fig. 2). Firstly, dozens of public hospitals and temporary ark hospitals were assigned as designated hospitals for medical services to confirmed patients and diagnosis to suspected and out patients (Yuan et al., 2020). Other hospitals (named as undesignated hospitals) served for patients suffering other diseases than COVID-19. HCWs collected from designated and undesignated hospitals were classified as infectious and routine HCWs respectively, following a traditional standard for HCWs classification (Lee and Huffman, 1996). Besides, close-contacts with COVID-19 patients were isolated in isolation locations and residential areas for no less than 14 days. Due to the fact that respiratory droplets generated from infected cases among close-contacts may land on the surface where the virus could remain viable, for instance garbage (Kampf et al., 2020, van Doremalen et al., 2020). MSWs collected from isolated sites and areas (named as infectious MSWs) were also considered as potential infectious vectors of the coronavirus and disposed as HCWs during the pandemic period. In summary, HCWs were composed by aforementioned three components, infectious HCWs (IHCWs), routine HCWs (RHCWs) and infectious MSWs (IMSWs). The strict and elaborate classification of HCWs favored the cutting off of transmitting routes of the coronavirus.
2.2.3. Data on production of HCWs

The data of daily production of total HCWs from hospitals (THCWs) and that of RHCWs were collected from Hubei Solid Waste and Chemical Pollution Prevention Center. The production of IHCWs was calculated by Eq. 1.

\[ W_{IHCWs} = \frac{W_{THCWs}}{C_0 W_{RHCWs}} \]  

Where \( W_{IHCWs} \), \( W_{THCWs} \) and \( W_{RHCWs} \) represent the production of IHCWs, THCWs and RHCWs respectively.

2.3. Development of the model

2.3.1. Hypothesis of the model

This study employed a MLR model to obtain the production rates of IHCWs. Due to the versatility and well-founded theory, MLR models have been widely employed in various scientific fields including prediction of the production of HCWs. The hypothesis to employ the MLR in this case is based on the influences of independent variables (numbers of COVID-19 patients) on the dependent variables (the production of IHCWs). In other words, authors assumed that the daily production of IHCWs by one kind of patient was consistent during the pandemic period. Based on aforementioned assumption, MLR model was the most suitable one to forecast the production of IHCWs.

2.3.2. Selected indexes

The presence of correlations between the production of IHCWs and selected indexes were examined. Numbers of three categories of COVID-19 patients were chosen as the indexes:

1. Number of confirmed patients: existing number of confirmed patients of COVID-19.
2. Number of suspected patients: existing number of suspected patients of COVID-19.
3. Number of out-patients: existing number of out-patients of COVID-19.

2.3.3. Correlation and regression modeling

All the above indices were investigated using correlation and regression analysis. Firstly, the statistically significant (at p less than 0.01) linear Pearson (r) correlation coefficients between all indices were calculated. Then, a multiple linear regression (MLR) model was developed with the production of IHCWs being the dependent variable and all aforementioned variables being the independent variables. The goal was to reach a MLR model that would adequately describe the production of IHCWs and determine production rates by patients. In this process, the full most complex model was firstly fitted to the data, and statistically insignificant terms (at \( a = 0.05 \)) were sequentially removed until a model with only statistically significant terms would result (Minoglou and Komilis, 2018). During the process, the auto-correlation among the independent variables was checked and auto-correlated terms were removed too. The full MLR model has the following generic form (Eq. 2).

\[ M_{IHCWs} = a_1 \times CP + a_2 \times SP + a_3 \times OP + e \]  

Where CP, SP and OP represent number of confirmed, suspected and out patients. Production of IHCWs (\( M_{IHCWs} \)) is a dependent variable describing the predicted generation of IHCWs, \( a_1 . . 3 \) are...
coefficients of the 3 independent variables (predictors), describing the predicted production rates of IHCWs per confirmed patient \((a_1)\), suspected patient \((a_2)\) or out-patient \((a_3)\) respectively; \(e\) is the residual of the model describing constant production of IHCWs which was generated in daily and necessary medical services to control the epidemic. All aforementioned efforts were conducted on the IBM SPSS 19.0.

3. Result and discussion

3.1. Production of HCWs

Before development of the model, the production of HCWs including RHCWs and THCWs were analyzed. The data on consumption of medical resources were provided for the deeper understanding of the curves on the production of HCWs.

3.1.1. Production of RHCWs

The production of RHCWs is demonstrated in Fig. 3A. The curve can be divided into two stages. At the first stage, the production of RHCWs increased drastically from 3.74 (21 February 2020) to 58.13 tons (12 March 2020). Along with that, the number of COVID-19 patients decreased dramatically (Fig. 1), for instance, the number of confirmed patients dropped from 36,680 (21 February 2020) to 12,358 (12 March 2020). In addition, only 44 suspected patients were reported at 12 March 2020 and the number decreased to zero at 17 March 2020. Notably, community screening of COVID-19 was completed at 8 March 2020, and all Fangcang shelter hospitals were closed at 10 March 2020 in Wuhan (Hao et al., 2020). All aforementioned data suggested mitigation of the spread of COVID-19 at 12 March 2020 in Wuhan. Based on aforementioned facts, we believed that the increase of the RHCWs production in this stage should be attributed to two reasons.

Firstly, at early time during the pandemic period, most medical resources were supplied to mitigate the pandemic. For instance, the number of designated hospitals for COVID-19 increased from 23 (1 February 2020) to 52 (28 February 2020) (Fig. 3B). In addition, the number of accessible medical beds in designated hospitals increased from 6808 (1 February 2020) to 25,341 (29 February 2020), and that of used medical beds increased from 6754 (1 February 2020) to 19,425 (25 February 2020) (Fig. 3C). As the epidemic abated, more medical resources were unoccupied, which could be supplied for patients suffering other ailments than COVID-19. For instance, numbers of designated hospitals, accessible and used medical beds in designated hospitals decreased to 35, 14,308 and 9121 at 12 March 2020, respectively (Fig. 3B,C). While, the consumption of medical resources for patients suffering other diseases than COVID-19 increased obviously following the abatement of the pandemic. For instance, the number of undesignated hospitals increased from 40 (18 March 2020) to 69 (24 April 2020) (Fig. 3B). In addition, the number of accessible medical beds in undesignated hospitals increased from 15,767 (18 March 2020) to 42,703 (24 April 2020), and that of used medical beds increased from 8858 (18 March 2020) to 27,793 (24 April 2020) (Fig. 3C). Secondly, inhabitants stayed at home uniformly due to the policy interventions including administrative orders of self-isolation and their fear to be infected by the coronavirus after their

![Fig. 3. The production of RHCWs (A), numbers of designated and undesignated hospitals (B), numbers of medical beds in designated (C) and undesignated (D) hospitals, the number of out-patients suffering other diseases than COVID-19 and the production of THCWs during the pandemic period in Wuhan, China.](image-url)
information-seeking on COVID-19 (Bento et al., 2020). For instance, Zhao et al., reported an investigation on the mental health among self-isolating citizens, suggesting that 11.4% and 29.7% of them felt anxiety and depression respectively (Zhao et al., 2020). Most patients with diseases other than COVID-19 stayed at home with self-protection and domiciliary medical measures, or chose to get medical services on website. For instance, the total number of online consultations for medical services exceeded 4.26 million from 22 January 2020 to 25 February 2020 in China, which increased by 278% compared with that of the last month (Sun et al., 2020). Due to flexible policies on self-isolation, data of abated epidemic and also good news such as closing of Fangcang shelter hospitals, more and more patients suffering other diseases than COVID-19 chose to go to hospital for medical services. For instance, the number of out-patients suffering other diseases than COVID-19 increases dramatically from 16,831 (18 March 2020) to 85,039 (24 April 2020) (Fig. 3E). The production of RHCWs reached 58.13 kg/d, nearly 20% higher than average production before the outbreak of COVID-19 (50 tons/d, Fig. 3A), which should be attributed to the release of stocked patients suffering other diseases at early time of this stage.

Then, the production of RHCWs fluctuated in the range of 35–50 tons/d at the second stage from 13 March 2020 to 24 April 2020, suggesting that RHCWs production regained to the routine value before outbreak of COVID-19 (50 tons/d) (Yang et al., 2021). The number of confirmed patients in Wuhan decreased to 0 at 26 April 2020, suggesting that regain of RHCWs generation occurred 45 days before completed clearing of COVID-19 infected patients in the case of Wuhan.

The aforementioned results suggested that at early time of respiratory coronavirus pandemic, RHCWs production decreased to a very low level (3.78 ton/d, lower than 10% of the routine production in the case of Wuhan). As the epidemic abated, the production of RHCWs bounced into the range of the routine production before epidemic (35–50 tons/d). The increase of RHCWs production occurred earlier (45 days earlier in the case of Wuhan) than the complete clearing of COVID-19 infected patients did.

3.1.2. Production of THCWs

Fig. 3F depicted the production of THCWs during the studied period. Opposite to the case of RHCWs, the production of THCWs decreased along with the clearing of infected patients from 143.00 tons (21 February 2020) to 93.42 tons (8 March 2020), then rebounded to 111.48 tons at 12 March 2020. Considering that the production of IHCWs was proportional to numbers of patients (vide infra in Eq. 3), it can be found that the rebounding was attributed to the dramatic increase of the RHCWs production (from 3.74 to 58.13 tons) during the period before 12 March 2020 (Fig. 3A). Since 13 March 2020, the production of THCWs further decreased from 107.42 tons (13 March 2020) to 64.66 tons (24 April 2020) which is closed to the routine production before the epidemic (50 tons). Aforementioned data clearly showed us the influences of COVID-19 pandemic on the production of HCWs in Wuhan. The production reached the highest level of three-fold of the routine value, and decreased into the routine value at nearly the same time of complete clearing of confirmed cases of COVID-19.

3.2. Correlation and regression analysis of the production of IHCWs

The linear matrix of Pearson (r) correlations between each two of indices is shown in Table 1. All correlation coefficients were statistically significant at a significance level a = 0.01 with r value higher than 0.8 (Ma et al., 2020b). The correlation coefficients between the production of IHCWs and numbers of COVID-19 patients including CP, SP and OP were 0.998, 0.822 and 0.961, respectively. The result suggests good linear relationships between

| Variables | IHCWs | CP | SP | OP |
|-----------|-------|----|----|----|
| IHCWs     | 1     | 0.998 | 0.822 | 0.961 |
| CP        |       | 1   | 0.812 | 1   |
| SP        |       |     | 0.964 | 0.876 |
| OP        |       |     |       | 1   |

the production of IHCWs and each number of three kinds of COVID-19 patients. The satisfactory linear relationships once again prove the MLR model suitable to describe the production of IHCWs. The correlation coefficient between CP and SP, CP and OP, SP and OP was calculated as 0.812, 0.964 and 0.876, respectively. Correlations between each other of the number of confirmed patients, suspected patients and out-patients were attributed to the high transmission of COVID-19 that most confirmed patients were transmitted from suspected patients, and they were all transmitted from out-patients (McMichael et al., 2020).

3.3. Fitting results of the MLR model

The linear relationship between the production of IHCWs and the number of COVID-19 patients was further studied by unary linear regression. As Fig. 4A-C demonstrated, the number of confirmed patients fitted best with the production of IHCWs, with a correlation coefficient (R²) of 0.975, followed by the number of out-patients (R² = 0.874) and that of suspected patients (R² = 0.593). The aforementioned result suggested the highly significant linear relationship between the number of confirmed patients and the production of IHCWs, which should be attributed to two reasons. Firstly, due to the severe acute and long cure period of confirmed patients, they generally consumed more medical resources than suspected or out ones, thus generated more IHCWs during their medical-care periods (Cummings et al., 2020). The aforementioned fact has been qualitatively proved by our MLR model that much larger daily production of IHCWs was produced by confirmed patients than that by other patients (vide infra in Eq. 3). Secondly, the number of confirmed patients (23 ~ 36680) is much larger than those of suspected patients (0 ~ 3414) and out-patients (204 ~ 3743). Especially, the number of suspected patients dropped to zero at 17 March 2020, suggesting that no IHCWs was generated in the medical service of suspected cases. Aforementioned data suggested that most IHCWs was generated from confirmed patients, which was one of the reasons leading to a more significantly linear correlation between number of confirmed patients and production of HCWs than those in the cases of other patients. Besides, the dispersion of the number of confirmed patients was more significant than those of suspected and out ones, which also contributed to the higher significance of the linear correlation between the production of IHCWs and the number of confirmed patients.

In addition, there is also a significant linear correlation between the production of IHCWs and the number of out-patients (R² = 0.874). This is attributed to the fact that at the end of the studied period (after 21 April 2020), the number of confirmed patients decreased to a very low level (100), while the number of out-patients maintained in a range of 200 ~ 400 (Fig. 1). At this stage, the production of IHCWs from out-patients (calculated as 0.02 ~ 0.04 tons by our MLR model) was similar to that from confirmed patients (calculated as 0 ~ 0.3 tons by our MLR model). Aforementioned facts suggested that a significant portion of IHCWs was generated from out-patients, which was the reason of the good significance of the linear correlation.

The linear correlation between the production of IHCWs and the number of suspected patients is not that significant with a
correlation coefficient of 0.593, which should be attributed to that the number of suspected patients is zero in 39 of the total 64 samples, where only confirmed and out patients contributed to the production of IHCWs. After 39 invalid samples (in which number of suspected patients dropped to zero) were abandoned, the correlation between the production of IHCWs and the number of suspected patients became more significant as that the correlation coefficient increased from 0.593 to 0.799 (Fig. 4D), suggesting a good linear relationship between the production of IHCWs and the number of suspected patients.

Aforementioned unary linear regression results once again suggested the significant linear correlation between IHCW generation and the three chosen indexes respectively. And the significance of linear correlation was in an order of confirmed patients > out-patients > suspected patients. The significant linear correlation once again suggested that MLR model is suitable for the prediction of the production of IHCWs during the pandemic period in Wuhan.

Based on aforementioned results, the MLR model was built as Eq. 3 and ANOVA results are depicted in Table 2. The fitting result is demonstrated in Fig. 5. The high F value (829.372) and $R^2$ (0.933), coupled with highly coincident curves of actual and predicted productions of IHCWs, suggested the satisfactory regression of this model.

$$M_{\text{IHCW}} = 0.0032 \times CP + 0.0018 \times SP + 0.0001 \times OP + 13.0000, \ R^2 = 0.933 \ (3)$$

The model directly determines production rates of IHCWs from confirmed, suspected and out-patients as 3.2, 1.8 and 0.1 kg/patient. In addition, the routine production of IHCWs was demonstrated as 13 tons/d. The previously reported production rates of RHCWs were listed in Table 3. For instance, Gao et al. suggested the production of HCWs in rural regions in China as 0.15 kg/patient (Gao et al., 2018) and Xin reported that in urban areas around 0.8 kg/bed (Xin 2015). IHCWs production rates of confirmed and suspected cases of COVID-19 are four-fold and two-fold of the production rate of HCWs in urban China respectively. The much higher production rate of HCWs per patient was attributed to more complex medical services for COVID-19 patients than those for patients with other diseases than COVID-19 such as emergency medical

![Fig. 4. Linear correlation between CP (A), SP (B), OP (C) or SP (39 invalid samples abandoned) (D) with the production of IHCWs.](image)

![Fig. 5. Fitting results of the MLR model.](image)

| Table 2 | ANOVA table for the MLR model of the IHCW. |
|---------|------------------------------------------|
|         | DF | Adj. SS   | Adj. MS | F-value | p-value |
| Regression | 3  | 9254.3    | 3834.77 | 829.372 | 0.001   |
| Error    | 60 | 223.4573  | 3.724288|         |         |
| Total    | 63 | 9727.76   |         |         |         |
services (Yang et al., 2020) and much more medical resources consumed (Yu et al., 2020). Aforementioned results once again suggested much higher production rates of IHCWs from infected or suspected patients during COVID-19 pandemic.

### 3.4. Limitation of the MLR model

Two aspects of limitation of the model were provided as follow:

1. The model did not consider the variation of production rates under different stages of the pandemic period. HCWs production rates might vary during the course of COVID-19 pandemic. On one hand, as doctors and healthcare workers increased their understanding of COVID-19, they got better at treating it and were thus theoretically less wasteful. On the other hand, due to deeper understanding of COVID-19, more complex therapeutic protocols were proposed, along with more production of HCWs. Considering that it is very hard to divide pandemic period into different stages, thus, aforementioned variations were not considered in this case. In the further application of the model achieved, researchers need to check the coefficients of the model by practical production data of IHCWs, to ensure that the model was keeping up with the newly emerging situations.

2. The model did not consider differences among nations who were/are in fight with COVID-19. Firstly, the definition of the patients is not totally the same in different nations/regions. Thus, the differences on the definition of the patients should be considered when someone employ the model for the prediction of IHCWs production. Then, therapeutic protocols for the patients were also distinguished among the nations. Therapeutic protocols were dependent on several factors including medical technology, economic levels and even recent pandemic development. For instance, the production of medical wastes in the eastern region of China was higher than that in the west under the influence of higher population and GDP (Wei et al., 2020). Hence, more efforts to demonstrate the influences of therapeutic protocols on IHCWs production should be paid before application of the model.

### 4. Conclusions

This is the first study on the MLR model to predict the production of IHCWs by the number of COVID-19 patients. The production rates of confirmed, suspected and out patients were calculated as 3.2, 1.8 and 0.1 kg/patient. IHCWs production rates of confirmed and suspected cases of COVID-19 are four-fold and two-fold of the production rate of routine HCWs in urban China respectively. The routine production of IHCWs was 13 tons/d.

Economically-efficient arrangement of collection, transportation and disposal facilities for IHCWs generated during COVID-19 pandemic is one of key works to fight against COVID-19. To achieve aforementioned task, a model to predict the production of IHCWs is highly desired. The MLR model and the production rates of IHCWs by confirmed, suspected and out patients paves an accurate quantitation approach to arrange facilities for collection, transportation and disposal of infectious HCWs. While, efforts should be paid to demonstrate the influences of knowledge of COVID-19 and therapeutic protocols on IHCWs production before application of the model.

The primary data on the production of routine HCWs and IHCWs along with the abatement of the pandemic in Wuhan also provide a novel and in-deep understanding on the generation of HCWs during coronavirus pandemics. Aforementioned prediction approach and novel understandings have implications to minimize the hazard impacts of IHCWs including transmitting the coronavirus and environmental pollution.

### 5. Associated content

No associated content of this study was attached.

### 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.

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