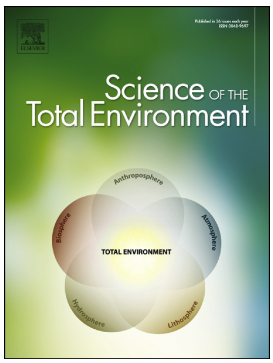

Real-time estimation and prediction of mortality caused by COVID-19 with patient information based algorithm

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Real-time Estimation and Prediction of Mortality Caused by COVID-19 with Patient Information Based Algorithm

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Key Words: Coronavirus; COVID-19; Death Rate; Inpatient; Normal distribution; Prediction

Running title: PIBA for Estimation of COVID-19 Mortality Rate

Abstract

The global COVID-19 outbreak is worrisome both for its high rate of spread, and the high case fatality rate reported by early studies and now in Italy. We report a new methodology, the Patient Information Based Algorithm (PIBA), for estimating the death rate of a disease in real-time using publicly available data collected during an outbreak. PIBA estimated the death rate based on data of the patients in Wuhan and then in other cities throughout China. The estimated days from hospital admission to death was 13 (standard deviation (SD), 6 days). The death rates based on PIBA were used to predict the daily numbers of deaths since the week of February 25, 2020, in China overall, Hubei province, Wuhan city, and the rest of the country except Hubei province. The death rate of COVID-19 ranges from 0.75% to 3% and may decrease in the future. The results showed that the real death numbers had fallen into the predicted ranges. In addition, using the preliminary data from China, the PIBA method was successfully used to estimate the death rate and predict the death numbers of the Korean population. In conclusion, PIBA can be used to efficiently estimate the death rate of a new infectious disease in real-time and to predict future deaths. The spread of 2019-nCoV and its case fatality rate may vary in regions with different climates and temperatures from Hubei and Wuhan. PIBA model can be built based on known information of early patients in different countries.

1. Introduction

The mortality rate is the most important factor that determines whether a highly infectious disease becomes a public concern and carries risks causing a pandemic. Different virus epidemics take place throughout the world every year, but only a few rise to the level of public concern (Schlagenhauf and Ashraf, 2003; Viboud and Simonsen, 2012; WHO Ebola Response Team, 2014). Severe acute respiratory syndrome (SARS), swine influenza A H1N1 virus (H1N1), and Zaire ebolavirus (Ebola) brought on the public's attention because they caused many severe infections and thousands of deaths (Dawood et al., 2012; Nicholls et al., 2003; WHO Ebola Response Team, 2014;). Similarly, the disease COVID-19 caused by a coronavirus (2019-nCoV) brought world-wide attention and caused public panic because many deaths had been reported without being put in the context of the many mild infections and its potentially low case fatality rate (Chan et al., 2020; Huang et al., 2020; Wang et al., 2020; Wu et al., 2020). For example, despite being a common infection, influenza rarely causes public concern because even though it is common, it leads to death in only 0.1% of cases. A variety of reports indicate that 2019-nCoV is highly infectious through multiple routes (Chen et al., 2020; Huang et al., 2020; Wu et al., 2020). While the high infection rate is certain, the mortality rate of COVID-19 has not been definitively determined. It is reasonable to suspect that the deaths of six of the first 41 patients (15%) in Wuhan (Huang et al., 2020) in the earliest reports by Chinese scholars were inaccurate. When the initial mortality rates were reported, only patients who were critically ill were included. Patients with mild symptoms, as well as those with asymptomatic infections, were not analyzed (Chen et al., 2020; Huang et al., 2020; Wu et al., 2020). Case-fatality rates reported by Huang et al. (2020) analyzed a skewed patient sample since it included only a small number of patients who had been transferred from other hospitals due to their critical condition.

Therefore Huang et al.'s sample was skewed towards a concentration of severely ill patients, while the general patient population includes more patients with COVID-19 who are asymptomatic or only have mild symptoms and who have not been hospitalized. Chen et al. (2020) reported an 11% death rate, again based on patients with severe conditions.

We have estimated the mortality rate using a Patient Information Based Algorithm (PIBA). The PIBA uses patient data in real-time to build a model that estimates and predicts death rates for the near future. PIBA uses data of patients identified early in the disease process to calculate the average number of days from hospitalization to death for those hospitalized. Another feature is to take into account variations based on mathematical models. The PIBA calculation method does not divide the total number of patients on a day by the number of deaths on the same day. Instead, the PIBA calculation method divides the number of deaths on that day by the number of possible patients of a day or days when the patients have just begun to develop the disease.

Classic death rate calculation method:

$$\text{Death rate} = \frac{\text{Total Number of deaths from the disease}}{\text{Total Number of infected patients}}$$

PIBA method:

$$\text{Death rate} = \frac{\text{Number of deaths (in a given day)}}{\text{Average number of patients in previous days determined by the algorithm}}$$

Thus, PIBA comprehensively and reasonably estimates the mortality rate based on the actual number of deaths and estimates the number of patients on a specific day. As time goes on, large amounts of data from northern and southern China have been accumulated through continuous reporting, all of which are used by PIBA, which then becomes more accurate as data

accumulates. We conclude that it is time to utilize the accumulated data to estimate the case fatality rate of COVID-19 infection. Based on national data from the China National Health Center, the COVID-19 death rate is much lower than that reported in Huang et al. (2020). Holistic data covering all of Wuhan, the epicenter city of COVID-19, also indicates a death rate lower than that reported by Huang et al. These data sources cover a larger patient sample, and include patients displaying symptoms with varying levels of severity. Therefore, the updated estimation of the death rate should reference these larger scale and more representative data.

Our study contributes to knowledge on COVID-19 death rate by building on Huang et al.'s (2020) estimation and available data from official websites and addressing the limitations with a larger and more representative sample.

2. Methodological approach

2.1. Steps for estimating and predicting mortality using PIBA.

1) To collect data from the patient's initial admission to death. Strive to collect data for a certain number of patients.

2) To calculate the average number of days (μ) from hospital admission to the death and the number of days between one standard deviation ($\mu \pm \sigma$) interval and two standard deviations ($\mu \pm 2\sigma$).

3) To use these parameters (μ, $\mu \pm \sigma$, $\mu \pm 2\sigma$) to calculate the daily mortality during the epidemic.

4) To predict the mortality of infectious diseases in the future based on the calculated known mortality combined with the number of patients in a region. The predicted numbers are compared with real mortality to test and correct model data.

5) To conduct following-up modification of the PIBA model according to different nationalities and regions. In particular, the initial patient data collected may vary significantly from country to country, one ethnic group to the other, and region to region.

2.2. Estimation of the number of days between hospitalization and death using PIBA.

The calculation based on the number of deaths and the number of patients on the same day does not reflect the real death rate because most patients with COVID-19 do not die on the same day that they entered the hospital (Chan et al., 2020; Huang et al., 2020; Wang et al., 2020). With the PIBA method, we recognize that the patient population size was inaccurate in the early days but trust the published information of patients who died right after COVID-19 outbreaks. The estimation is built upon data from patients with a normal distribution model.

Based on information about patients in Wuhan who died during the period between Dec 16, 2019, to Jan 2, 2020 (Huang et al., 2020), two parameters were used to estimate days from onset of symptoms to death and days from admission to the intensive care unit (ICU) to death. These two parameters are adopted in the estimation and prediction of COVID-19 death rate. Each parameter has five values including the mean, μ, one standard deviation from the mean, $\mu \pm \sigma$, and two standard deviations from the mean, $\mu \pm 2\sigma$.

2.3. Data collection of patient information.

We collected data from COVID-19 patients in China from three public websites. The data from the whole country are collected and made available on the official website of the Health Emergency Office of the National Health Commission of the People's Republic of China at http://www.nhc.gov.cn/yjb/new_index.shtml. The data from Hubei Province and Wuhan are from the Health Commission of Hubei Province at http://wjw.hubei.gov.cn/fbjd/dtyw/. These data include the number of patients with COVID-19 who were confirmed as having the disease,

who died from the disease, whose condition was severe, and who were admitted to the hospital or ICU. Other collected data included daily new cases, new deaths, people who were in close contact with an infection source, and accumulated number of patients. We paid particular attention to data from Wuhan, plus two additional cities in Hubei Province, Xiaogan, and Huanggang, in which the number of patients was higher than in other cities in Hubei Province.

Information from a northern province, Heilongjiang Province, was collected from the official website of Outbreak Information of the Health Commission of Heilongjiang province at http://wsjkw.hlj.gov.cn/index.php/Home/Zwgk/all/typeid/42. Data of Heilongjiang Province and Harbin city were included because the province is located in the northern high-altitude zone. These data are used to assess whether the COVID-19 is more, less, or equally likely to spread to an area with a cold climate. Collected information included numbers of patients and numbers of deaths from each city and in the whole province.

For any missing data in any day, a formula was used to estimate the data in that day: $Ni = \{(N(i+j) + (N(i-j))/(j+1)\} + (N(i-j)$, where Ni = the estimated value of the missing data of the day i. j is the number of days of missing data, usually is 1; in the rare case, data of two consecutive days may be missing. If the data of two days are missing, the first day will be considered as the day i, the second day N(i+1) will be calculated as $N(i+1) = Ni + \{(N(i+j) + (N(i-j))/(j+1)\}$

2.4. PIBA formula building for death rate estimation.

Based on the days between confirmation of COVID-19 and the days of death in the hospital, calculated from Wuhan, as mentioned in method 1 and information from the whole country and Hubei Province, we tested the number of days from diagnosis to death, that most likely reflects the actual death rate. The estimated days are used to estimate the death rate using

data from Hubei province and Wuhan city with the five values from above (μ, $\mu \pm \sigma$, $\mu \pm 2\sigma$). In consideration of the contribution of a variety of sources for the estimation, we fractured the data from (μ, $\mu \pm \sigma$ and $\mu \pm 2\sigma$ into the PIBA and built the testing model as follows.

1) $M_i = (D_i - D_{i-1})/(P_{i-n} - P_{i-n-1})$ (death rate at increments)
2) $M_i = D_i/P_{i-n}$ (death rate at accumulative numbers)

where M_i = mortality rate, D_i = the cumulative numbers of deaths on day i, P_i = the cumulative numbers of patients on day $_i$, $_i$ = the current day for calculating the death rate, n = the number of days from severe infection to death.

When we considered these five partial values in normal distribution as a good indicator with a width of one standard deviation, each one of the five death rates calculated above on each day would have its own weight as the possible normal distribution. (μ = 38.2%, $\mu - \sigma = \mu + \sigma$ = 24.2%, and $\mu + 2\sigma = \mu - 2\sigma$ = 6.7%)

From here, we could give the death rate for every single day just a single value that results from the weighted average of all five cohorts of patients, as defined by time from severe illness to death. The equation is as follows:

$$D = M\mu \times W\mu + M\mu\text{-}\sigma \times W\mu\text{–}\sigma + M\mu\text{+}\sigma \times W\mu\text{+}\sigma + M\mu\text{+}2\sigma \times W\mu\text{+}2\sigma + M\mu\text{-}2\sigma \times W\mu\text{-}2\sigma$$

Where D = death rate, $M\mu$ = mortality rate with μ days, $W\mu$ = weight with μ days gap, μ = Mean in normal distribution, σ = Standard deviation.

2.5. Confirmation of the best estimation of the days to calculate the death rate in the other cities.

The same formula was then used to estimate the death rate from the other two cities in Hubei province, namely Xiaogan and Huanggang. The PIBA model was developed using data from Hubei province, including Wuhan, Xiaogan, and Huanggang, and was further validated using

data from Heilongjiang province and Harbin city. PIBA was then used to predict trends in new number of deaths.

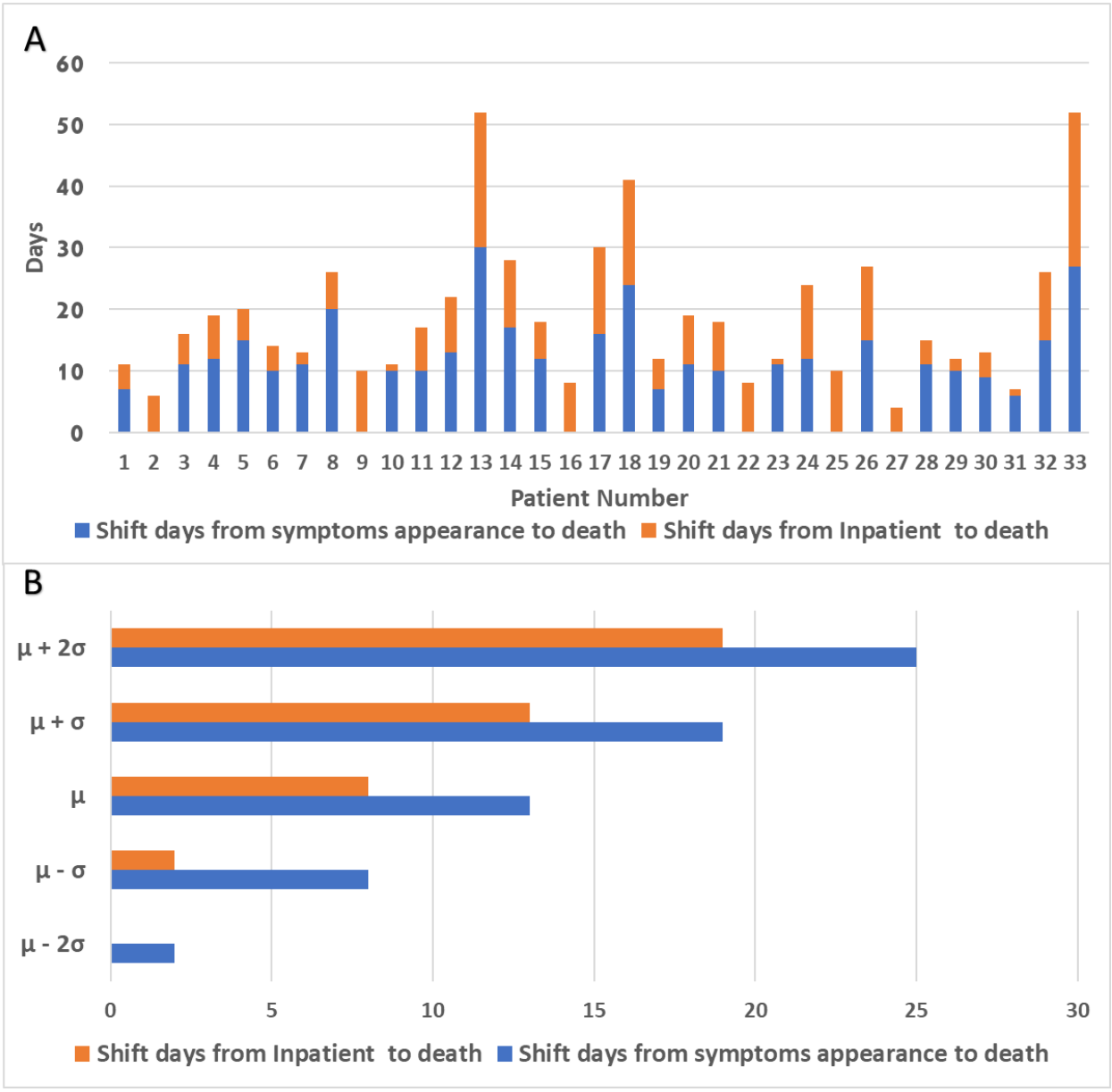
2.6. Prediction of the number of deaths per day in the coming weeks using PIBA

In order to further test the validity of our PIBA method in predicting actual mortality, we used a combination of the curve trend data and the overall mortality rate of the country, Hubei, Wuhan, and the rest of the country (China overall except Hubei). Based on our prediction of the days from actual hospitalization to death, we separately predicted the number of deaths in each day of the coming week. That is, from the comprehensive information of the number of new patients on the seventh day, the 13th day, and the 19th day before the targeted prediction day, we obtained three numbers of deaths for each of the predicted days. Then from three of these numbers, the lower and upper values of the number of deaths on that day are used as the minimum and the maximum number of predicted deaths on that day, respectively. Also, the same formula was used to predict the death number of a week in South Korea.

3. Results

3.1. Estimated days from diagnosis to death and from ICU intake to death

Using information published by Wuhan, we calculated the days between ICU admission and death. We obtained the actual data from 33 patients who died in the hospital in Wuhan. The days from onset of symptoms to deaths ranged from 6 to 30 (see Fig. 1A). From ICU intake to death, the shortest number is one day, and the longest is 22 days. We derived two parameters, each from the 33 death cases, i.e., the days from onset of symptoms to death and the days from inpatient admission to death. Since there are six patients out of these 33 death cases who have the same date of symptoms' appearance and inpatient, there were 33 values in the dataset related to inpatient and 27 values in another dataset related to symptoms' appearance (Fig. 1A).


A
60
50
40
30
20
10
0
Days
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Patient Number
Shift days from symptoms appearance to death
Shift days from Inpatient to death
B
μ + 2σ
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5
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Shift days from Inpatient to death
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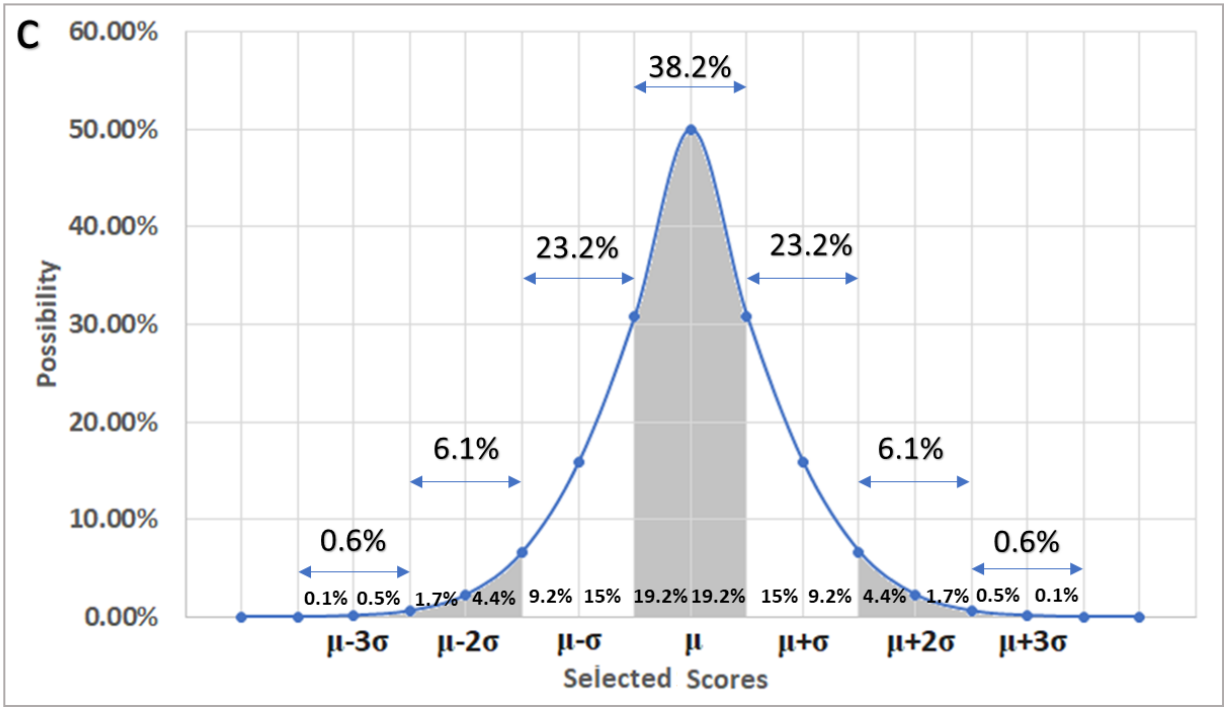

Fig. 1. Duration distribution of 33 death cases in Wuhan. 1A. Distribution of days between disease symptoms and death and between time of ICU admission and death. Vertical axis: days, Horizontal axis: cases. 1B. Estimated days from first symptoms to death and days from ICU admission to death. 1C. Lagging days (days from first symptoms to the day of death), μ, μ ± σ and μ ± 2σ and their weight (in percentages) used for the estimation of death rate in the broader patient population. Note: Among these values above, the lagging day μ - 2σ from symptom confirmation to death in Figure 1B that equals to -3 has been set to 0.

The results indicated that the average time from onset of the symptoms to death is 13 days (M = 13, $S.D.$ = 6) (see Fig. 1B). Accordingly, the lagging days from the day of death and their weight in the calculation of death rate were derived based on the new inpatient days (Fig. 1C). The prediction of death rate is based on data from Wuhan city in which patients diagnosed with COVID-19 had been confirmed since January 19, 2020 and where deaths had occurred, which were among the first confirmed cases of coronavirus.

3.2. Estimated death rate for the whole country and Hubei province using PIBA formula.

According to our five estimation parameters, from illness (i.e., symptom appearance) to death, the maximum number of days is 25 days. The earliest reported data in Wuhan was published on January 19, 2020. Based on these data, we were able to calculate the mortality rate from February 8, 2020, to the present. However, on February 12, the National Health Committee revised the data again (see Appendix Table 1). Because of this amendment, the number of confirmed cases appeared to have changed significantly in only one day. We chose the calculation results from February 14 up to February 25 (Appendix Table 2), considering that the death rates on February 12 and February 13 are likely distorted by this sharp rise within a short term. Figures 2A through 2D provide information about the overall death rates in mainland China (hereafter referred to as country), Hubei, Wuhan, and rest of country (excluding Hubei) (Appendix Table 3).

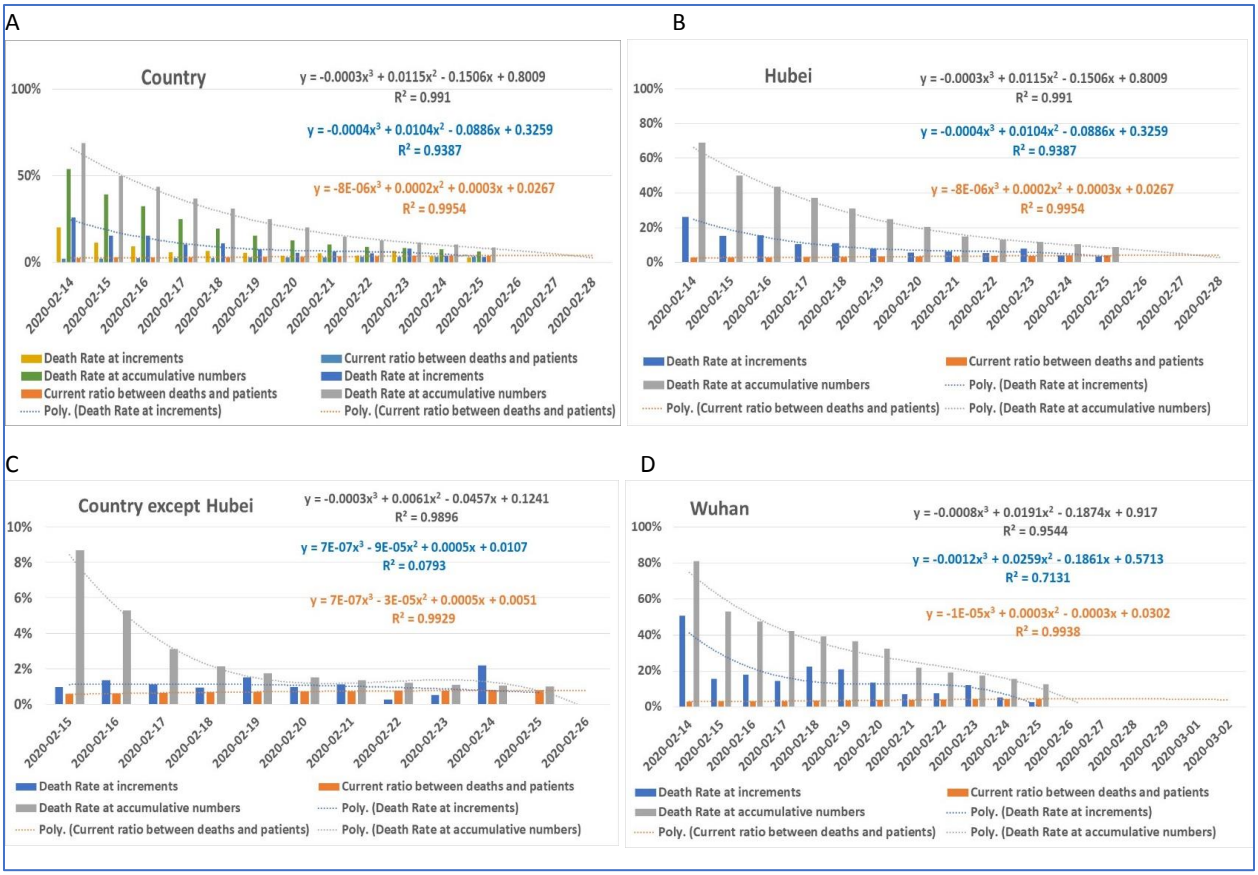

Fig. 2. The estimated death rate in Mainland China and Hubei Province. The blue curve represents the mortality calculated by the actual increase in deaths per lagging day divided by the increase in actual patients on the previous corresponding day. The gray curve represents the total number of deaths per lagging day, divided by the total number of identified actual patients on the corresponding previous day. The orange curve shows the number of deaths per day divided by the total number of patients the same day. The number on the vertical bar represent the death rate; the number on the horizontal bar shows the date. Fig. 2A: Overall death rate in Mainland China. Fig. 2B: Death rate in Hubei province. Fig. 2C. The death rate in the rest of the country except Hubei province. Fig. 2D: Death rate in Wuhan city.

We noticed that the death rate at increments based on PIBA in the whole country (in blue) in Fig. 2A is below 10%, with most values between 2.7% and 6% in the last five days. The death rate in Hubei province is similar to that of the whole country because 90% of the patients in the whole country were from Hubei province (see Appendix Table 1) (Fig. 2B). In Wuhan,

the accumulated death rate was still high, as much as 20% (Fig. 2D). When we used the data from the rest of the country to test our PIBA formula, as expected, the curve is different from the curves from Hubei and Wuhan. Unlike in Hubei and Wuhan, the death rate of the rest of the country is much lower and stable, mostly lower than 1% (Fig. 2C). The predicted death rate will remain between 1% and 2% for the near future.

3.3. Estimation of death rate in other cities in Hubei province and in Heilongjiang province.

Xiaogan and Huanggang are the two cities in Hubei province. The number of patients with COVID-19 in these two cities is higher than in other cities in Hubei except Wuhan. They also are the cities with the largest number of patients with COVID-19 in China. We, therefore, tested the PIBA formula using data from these two cities. Currently, the death rate based on the increment data is around 3%, lower than that in Wuhan but higher than that in the rest of the country. However, according to PIBA, the rate of deaths may decrease in the near future.

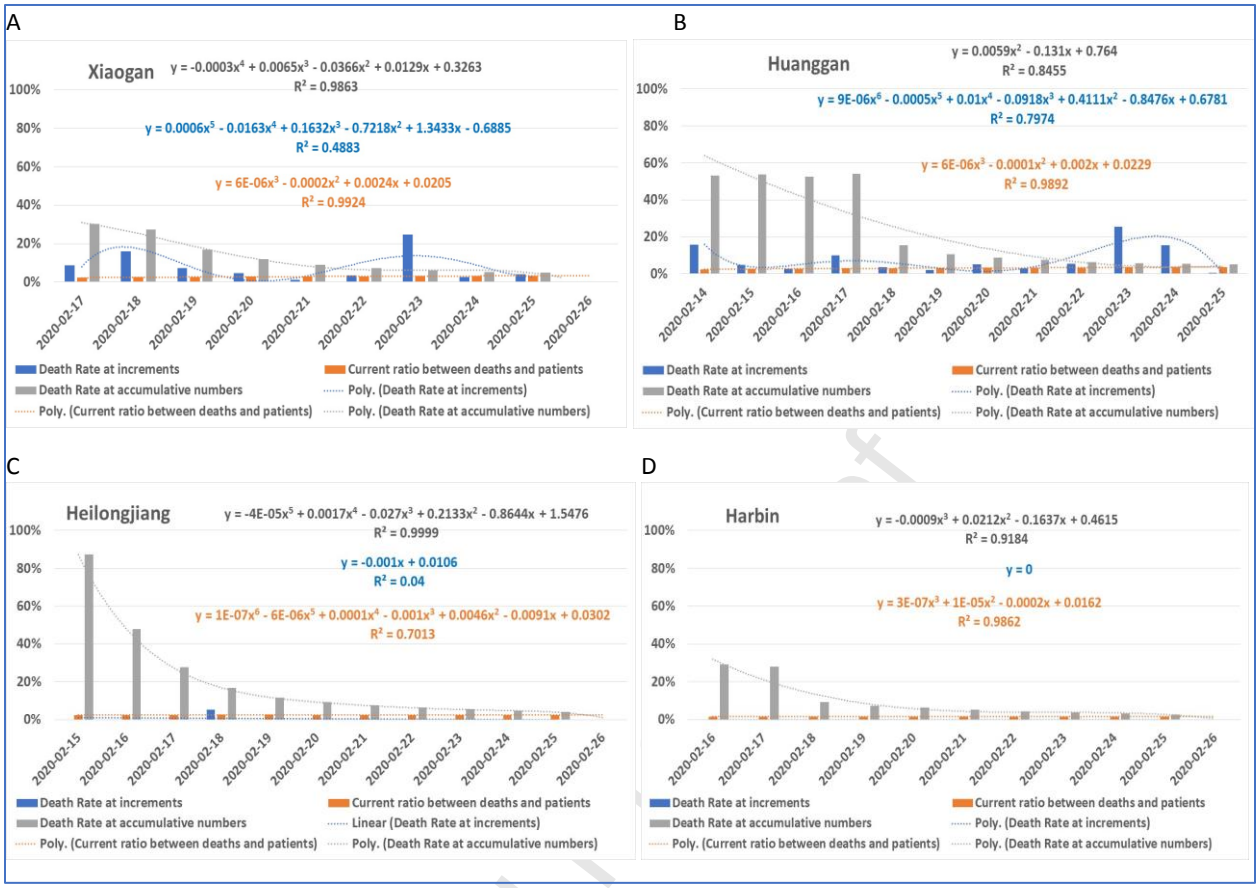

Fig. 3. Death rate estimations of four places. The blue curve represents the mortality calculated by the actual increase in deaths per lagging day divided by the increase in actual patients on the previous corresponding day. The gray curve represents the total number of deaths per lagging day, divided by the total number of identified actual patients on the corresponding previous day. The orange curve shows the number of deaths per day divided by the total number of patients the same day. Numbers on the vertical axis represent the death rate; on the horizontal axis is the date. Fig. 3A. The death rate of Xiaogan city in Hubei province Fig. 3B. Death rate of Huanggang city in Hubei province. Fig. 3C. The death rate in Heilongjiang province. Fig. 3D. The death rate in Harbin city.

Heilongjiang province, including its capital city, Harbin, is the province outside of Hubei with the largest number of diagnosed patients. Harbin city is located in the northeast of China and is in the coldest area in China. No patients from Harbin city or the Heilongjiang province were reported during the SARS epidemic period. We used the PIBA formula to estimate the death rate in both the Heilongjiang province (Fig. 3C) and Harbin city (Fig. 3D). The death rate

of Harbin decreased sharply in the past several days, into 0%. The low rate of less than 1% will possibly remain for the future.

3.4. Test the PIBA by predicting the daily death rate in the coming week.

Based on the PIBA and the death rate of accumulated numbers, the expected final death rate of the whole country, Hubei, Wuhan, and rest of the country except Hubei, is predicted as follows (see Table 1). The predicted values are from the intersection points between the incremental estimation and net values estimation.

Table 1. Prediction of death rate related to COVID-19

Prediction of death rate	intersect1	intersect2	Max.
Country	3.23%	3.28%	3.28%
Hubei	4.72%	5.00%	5.00%
Wuhan	5.20%	5.20%	5.20%
Rest of country	0.71%	0.78%	0.78%

We used the predicted death rate to calculate the potential number of deaths per day in the coming week. Because our initial estimation on the lagging days between inpatient and death was only based on 33 patients, we, therefore, used the days of average 13 days plus (19 days) and minus one standard deviation (7 days) as the range of number of deaths on a given day in the coming week (see Appendix Table 4. Predicted number of deaths in the days of the coming week after February 25, 2020). As shown in Fig. 4, the actual number of deaths in the past four days fell into the predicted range. In the country (Fig. 4A), Hubei (Fig. 4B), and Wuhan (Fig. 4C), the numbers of actual death were near the predicted minimum numbers. While, for the rest of the regions of the country except Hubei, the actual death data fluctuates between the predicted maximum and minimum values (Fig. 4C).

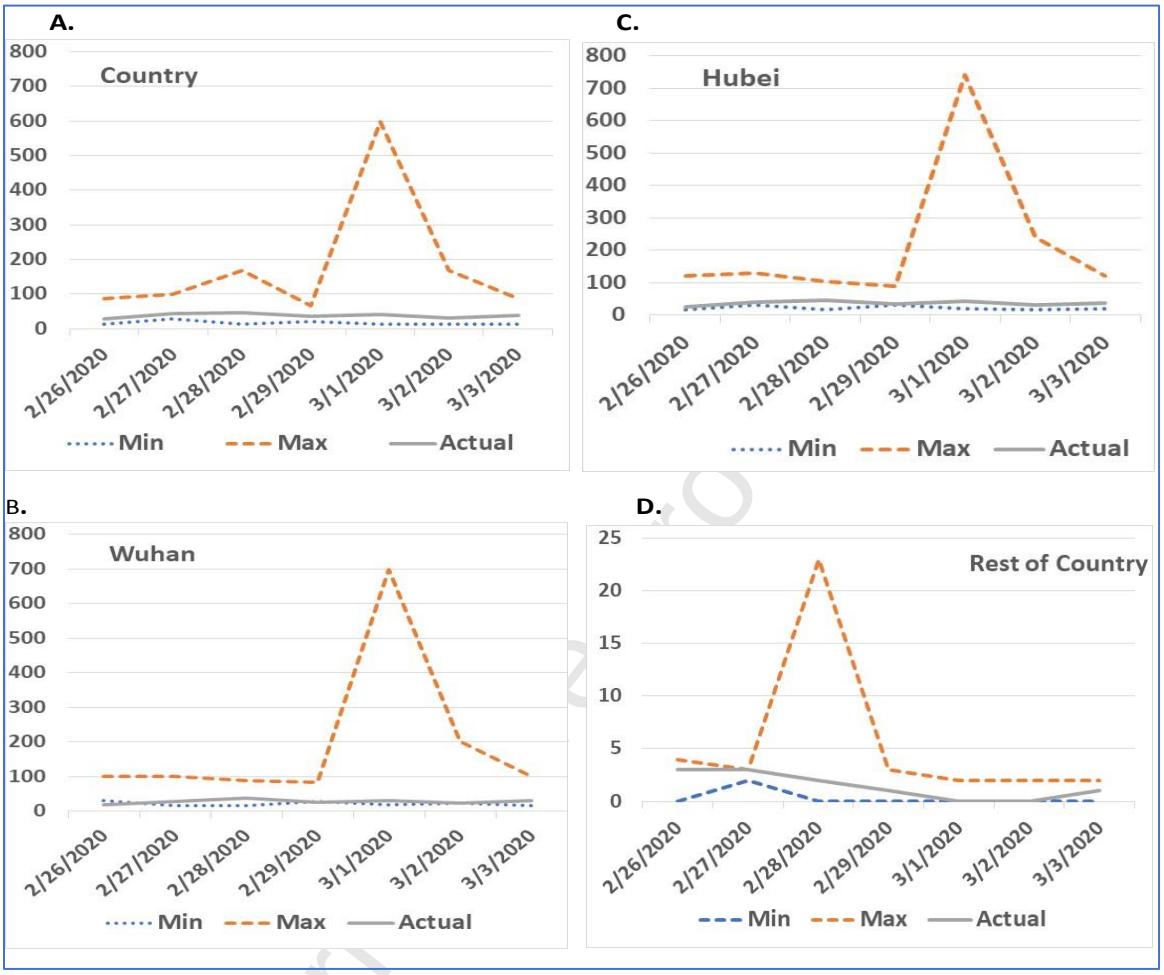

Fig. 4. Comparison between the predicted number of deaths based on PIBA and the actual number of deaths. The blue color represents the estimated minimum number of deaths line. The orange color represents the estimated maximum number of deaths line. The grey line represents the actual number of deaths. Fig. 4A, 4B, 4C, and 4D showed these death numbers in the country, Hubei, Wuhan and the rest of country except Hubei.

Due to the number of newly infected patients dropping in the last few days, the total number of patients tends to be constant or even less in the coming days if unexpected events do not occur. The peaks in these figures reflect sudden changes in numbers of patients (see Fig. 4). We believe that the intersecting point between the trendlines could reasonably be considered one of the rates in its range of the death rate of patients infected in the future.

3.5. Testing the PIBA using data from South Korea

As shown in the data above, the incidence in mainland China's provinces and cities was basically zero in late middle March. Because of this, we were not able to prove the feasibility of this method in more regions in mainland China. However, because the environment, medical conditions, and population races in different countries are different, to test the usefulness of the PIBA model in other countries, we need to get the basic information of the initial population. This information includes the specific number of days from onset to death of a reasonable number of patients in different regions of different countries. At present, we could not access these data accurately. The only thing we can do is to test Asian countries such as South Korea and Japan based on their ethnic similarities with populations in China. Taking all aspects into consideration, we believe that South Korea's data are more reliable. Therefore, we further tested our model using the affected population in South Korea. As shown in Fig. 5, the trend of deaths in South Korea in recent days is consistent with our prediction.

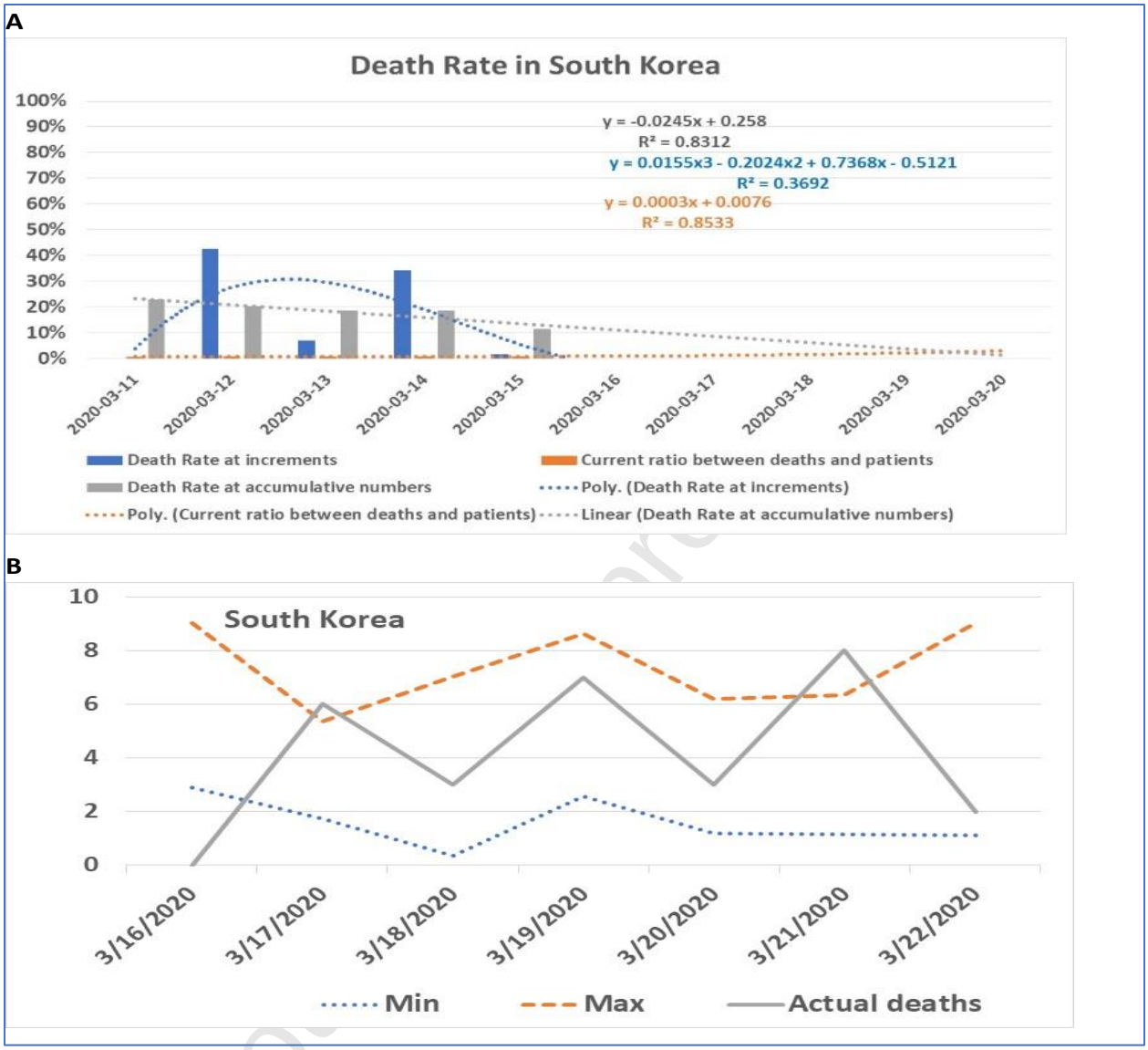

Fig. 5. Test PIBA model using COVID-19 population from South Korea. Fig.5A. Estimation of death rate in the Korean population using the PIBA method. The blue curve represents the mortality calculated by the actual increase in deaths per lagging day divided by the increase in actual patients on the previous corresponding day. The gray curve represents the total number of deaths per lagging day, divided by the total number of identified actual patients on the corresponding previous day. The orange curve shows the number of deaths per day divided by the total number of patients the same day. The number on the vertical bar represents the death rate, number on the horizontal bar shows the date. Fig. 5B. Comparison between the predicted number of deaths based on PIBA and the actual

number of deaths. The blue color represents the estimated minimum number of deaths line. The orange color represents the estimated maximum number of deaths line. The grey line represents the actual deaths.

4. Discussion

First, PIBA is capable of accurately estimating the disease mortality and the number of future deaths. This real-time accurate prediction and estimation of disease mortality provide the public, government, and society with more accurate disease information. Based on currently available data that includes patients with varying degrees of severity, the estimated prediction of the mortality rate of COVID-19 is less than 3%, and less than the prior prediction based on limited available data. This finding may ease public concern and panic. Updated scientific findings will be widely disseminated to broaden public awareness and contribute to helping fight COVID-19. The medical, clinical, and research community should strive to publish scientifically rigorous findings related to urgent public health issues. Publishing findings based on the availability of limited data contributes to unnecessary public concern and government action. In this particular case, the first report on the estimation of coronavirus death rate is an applaudable effort. However, it also had the limitations of a skewed dataset that focused on patients who were transferred from local hospitals because of their critical condition while excluding patients with less severe symptoms who remained at local hospitals. As soon as more data are available, we should provide updated reports and introduce improved estimation and prediction algorithms.

This study indicates that as the number of transmissions of 2019nCOV increases among the human population, its lethality will gradually decrease. Indeed, the reasons are not necessarily all because of their reduced toxicity. There may also be improvements in treatments and implementation of early detection methods. Therefore, a real-time estimate of death rate

using patient information such as the PIBA method would demonstrate an appreciation of the importance of public and societal awareness.

A critical issue to consider is that if the mortality rate of the COVID-19 in a certain area is relatively high, the COVID-19 in the area is still spreading and endemic. One of the most obvious questions is why the mortality rate in Wuhan is considerably higher than in other places. Based on our assessment, Wuhan's medical equipment and rescue measures are comparable with other areas in China, and the pathogenicity of the virus is similar. We conclude that there is a large proportion of patients in Wuhan who have mild illness and not been hospitalized at all. Due to the uncertainty of the movement of infected people in the early stages of the onset, these mildly ill people move around in Wuhan unidentified. This problem reminds other parts of the world that if the fatality rate of the COVID-19 is found to be high, a large number of infected people have not been able to be identified or diagnosed. Therefore, the work of controlling and isolating this infected group has not been completed, and the disease is still spreading and circulating in the area.

The data on Heilongjiang Province and Harbin show that, unlike some experts' predictions (cf. https://news.ifeng.com/c/7uHMHXcFHmq), it will occur more intensely in the high-altitude regions with a cold climate, and the mortality rate will be higher. With the development of the generations of 2019-nCoV, its toxicity will gradually weaken, and we expect that the mortality rate in the cold northern regions will not increase, nor will it exceed that in Wuhan or Hubei Province.

Our research has limitations, mainly due to available data. First, the estimation of number of patients from the date of hospital admission or ICU intake to the date of death is based on data from official public websites. Information from 33 individuals was estimated. If the information

had been available regarding more patients, the initial estimate would have been more accurate. The second aspect is the accuracy of the number of patients diagnosed and the number of hospitalizations per day. Due to the back and forth revision and correction of the data as announced by the official sources, we are not confident that all the data are error-free; however, we feel that these data as a whole are reliable. The third limitation of the PIBA method is that it depends on accurate patient information at the beginning of the epidemic. Depending on different situations from different countries or regions, this information may or may not be available, or the information may not be accurate.

5. Conclusion

The PIBA model accurately predicted a case fatality of 1.6% for symptomatic patients in China at a very early stage in the Covid-19 pandemic. The model can be generalized to predict case fatality for any infection (including asymptomat), to predict the rate of severe disease, and to predict the death rate for patients who develop severe disease. These early, accurate predictions inform the public, society, and governments to estimate the extent of the disease's harm and to develop suitable strategies.

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Author Contributions

Conceived and designed the experiments: LW, WG, CG, SW, DS, JJ. Performed data searching and collection: LW, JL, LY, TG, SG, NX, WG. Analyzed the data: JL NX, TG, LY, WG. Contributed analysis tools: JL, LY, WG, DS. Wrote the manuscript: LW, JL, SG, NX, YC, SH, SD, CG, LY, WG. Revise and approve and manuscript: All authors.

Competing interests

The authors declare no competing financial interests.

Human Subjects

All the data of patients in this study are from official public websites.

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Appendix Table 1. Disease information from different regions of China

Date*	3/3/2020	3/2/2020	3/1/2020	2/29/2020	2/28/2020	2/27/2020	2/26/2020	2/25/2020	2/24/2020
TOTAL/closely contacted	**666397**	**664899**	**663240**	**660716**	**658587**	**656054**	**652174**	**647406**	**641742**
Under observation	36432	40651	46219	51856	58233	65225	71572	79108	87902
Total accumulation	80270	80151	80026	79824	79251	78824	78497	78064	77658
Serious& ICU	6416	6806	7110	7365	7664	7952	8346	8752	9126
Accumulated deaths	2981	2943	2914	2870	2835	2788	2744	2715	2663
Dismiss accumulation	-	47204	44462	41625	39002	36117	32495	29745	27323
New cases	119	125	202	573	427	327	433	406	508
New deaths	38	31	42	35	47	44		52	71
HUBEI/accumulation	**67332**	**67217**	**67103**	**66907**	**66337**	**65914**	**65596**	**65187**	**64786**
Closely contacted	269379	268546	267585	265617	263916	262195	259491	255750	251265
Under observation	25290	28400	32143	35766	39303	65914	46326	49438	53474
Inpatient/current	25905	28216	26901	28912	31064	32878	39755	41660	43369
Serious	6232	6593	5646	5858	6056	6270	7984	8326	8675
ICU	-	-	1226	1249	1314	1363	-	-	-
Accumulated deaths	2871	2834	2803	2761	2727	2682	2461	2615	2563
Dismiss accumulation	38556	36167	33757	31187	28895	26403	23200	20912	18854
New cases	115	114	196	570	423	318	409	401	499
New deaths	37	31	42	34	45	41	26	52	68
WUHAN/ accumulation	**49540**	**49426**	**49315**	**49122**	**48557**	**48137**	**47824**	**47441**	**47071**
Serious/ICU	5723	6020					7049	7355	7647
Accumulated deaths	2282	2251	2227	2195	2169	2132	2104	2085	2043
Dismiss/ accumulation	24890	23031	21185	19227	17552	15826	13328	11793	10337
New cases	114	111	193	565	420	313	383	370	464
New deaths	31	24	32	26	37	28	19	42	56
XIAOGAN/ Accumulation	**3518**	**3518**	**3518**	**3518**	**3518**	**3517**	**3516**	**3501**	**3482**
New case	0	0	0	0	1	1	15	19	17
Accumulated deaths	120	120	120	118	115	114	113	113	110
New deaths	0	0	2	3	1	1		3	2
HUANGGANG/ accumulation	**2907**	**2907**	**2905**	**2905**	**2904**	**2904**	**2904**	**2904**	**2904**
New cases	0	2	0	0	0	0	0	0	0
Accumulated deaths	121	119	116	115	115	114	110	107	106
New deaths	2	3	1	0	1	4	3	1	3
HEILOINGJIANG/total	**480**	**480**	**480**	**480**	**480**	**480**	**480**	**480**	**480**
closely contacted	16224	16212	16212	16210	16208	16199	16188	16146	16126
Dismissed from observation	15787	15653	15526	15458	15170	15000	14711	14536	14120
Under observation	308	430	557	623	909	1070	1348	1481	1877
New cases	0	0	0	0	0	0	0	0	0
Accumulated deaths	13	13	13	13	13	13	13	12	12
New deaths	0	0	0	0	0	0	1	0	0
HARBIN/ accumulation	**198**	**198**	**198**	**198**	**198**	**198**	**198**	**198**	**198**
New cases	0	0	0	0	0	0	0	0	0
Accumulated deaths	4	4	4	4	4	4	4	3	3

New deaths	0	0	0	0	0	0	0	0	0

Date	**2/23/2020**	**2/22/2020**	**2/21/2020**	**2/20/2020**	**2/19/2020**	**2/18/2020**	**2/17/2020**	**2/16/2020**	**2/15/2020**
TOTAL/closely contacted	**635531**	**628517**	**618915**	**606037**	**589163**	**574418**	**560901**	**546016**	**529418**
Under observation	97481	106089	113564	120302	126363	135881	141552	150539	158764
Total accumulation	77150	76936	76288	75465	74576	74185	72436	70548	68500
Serious& ICU	9915	10968	11477	11633	11864	11977	11741	10644	11272
Accumulated deaths	2592	2442	2345	2236	2118	2004	1868	1770	1665
Dismiss accumulation	24735	22889	20659	18264	16155	14376	12552	10844	9419
New cases	409	648	397	889	394	1749	1886	2048	2009
New deaths	150	97	109	118	114	136	98	105	142
HUBEI/accumulation	**64287**	**64084**	**63454**	**62662**	**62031**	**61682**	**59989**	**58182**	**56249**
Closely contacted	246781	240937	234217	225696	214093	206087	199322	191434	183183
Under observation	58575	61181	62787	63126	65525	68345	69270	71613	74261
Serious	9430	10428	8400	10997	11178	11246	10970	9797	10396
ICU			2492						1957
Accumulated deaths	2495	2346	2250	2144	2029	1921	1789	1696	1596
Dismiss accumulation	16738	15299	13557	11788	10337	9128	7862	6639	5623
New cases	398	630	366	631	349	1693	1807	1933	1843
New deaths	149	96	106	115	108	132	93	100	139
WUHAN/ accumulation	**46607**	**46201**	**45660**	**45346**	**45027**	**44412**	**42752**	**41152**	**39462**
Serious/ICU	8329	9228		9628	9689	9562	9222	8056	8530
Accumulated deaths	1987	1856	1774	1684	1585	1497	1381	1309	1233
Dismiss/ accumulation	8946	8171	7206	6214	5448	4895	4219	3458	2915
New cases	348	541	314	319	615	1660	1600	1690	1548
New deaths	131	82	90	99	88	116	72	76	110
XIAOGAN/ Accumulation	**3465**	**3443**	**3429**	**3427**	**3329**	**3344**	**3320**	**3279**	**3201**
New case	22	14	2	5	15	24	5	78	87
Accumulated deaths	108	102	98	94	89	82	75	70	65
New deaths	6	4	4	5	7	7	5	5	3
HUANGGANG/ accumulation	**2904**	**2904**	**2899**	**2883**	**2839**	**2844**	**2828**	**2831**	**2823**
New cases	0	5	16	3	5	16	6	8	6
Accumulated deaths	103	98	95	90	87	82	81	75	75
New deaths	5	3	5	3	5	1	6	0	6
HEILOINGJIANG/total	**480**	**480**	**479**	**479**	**476**	**470**	**464**	**457**	**445**
closely contacted	16110	16061	15906	15790	15574	15474	15338		
Dismissed from observation	13954	13644	13628	12953	12438	11909	11264		
Under observation	2027	2288	2509	2709	2939	3442	3957		
New cases	0	1	0	3	6	6	7	12	20
Accumulated deaths	12	12	12	12	12	12	11	11	11
New deaths	0	0	0	0	0	1	0	0	0
HARBIN/ accumulation	**198**	**198**	**197**	**197**	**194**	**192**	**190**	**188**	**182**
New cases	0	1	0	3	2	2	2	6	15
Accumulated deaths	3	3	3	3	3	3	3	3	3

New deaths	0	0	0	0	0	0	0	0	0

Date	**2/14/2020**	**2/13/2020**	**2/12/2020**	**2/11/2020**	**2/10/2020**	**2/9/2020**	**2/8/2020**	**2/7/2020**	**2/6/2020**
TOTAL/closely contacted	**513183**	**493067**	**471531**	**451462**	**428438**	**399487**	**371905**	**345498**	**314028**
Under observation	169039	177984	181386	185037	187728	187518	188183	189660	186045
Total accumulation	66492	63851	59804	44653	42638	40171	37198	34546	28985
Serious& ICU	11053	10204	8030	8204	7333	6484	6188	6101	4821
Accumulated deaths	1523	1380	1367	1113	1016	908	811	722	636
Dismiss accumulation	8096	6723	5911	4740	3996	3281	2649	2050	1540
New cases	2641	5090	15152	2015	5090	3062	2656	3399	3143
New deaths	143	121	254	97	121	97	89	86	73
HUBEI/accumulation	**54406**	**51986**	**48206**	**33366**	**31728**	**29631**	**27100**	**24953**	**22112**
Closely contacted	176148	166818	158377	152251	144279	132555	123827	114044	101599
Under observation	77323	77685	77308	77195	76207	73127	70438	67802	64057
Serious	8276	9278	5647	5724	5046	4269	4093	4188	3161
ICU	2155	1685	1437	1517	1298	1236	1154	1007	841
Accumulated deaths	1457	1318	1310	1068	974	871	780	699	618
Dismiss accumulation	4774	4107.5	3441	2639	2222	1795	1439	1115	817
New cases	2420	4823	14840	1638	2097	2618	2147	2841	2447
New deaths	139	116	242	94	116	91	81	81	69
WUHAN/ accumulation	**37914**	**35991**	**32994**	**19558**	**18454**	**16902**	**14982**	**13603**	**11618**
Serious/ICU	8335	7492	5426						
Accumulated deaths	1123	1016	1036	820	748	681	608	545	478
Dismiss/ accumulation	2502	2016	3441						
New cases	1923	3910	13436	1104	1552	1920	1379	1985	1501
New deaths	107	88	216	72	67	73	63	67	64
XIAOGAN/ Accumulation	**3114**	**3009**	**2874**	**2751**	**2642**	**2541**	**2436**	**2313**	**2141**
New case	105	135	123	109	101	105	123	172	255
Accumulated deaths	62	57	49	45	41	33	29	26	25
New deaths	5	8	4	4	8	4	3	1	0
HUANGGANG/ accumulation	**2817**	**2791**	**2662**	**2398**	**2332**	**2252**	**2141**	**2041**	**1897**
New cases	26	129	264	66	80	111	100	144	90
Accumulated deaths	69	60	58	54	52	45	43	36	32
New deaths	9	2	4	2	7	2	7	4	3
HEILOINGJIANG/total	**425**	**418**	**395**	**378**	**360**	**331**	**307**	**295**	**277**
closely contacted									
Dismissed from observation									
Under observation									
New cases	7	23	17	18	29	24	12	18	50
Accumulated deaths	11	11	9	8	8	6	6	5	3
New deaths	0	2	1	0	2	0	1	2	0
HARBIN/ accumulation	**167**	**164**	**159**	**150**	**146**	**128**	**114**	**100**	**94**
New cases	3	5	9	4	18	14	14	6	12
Accumulated deaths	3	3	1	0	0	0	0	0	0

New deaths	0	2	1	0	0	0	0	0	0

Date	**2/5/2020**	**2/4/2020**	**2/3/2020**	**2/2/2020**	**2/1/2020**	**1/31/2020**	**1/30/2020**	**1/29/2020**	**1/28/2020**
TOTAL/closely contacted	**282813**	**252154**	**221015**	**189583**	**163844**	**136987**	**113579**	**88693**	**65537**
Under observation	186354	185555	171329	152700	137594	118478	102427	81947	59990
Total accumulation	28018	24324	20438	17205	14380	11791	9692	7711	5974
Serious& ICU	3859	3219	2788	2296	2110	1795	1527	1370	1239
Accumulated deaths	563	490	425	361	304	259	213	170	132
Dismiss accumulation	1153	892	632	475	328	243	171	124	103
New cases	3694	3887	3235	2829	2590	2102	1982	1737	1459
New deaths	73	65	64	57	45	46	43	38	26
HUBEI/accumulation	**19665**	**16678**	**13522**	**11177**	**9074**	**7153**	**5806**	**4586**	**3554**
Closely contacted	90997	81039	68988	56088	48571	41075	35144		
Under observation	64127	66764	58544	48171	43121	36838	32340		
Serious	2328	1809	1567	1223	1118	956	804	711	671
ICU	756	711	576	478	444	338	290	277	228
Accumulated deaths	549	479	414	350	294	249	204	162	125
Dismiss accumulation	633	520	396	295	215	166	116	90	80
New cases	2987	377	2345	2103	1921	1252	1152	985	782
New deaths	70	65	64	56	45	45	42	37	25
WUHAN/ accumulation	**10117**	**8351**	**6384**	**5142**	**4109**	**3215**	**2639**	**2261**	**1905**
Serious/ICU									
Accumulated deaths	414	362	313	265	224	192	159	129	104
Dismiss/ accumulation									
New cases	1766	1967	1242	1033	894	576	378	356	315
New deaths	52	49	48	41	32	33	30	25	19
XIAOGAN/ Accumulation	**1886**	**1462**	**1120**	**918**	**749**	**628**	**541**	**399**	**274**
New case	424	342	202	169	121	87	142	125	101
Accumulated deaths	25	18	17	14	14	12	9	6	3
New deaths	7	1	3	0	2	3	3	3	2
HUANGGANG/ accumulation	**1807**	**1645**	**1422**	**1246**	**1002**	**726**	**573**	**496**	**324**
New cases	162	223	176	244	276	153	77	172	111
Accumulated deaths	29	25	19	17	15	14	12	12	5
New deaths	4	6	2	2	1	2	0	7	1
HEILOINGJIANG/total	**227**	**190**	**155**	**118**	**95**	**80**	**59**	**43**	**37**
closely contacted									
Dismissed from observation									
Under observation									
New cases	37	35	37	23	15	21	16	6	7
Accumulated deaths	3	2	2	2	2	2	2	1	1
New deaths	1	0	0	0	0	0	1	0	0
HARBIN/ accumulation	**82**	**73**	**63**	**45**	**34**	**25**	**18**	**13**	**11**
New cases	9	10	18	11	9	7	5	2	1

Accumulated deaths	0	0	0	0	0	0	0	0	0
New deaths	0	0	0	0	0	0	0	0	0

Date	**1/27/2020**	**1/26/2020**	**1/25/2020**	**1/24/2020**	**1/23/2020**	**1/22/2020**	**1/21/2020**	**1/20/2020**	**1/19/2020**
TOTAL/closely contacted	**47833**	**32799**	**23431**	**15197**	**9507**	**5897**	**2197**		
Under observation	44132	30453	21556	13967	8420	4928	1394		
Total accumulation	4515	2744	1975						
Serious& ICU	976	461	324	237	177	95	102	51	9
Accumulated deaths	106	80	56	41	25	17	9	6	4
Dismiss accumulation	60	51	49	38	34	28	27	25	25
New cases	1771	769	688	444	259	571	149	77	
New deaths	26	24	15	16	25	17			
HUBEI/accumulation	**2714**	**1423**	**1052**	**729**	**549**	**444**	**375**	**270**	**198**
Closely contacted									
Under observation									
Serious	563	221	129	100	106	71	102	51	35
ICU	127	69	63	57	23	24	18	12	9
Accumulated deaths	100	76	52	39	24	17	9	6	4
Dismiss accumulation	47	44	42	32	31	28	27	25	25
New cases	637	636	636	164	95	80	80	70	169
New deaths	24	24	13		24	17	3		
WUHAN/ accumulation	**1590**	**698**	**618**	**572**	**495**	**425**	**363**	**258**	**198**
Serious/ICU									
Accumulated deaths	85	63	45	38	24	17	9	6	4
Dismiss/ accumulation									
New cases	892	80	46	77	70	62	105	60	198
New deaths	22	18	7	14	7	8	3	2	4
XIAOGAN/ Accumulation	**173**	**100**	**55**	**26**	**22**				
New case	73	45	29	4	22	0			
Accumulated deaths	1	1							
New deaths	0	1	0	0	0	0	0	0	0
HUANGGANG/ accumulation	**213**	**154**	**122**	**64**	**12**	**12**	**12**	**12**	**0**
New cases	59	32	58	52	0	0	0	12	0
Accumulated deaths	4	4	2						
New deaths	0	2	2	0	0	0	0	0	0
HEILOINGJIANG/total	**30**	**21**	**15**	**9**	**4**	**2**	**1**		
closely contacted									
Dismissed from observation									
Under observation									
New cases	9	6	6	5	2	1	1	0	0
Accumulated deaths	1	1	1	1	1	0	0		
New deaths	0	0	0	0	1	0	0	0	0
HARBIN/ accumulation	**10**	**8**	**8**	**6**	**1**	**1**	**0**		

New cases	2	0	2	5	0	1	0	0	0
Accumulated deaths	0	0	0	0	0	0	0		
New deaths	0	0	0	0	0	0	0	0	0

* Data were collected based on the availability. Not every data was collected or available.

Appendix Table 2. Death rate analysis in Hubei

Death rate 1 from the date Symptoms	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17
mean-13	0.35%	4.15%	7.11%	3.79%	4.94%	4.05%	4.41%	4.42%	2.95%
1STDEV-8	2.88%	3.52%	8.08%	3.97%	2.80%	0.77%	6.59%	6.29%	3.67%
1STDEV-19	2.13%	2.28%	4.72%	4.09%	5.04%	5.99%	8.02%	10.82%	9.01%
2STDEV-25	3.86%	5.57%	14.44%	11.43%	8.21%	31.00%	33.44%	73.33%	88.57%
2STDEV-2	25.62%	10.79%	18.81%	15.21%	30.37%	6.79%	5.98%	6.83%	5.05%
Death rate 1 from the date Symptoms	2020-02-16	2020-02-15	2020-02-14	2020-02-13	2020-02-12	2020-02-11	2020-02-10	2020-02-09	2020-02-08
mean-13	4.26%	6.61%	7.24%	0.59%	19.84%	9.11%	12.26%	7.05%	21.83%
1STDEV-8	4.66%	4.89%	5.68%	0.27%	7.67%	4.01%	4.90%	4.74%	6.01%
1STDEV-19	11.90%	10.77%	37.47%	2.48%	134.44%	89.52%	149.28%	86.67%	112.50%
2STDEV-25	144.93%	132.38%	193.06%						
2STDEV-2	4.13%	3.68%	0.94%	0.49%	11.54%	3.71%	4.80%	3.20%	3.31%
Death rate 1 from the date Symptoms	2020-02-07	2020-02-06	2020-02-05	2020-02-04	2020-02-03	2020-02-02	2020-02-01	2020-01-31	2020-01-30
mean-13	25.08%	38.33%	66.67%	94.20%	60.95%	77.78%			
1STDEV-8	6.64%	6.69%	8.33%	5.03%	17.25%	17.34%	25.00%	42.86%	60.87%
1STDEV-19									
2STDEV-25									
2STDEV-2	2.71%	2.19%	2.99%	3.09%	3.33%	4.16%	3.69%	4.36%	5.00%
Death rate 1 from the date Symptoms	2020-01-29	2020-01-28	2020-01-27	2020-01-26	2020-01-25	2020-01-24	2020-01-23	2020-01-22	2020-01-21
mean-13									
1STDEV-8	35.24%	34.72%							
1STDEV-19									
2STDEV-25									
2STDEV-2	2.87%	6.74%	7.43%	13.33%	12.38%	21.74%	6.67%	11.11%	

Death rate 1 from the day Severe	2/25/2020	2/24/2020	2/23/2020	2/22/2020	2/21/2020	2/20/2020	2/19/2020	2/18/2020	2/17/2020
mean-8	22.93%	0.00%	0.00%	8.33%	10.07%	0.00%	12.04%	15.73%	36.05%
1STDEV-2	0.00%	0.00%	0.00%	0.00%	0.00%	41.67%	28.39%	0.00%	0.00%
1STDEV-13	0.00%	7.58%	17.76%	37.21%	203.85%	9.64%	11.76%	23.40%	24.67%
2STDEV -19	5.66%	12.06%	39.52%	21.72%	76.26%	42.91%	54.00%	124.53%	104.49%
2STDEV -0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	47.83%	28.30%
Death rate 1 from the day Severe	2/16/2020	2/15/2020	2/14/2020	2/13/2020	2/12/2020	2/11/2020	2/10/2020	2/9/2020	2/8/2020
mean-8	192.31%	11.65%	15.14%	1.42%	64.19%	21.27%	74.10%	33.96%	40.50%
1STDEV-2	8.67%	12.67%	0.00%	0.89%	28.84%	36.43%	198.08%	7.63%	8.82%
1STDEV-13	22.62%	100.00%	51.87%	4.00%	228.30%	105.62%	49.28%	22.75%	82.65%
2STDEV -19	47.85%	34.75%	141.84%	22.86%	864.29%	579.41%	0.00%	159.65%	426.32%
2STDEV -0	0.00%	0.00%	12.06%	11.39%	0.00%	10.48%	12.28%	35.27%	155.77%
Death rate 1 from the day Severe	2/7/2020	2/6/2020	2/5/2020	2/4/2020	2/3/2020	2/2/2020	2/1/2020	1/31/2020	1/30/2020

mean-8	76.42%	77.53%	33.49%	16.25%	65.31%	160.00%	160.71%	255.88%	0.00%
1STDEV-2	14.36%	18.30%	15.84%	46.76%	23.88%	28.00%	42.45%	50.56%	20.10%
1STDEV-13	231.43%	246.43%	397.06%	0.00%	112.28%	294.74%			
2STDEV -19									
2STDEV -0	6.79%	7.52%	12.41%	17.24%	14.48%	40.29%	16.79%	22.50%	39.62%
Death rate 1 from the day Severe	**1/29/2020**	**1/28/2020**	**1/27/2020**	**1/26/2020**	**1/25/2020**	**1/24/2020**	**1/23/2020**	**1/22/2020**	**1/21/2020**
mean-8	64.91%	131.58%							
1STDEV-2	9.25%	25.51%	68.57%	85.71%	82.35%	0.00%	12.28%	42.11%	
1STDEV-13									
2STDEV -19									
2STDEV -0	41.57%	11.96%	6.00%	24.49%	37.14%	53.57%	44.12%	0.00%	5.26%

*** Death rate1 above=new deaths/new patients (or new severe and ICU) days ago in Hubei**

Death rate2 from the date Symptoms	**2020-02-25**	**2020-02-24**	**2020-02-23**	**2020-02-22**	**2020-02-21**	**2020-02-20**	**2020-02-19**	**2020-02-18**	**2020-02-17**
mean-13	5.42%	7.68%	7.86%	7.92%	8.30%	8.59%	9.18%	9.77%	10.73%
1STDEV-8	4.36%	4.41%	4.44%	4.31%	4.33%	4.45%	6.08%	6.05%	6.04%
1STDEV-19	11.83%	13.03%	14.96%	17.35%	20.13%	23.63%	28.37%	33.09%	39.01%
2STDEV-25	36.56%	44.14%	54.40%	66.01%	82.90%	150.67%	192.87%	263.51%	325.87%
2STDEV-2	4.07%	4.00%	3.93%	3.74%	3.63%	3.48%	3.38%	3.30%	3.18%
Death rate2 from the date Symptoms	**2020-02-16**	**2020-02-15**	**2020-02-14**	**2020-02-13**	**2020-02-12**	**2020-02-11**	**2020-02-10**	**2020-02-09**	**2020-02-08**
mean-13	12.54%	14.28%	16.06%	18.43%	22.56%	23.29%	27.41%	32.09%	54.81%
1STDEV-8	6.26%	6.40%	6.59%	6.70%	7.85%	7.90%	8.71%	9.60%	10.90%
1STDEV-19	47.72%	58.81%	102.39%	125.29%	179.70%	194.54%	219.37%	232.27%	288.89%
2STDEV-25	381.98%	425.60%	539.63%	665.66%					
2STDEV-2	3.12%	3.07%	3.02%	3.95%	4.13%	3.60%	3.59%	3.49%	3.53%
Death rate2 from the date Symptoms	**2020-02-07**	**2020-02-06**	**2020-02-05**	**2020-02-04**	**2020-02-03**	**2020-02-02**	**2020-02-01**	**2020-01-31**	**2020-01-30**
mean-13	66.44%	84.77%	100.00%	107.88%	110.40%	129.63%	148.48%		
1STDEV-8	12.04%	13.48%	15.45%	17.65%	29.09%	33.27%	40.33%	45.36%	45.95%
1STDEV-19	353.03%								
2STDEV-25									
2STDEV-2	3.55%	3.71%	4.06%	4.29%	4.56%	4.89%	5.06%	5.43%	5.74%
Death rate2 from the date Symptoms	**2020-01-29**	**2020-01-28**	**2020-01-27**	**2020-01-26**	**2020-01-25**	**2020-01-24**	**2020-01-23**	**2020-01-22**	**2020-01-21**
mean-13									
1STDEV-8	43.20%	46.30%	50.51%						
1STDEV-19									
2STDEV-25									
2STDEV-2	5.97%	8.78%	9.51%	10.43%	9.47%	8.78%	6.40%	6.30%	4.55%

Death rate2 from the day Severe	**2/25/2020**	**2/24/2020**	**2/23/2020**	**2/22/2020**	**2/21/2020**	**2/20/2020**	**2/19/2020**	**2/18/2020**	**2/17/2020**
mean-8	23.84%	26.16%	24.00%	22.49%	24.25%	30.27%	28.02%	30.28%	32.50%

1STDEV-2	27.73%	24.58%	22.91%	21.33%	20.13%	19.06%	18.50%	19.61%	17.21%
1STDEV-13	36.91%	35.40%	39.33%	42.62%	42.88%	41.27%	50.70%	62.29%	70.99%
2STDEV -19	65.34%	83.11%	99.01%	109.47%	132.28%	137.26%	156.80%	175.59%	181.07%
2STDEV -0	4.01%	3.96%	3.88%	3.66%	3.55%	3.42%	3.27%	3.11%	2.98%
Death rate2 from the day Severe	**2/16/2020**	**2/15/2020**	**2/14/2020**	**2/13/2020**	**2/12/2020**	**2/11/2020**	**2/10/2020**	**2/9/2020**	**2/8/2020**
mean-8	32.32%	30.72%	36.41%	42.74%	51.98%	49.84%	57.26%	55.76%	60.28%
1STDEV-2	16.26%	17.20%	20.57%	18.20%	20.65%	19.40%	18.56%	16.77%	19.49%
1STDEV-13	79.14%	93.83%	93.28%	101.85%	119.74%	108.10%	108.34%	126.23%	268.97%
2STDEV -19	188.65%	231.30%	502.41%	686.46%	834.39%	827.91%	1025.26%	725.83%	1238.10%
2STDEV -0	2.91%	2.84%	2.68%	2.54%	2.72%	3.20%	3.07%	2.94%	2.88%
Death rate2 from the day Severe	**2/7/2020**	**2/6/2020**	**2/5/2020**	**2/4/2020**	**2/3/2020**	**2/2/2020**	**2/1/2020**	**1/31/2020**	**1/30/2020**
mean-8	63.89%	62.55%	61.07%	69.42%	142.76%	182.29%	187.26%	193.02%	214.74%
1STDEV-2	22.67%	24.52%	25.62%	28.16%	26.50%	27.05%	26.87%	25.20%	22.69%
1STDEV-13	364.06%	393.63%	425.58%	504.21%	345.00%	555.56%	668.18%		
2STDEV -19	1588.64%								
2STDEV -0	2.80%	2.79%	2.79%	2.87%	3.06%	3.13%	3.24%	3.48%	3.51%
Death rate2 from the day Severe	**1/29/2020**	**1/28/2020**	**1/27/2020**	**1/26/2020**	**1/25/2020**	**1/24/2020**	**1/23/2020**	**1/22/2020**	**1/21/2020**
mean-8	135.00%	198.41%	227.27%						
1STDEV-2	23.48%	43.10%	52.08%	48.41%	40.31%	41.05%	20.00%	26.98%	20.45%
1STDEV-13									
2STDEV -19									
2STDEV -0	3.53%	3.52%	3.68%	5.34%	4.94%	5.35%	4.37%	3.83%	2.40%

*** Death rate 2 above=total deaths/patients (or new severe disease and new ICU admissions) days ago in Hubei**

Death rate weighted

Date	**2020-02-25**	**2020-02-24**	**2020-02-23**	**2020-02-22**	**2020-02-21**	**2020-02-20**	**2020-02-19**	**2020-02-18**	**2020-02-17**
Death rate 1 from the date Symptoms	**3.32%**	**4.08%**	**8.04%**	**5.18%**	**6.37%**	**5.71%**	**7.86%**	**11.20%**	**10.47%**
mean-13	0.13%	1.59%	2.71%	1.45%	1.89%	1.55%	1.69%	1.69%	1.13%
1STDEV-8	0.70%	0.85%	1.96%	0.96%	0.68%	0.19%	1.60%	1.52%	0.89%
1STDEV-19	0.51%	0.55%	1.14%	0.99%	1.22%	1.45%	1.94%	2.62%	2.18%
2STDEV-25	0.26%	0.37%	0.97%	0.77%	0.55%	2.08%	2.24%	4.91%	5.93%
2STDEV-2	1.72%	0.72%	1.26%	1.02%	2.03%	0.46%	0.40%	0.46%	0.34%
Date	**2020-02-16**	**2020-02-15**	**2020-02-14**	**2020-02-13**	**2020-02-12**	**2020-02-11**	**2020-02-10**	**2020-02-09**	**2020-02-08**
Death rate 1 from the date Symptoms	**15.62%**	**15.43%**	**26.20%**						
mean-13	1.63%	2.52%	2.76%						
1STDEV-8	1.13%	1.18%	1.37%						
1STDEV-19	2.88%	2.61%	9.07%						
2STDEV-25	9.71%	8.87%	12.93%						
2STDEV-2	0.28%	0.25%	0.06%						

Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17
Death rate 1 from the day Severe	**20.36%**	**3.88%**	**10.20%**	**20.03%**	**85.59%**	**16.39%**	**19.22%**	**23.22%**	**28.64%**
mean-8	8.76%	0.00%	0.00%	3.18%	3.85%	0.00%	4.60%	6.01%	13.77%
1STDEV-2	0.00%	0.00%	0.00%	0.00%	0.00%	10.08%	6.87%	0.00%	0.00%
1STDEV-13	0.00%	1.83%	4.30%	9.00%	49.33%	2.33%	2.85%	5.66%	5.97%
2STDEV -19	0.38%	0.81%	2.65%	1.46%	5.11%	2.88%	3.62%	8.34%	7.00%
2STDEV -0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.20%	1.90%
Date	**2020-02-16**	**2020-02-15**	**2020-02-14**	**2020-02-13**	**2020-02-12**	**2020-02-11**	**2020-02-10**	**2020-02-09**	**2020-02-08**
Death rate 1 from the day Severe	**84.24%**	**34.05%**	**28.65%**	**4.02%**	**144.66%**	**82.02%**	**88.99%**	**33.38%**	**76.61%**
mean-8	73.46%	4.45%	5.78%	0.54%	24.52%	8.12%	28.31%	12.97%	15.47%
1STDEV-2	2.10%	3.07%	0.00%	0.22%	6.98%	8.82%	47.93%	1.85%	2.14%
1STDEV-13	5.48%	24.20%	12.55%	0.97%	55.25%	25.56%	11.93%	5.51%	20.00%
2STDEV -19	3.21%	2.33%	9.50%	1.53%	57.91%	38.82%	0.00%	10.70%	28.56%
2STDEV -0	0.00%	0.00%	0.81%	0.76%	0.00%	0.70%	0.82%	2.36%	10.44%

Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17
Death rate2 from the date of onset of symptoms	**8.71%**	**10.38%**	**11.61%**	**12.94%**	**14.89%**	**20.40%**	**24.99%**	**31.08%**	**37.05%**
mean-13	2.07%	2.93%	3.00%	3.02%	3.17%	3.28%	3.51%	3.73%	4.10%
1STDEV-8	1.05%	1.07%	1.07%	1.04%	1.05%	1.08%	1.47%	1.47%	1.46%
1STDEV-19	2.86%	3.15%	3.62%	4.20%	4.87%	5.72%	6.86%	8.01%	9.44%
2STDEV-25	2.45%	2.96%	3.65%	4.42%	5.55%	10.09%	12.92%	17.66%	21.83%
2STDEV-2	0.27%	0.27%	0.26%	0.25%	0.24%	0.23%	0.23%	0.22%	0.21%
Date	**2020-02-16**	**2020-02-15**	**2020-02-14**	**2020-02-13**	**2020-02-12**	**2020-02-11**	**2020-02-10**	**2020-02-09**	**2020-02-08**
Death rate2 from the date of onset of symptoms	**43.66%**	**49.95%**	**68.86%**	**83.84%**					
mean-13	4.79%	5.45%	6.13%	7.04%					
1STDEV-8	1.51%	1.55%	1.59%	1.62%					
1STDEV-19	11.55%	14.23%	24.78%	30.32%					
2STDEV-25	25.59%	28.52%	36.16%	44.60%					
2STDEV-2	0.21%	0.21%	0.20%	0.26%					

Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17
Death rate2 from the date of onset of severe disease	**29.40%**	**30.34%**	**31.12%**	**31.65%**	**33.61%**	**35.59%**	**38.17%**	**43.36%**	**46.09%**
mean-8	9.11%	9.99%	9.17%	8.59%	9.26%	11.56%	10.70%	11.57%	12.41%
1STDEV-2	6.71%	5.95%	5.54%	5.16%	4.87%	4.61%	4.48%	4.75%	4.16%
1STDEV-13	8.93%	8.57%	9.52%	10.31%	10.38%	9.99%	12.27%	15.07%	17.18%
2STDEV -19	4.38%	5.57%	6.63%	7.33%	8.86%	9.20%	10.51%	11.76%	12.13%
2STDEV -0	0.27%	0.27%	0.26%	0.25%	0.24%	0.23%	0.22%	0.21%	0.20%

Date	2020-02-16	2020-02-15	2020-02-14	2020-02-13	2020-02-12	2020-02-11	2020-02-10	2020-02-09	2020-02-08
Death rate2 from the date of onset of severe disease	**48.27%**	**54.29%**	**75.30%**	**91.54%**	**109.92%**	**105.58%**	**121.48%**	**104.73%**	**175.98%**
mean-8	12.35%	11.74%	13.91%	16.33%	19.86%	19.04%	21.87%	21.30%	23.03%
1STDEV-2	3.93%	4.16%	4.98%	4.40%	5.00%	4.69%	4.49%	4.06%	4.72%
1STDEV-13	19.15%	22.71%	22.57%	24.65%	28.98%	26.16%	26.22%	30.55%	65.09%
2STDEV -19	12.64%	15.50%	33.66%	45.99%	55.90%	55.47%	68.69%	48.63%	82.95%
2STDEV -0	0.20%	0.19%	0.18%	0.17%	0.18%	0.21%	0.21%	0.20%	0.19%

Appendix Table 3. Death rate estimation in different regions in China

Hubei	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	3.32%	4.08%	8.04%	5.18%	6.37%	5.71%	7.86%	11.20%	10.47%	
	current ratio	4.01%	3.96%	3.88%	3.66%	3.55%	3.42%	3.27%	3.11%	2.98%	
	Death rate 2	8.71%	10.38%	11.61%	12.94%	14.89%	20.40%	24.99%	31.08%	37.05%	
	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Severe and ICU	Death rate 1	20.36%	3.88%	10.20%	20.03%	85.59%	16.39%	19.22%	23.22%	28.64%	
	current ratio	31.41%	29.54%	26.46%	22.50%	20.66%	19.50%	18.15%	17.08%	16.31%	
	Death rate 2	29.40%	30.34%	31.12%	31.65%	33.61%	35.59%	38.17%	43.36%	46.09%	

Note: The current ratioes between deaths and patients in severe and ICU begin to rise after Feb.19, 2020 due to the decrement of the total number of patients in severe and rates in severe and ICU is probably the values between 19.5% and 18.15% as.

Wuhan	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	2.61%	5.19%	12.14%	7.73%	6.98%	13.45%	21.05%	22.30%	14.40%	
	current ratio	4.39%	4.34%	4.26%	4.02%	3.89%	3.71%	3.52%	3.37%	3.23%	
	Death rate 2	12.58%	15.56%	17.27%	19.22%	21.80%	32.30%	36.54%	39.12%	42.00%	

Total except Hubei	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	0.00%	2.18%	0.51%	0.26%	1.12%	0.96%	1.51%	0.93%	1.13%	
	current ratio	0.78%	0.78%	0.75%	0.75%	0.74%	0.72%	0.71%	0.66%	0.63%	
	Death rate 2	0.99%	1.05%	1.10%	1.19%	1.34%	1.49%	1.72%	2.12%	3.11%	

Note: The values in red have not been adopted in Charts due to the spike.

Total except Wuhan	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	1.91%	3.29%	3.54%	2.69%	1.92%	4.98%	3.47%	3.15%	6.76%	
	current ratio	2.99%	2.94%	2.87%	2.74%	2.68%	2.66%	2.61%	2.46%	2.37%	
	Death rate 2	4.40%	4.79%	5.33%	6.03%	7.15%	8.95%	12.15%	23.97%	57.68%	

Xiaogan in Hubei	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17
Symptoms	Death rate 1	4.13%	2.49%	24.78%	3.40%	1.25%	4.71%	7.31%	15.83%	8.55%
	current ratio	3.23%	3.16%	3.12%	2.96%	2.86%	2.73%	2.67%	2.45%	2.26%
	Death rate 2	5.03%	5.33%	6.19%	7.22%	8.90%	11.80%	16.82%	27.38%	30.22%

Huanggang in Hubei	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	0.65%	15.54%	25.39%	5.48%	3.13%	5.13%	2.13%	3.75%	9.88%	
	current ratio	3.68%	3.65%	3.55%	3.37%	3.28%	3.16%	3.06%	2.99%	2.97%	
	Death rate 2	5.05%	5.50%	5.71%	6.43%	7.58%	8.90%	10.51%	15.37%	54.05%	

Heilongjiang	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5.28%	0.00%	
	current ratio	2.50%	2.50%	2.50%	2.50%	2.51%	2.51%	2.52%	2.55%	2.37%	
	Death rate 2	4.01%	4.66%	5.49%	6.28%	7.50%	9.35%	11.59%	16.86%	27.80%	

Harbin in Heilongjiang	Date	2020-02-25	2020-02-24	2020-02-23	2020-02-22	2020-02-21	2020-02-20	2020-02-19	2020-02-18	2020-02-17	20
Symptoms	Death rate 1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
	current ratio	1.52%	1.52%	1.52%	1.52%	1.52%	1.52%	1.55%	1.56%	1.58%	
	Death rate 2	2.78%	3.25%	3.83%	4.41%	5.17%	6.36%	7.23%	9.39%	27.93%	

Appendix Table 4. Death prediction by PIBA and actual death data of different regions in China

Date	3/3/2020	3/2/2020	3/1/2020	2/29/2020	2/28/2020	2/27/2020	2/26/2020
All China/3.28%							
*7 days	13	17	13	21	13	29	13
13 days	29	13	57	62	67	66	87
19 days	87	167	497	66	167	100	87
Actual deaths	**38**	**31**	**42**	**35**	**47**	**44**	**29**
Hubei/5.00%							
7 days	20	25	20	32	18	32	17
13 days	32	17	85	90	97	92	121
19 days	121	241	742	82	105	131	107
Actual deaths	**37**	**31**	**42**	**34**	**45**	**41**	**26**
Wuhan/5.20%							
7 days	19	24	18	28	16	17	32
13 days	17	32	86	83	88	80	100
19 days	100	203	699	57	81	100	72
Actual deaths	**31**	**24**	**32**	**26**	**37**	**28**	**19**
Rest of country/0.78%							
7 days	0	0	0	0	0	2	0
13 days	2	0	0	1	1	1	2
19 days	2	2	2	3	23	3	4
Actual deaths	**1**	**0**	**0**	**1**	**2**	**3**	**3**

- The number of deaths is calculated based on the patient number on the previous days, thus, the 7^{th}, 13^{th}, and 19^{th} day before the day of prediction.

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Graphical abstract

Highlights

- The mortality rate determines whether a highly infectious disease becomes a public concern
- Summarizing information after the fact does not contribute to real-time readiness to deal with the disease
- The Patient Information Based Algorithm (PIBA) estimates the death rate of a disease in real-time
- PIBA can be used to estimate the death rate of a new infectious disease in real time and to predict future deaths