Comprehensive Risk Assessment and Spatial Pattern Analysis of COVID-19 of China

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Abstract: The outbreak of COVID-19 has a certain impact on China, an objective assessment of COVID-19 risk is of great significance for epidemic preparedness and public health management. In this paper, the spatial distribution pattern and spatial aggregation pattern of comprehensive risk of COVID-19 are studied by constructing an index system of COVID-19 with using an exploratory spatial data analysis method. The results show that the overall Moran's I index of comprehensive risk is 0.2417, indicating that there is a positive spatial correlation and a significant spatial clustering feature. The comprehensive risk distribution of COVID-19 in some regions follows the characteristics of geographical proximity, and there is a risk of transmission between regions. Tianjin, Hubei, Sichuan, Liaoning, Shanghai and Hainan are the areas with high comprehensive risk of COVID-19, while the low risk areas are Guangdong, Yunnan, Tibet, Shanxi, Qinghai, Ningxia and Xinjiang. There are 13 regions with low-low clustering pattern (LL), there are 5 regions with high-high clustering pattern (HH). According to the distribution of comprehensive risk, we should formulate prevention, control and emergency response strategies, strengthen the construction of public health facilities and training of medical professional and technical personnel, and reduce the level of epidemic risk.

1 INTRODUCTION

Corona Virus Disease 2019, or COVID-19, was named by the World Health Organization. Since December 2019, some hospitals in Wuhan, Hubei Province have found a number of unexplained pneumonia cases with a history of exposure to the seafood market in South China, which has been confirmed to be an acute respiratory infectious disease caused by the 2019 novel corona-virus infection. Chinese government departments quickly launched a first-level response to major public health emergencies. The epidemic is highly and fast infectious, leading to the outbreak of a massive public health crisis across the country, posing a certain threat to urban public health safety.

The rapid spread of COVID-19 is a global public health challenge. As of 24:00 on June30, 2021, according to 31 provinces (autonomous regions, municipalities directly under the Central Government) and Xinjiang Production and Construction Corps, 421 confirmed cases (including 7 severe cases), a total of 78,479 discharged cases, 4,634 deaths and 83,534 confirmed cases were reported. After the outbreak of the epidemic, the government promptly launched an emergency response and resolutely took a series of public emergency measures. Many places in China resolutely took measures such as nucleic acid testing, community control, and personnel isolation to prevent the spread of the epidemic. All 31 provinces (autonomous regions and municipalities directly under the Central Government) have experienced COVID-infected people, with a wide range and strong infectivity.

Number of beds in hospitals, medical resources, rescue teams and other resources exposed regional gaps, which also showed the difference of the prevalence and mortality of COVID-19 in different regions. In addition, the improvement of the

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interurban transportation system accelerated the spread of epidemic among regions, and so did the spatial proximity. How to evaluate and analyse the risks of the epidemic in various places objectively and comprehensively, classify the risk levels in different regions, provide a theoretical basis for epidemic prevention has become the focus of scholars at present. In view of this, it is very necessary to explore the regional risk index and pattern of COVID-19 and its spatial distribution mode deeply, so as to provide theoretical guidance for the prevention and control of the epidemic, and draw lessons from experience for public health risk management.

In this paper, the spatial distribution pattern and spatial aggregation pattern of comprehensive risk of COVID-19 are studied by constructing an index system with using an exploratory spatial data analysis method, which may deepen the understanding of the spatial nature of the epidemic distribution, supplement the lack of ignoring spatial autocorrelation in the modelling of the distribution of infectious diseases in traditional studies. At the same time, this paper may provide an assistance of resource allocation to response to COVID-19 and even provide an effective method or perspective for scientifically understanding the risk of epidemic in various regions.

2 LITERATURE REVIE

The outbreak of COVID-19 has a phased impact on China's economy growth. Economic growth rate in 2020 was reversed from low before high in 2020 (Jia 2020). Wang Xuyang et al. (2020) focused on a prediction analysis in Hubei Province based on the index smoothing model, and the model fits well and can be used for COVID-19 epidemic prediction, to ensure the normal production and operation order of enterprises, and reduce the negative impact on the economy.

Pan Jiahua (2020), from the perspective of urban spatial pattern and urban form, believes that urban spatial aggregation, pattern differentiation and spatial planning concept affect the spread and diffusion of the epidemic to a certain extent, which is the objective condition for the aggravation of disaster impact. The spread of COVID-19 epidemic is in line with the law of geographical proximity (Zeng et al. 2020), especially in the intercity communication stage, and the spatial adjacent diffusion effect is obvious (Liu and Jin 2020). Liu Yi et al (2020) analyzed the spatial and temporal diffusion characteristics of COVID-19 cases in Guangdong Province and the spatial differences in the spread and change of the epidemic in various prefecture-level cities, and found that the diffusion risk of medium-tier cities is high but the comprehensive risk is at the medium level, and the diffusion risk of developed cities is low but the highest of comprehensive risk. Liang Ze et al (2020) took 282 cities in China as the basic research unit. They explored the impact of urban population migration and socio-economic factors on COVID-19 incidence through geographical weighted regression method, and found that the migration rate in Wuhan greatly increased the incidence of COVID-19 in surrounding cities of Wuhan, and the effect presents spatial attenuation characteristics with the increase of geographical distance from Wuhan (except in northeast and southwest regions).

In the literature of COVID-19, most of the samples were conducted in Hubei Province. For example, Lv Zhenhua and Cheng Shaowen (2020) used Crystal Ball and GIS to analyze the space-temporal characteristics of COVID-19 development, and found a spatial correlation between cities in the risk areas of Hubei Province. But Wuhan is the only area of high-low diffusion in Hubei province. Li Chenxi et al. (2020), Liu Xun et al. (2020) analyzed the spatial pattern of COVID-19 epidemic in Hubei Province and explored its spatial and temporal aggregation by using the ESDA method and GIS, respectively. In view of this, from the perspective of geography, it is very necessary to explore the regional risk index and pattern of COVID-19 and its spatial distribution mode deeply, so as to provide theoretical guidance for the prevention and control and planning of the epidemic, and draw lessons from experience for public health risk management.

3 CONSTRUCTION OF COVID-19 COMPREHENSIVE RISK ASSESSMENT SYSTEM

Risk assessment is the premise of risk management, and plays a very important role in the whole process of epidemic prevention control and treatment. Based on the triangle model of the public safety system, the risk assessment model is constructed from the three edges of the triangle, respectively (showed in Fig.1).

Figure 1: Public safety risk assessment "triangle" model

The first edge of the "triangle" model is emergency, which refers to virus outbreak risk of COVID-19. In this article, we use the prevalence rate of 10,000 and the fatality rate to reflect the risk of COVID-19. The prevalence rate of 10,000 people equals the number of confirmed cases divided by the resident population (10,000), and the fatality rate equals to the number of deaths divided by the number of confirmed cases.

The second edge is the Hazard-affected Carriers. In the field of public safety, we believe that the most vulnerable disaster carrier that needs protection is people. According to the early summary of 44,672 cases in the China Centre for Disease Control and Prevention Weekly, it found that age had a great impact on mortality, and deaths mainly occurred in older people. The report revealed that child case symptoms are relatively mild, children aged 0 to 9 died of infection was 0, and no deaths in cases younger than 30 basically. Patients under 50 died below 1%, increasing only in the elderly and with a poor prognosis. Therefore, the Vulnerability of Hazard-affected Carriers is reflected by the proportion of the elderly population over 60 in the total population at the end of the year. The higher the proportion indicates that the greater the vulnerability of Hazard-affected carriers and the higher comprehensive risk of COVID-19 in the region.

Due to the characteristics of disaster carrier mobility, the series of methods adopted after the COVID-19 outbreak are: detection of sources of infection, isolation of high-risk people, and traffic control in high-risk areas. Relevant studies also show that the spatial distribution of epidemic risk is not random and is partly affected by spatial transmission in adjacent areas. Therefore, to a large extent, measures such as "lockdown cities" and restricting travel can curb the spatial spread of the epidemic. The impact of population mobility caused by the property of convenient transportation aggravates the spatial risk of the epidemic, which specifically shows at the two aspects of population inflow and outflow. Population inflow may increase the risk of the local epidemic, while population outflow, especially in the key epidemic areas, may lead to the risk of external spread and increase the scope of the spatial spread. The intercity communication and family-oriented local communication brought about by population flow constitute a two-stage model of the spread of the epidemic in China, shaping the spatial and temporal pattern of the epidemic (Liu and Jin 2020). Population migration, transportation, economy and other factors are internally related to the transmission of COVID-19 (Qi et al. 2020). So this paper will uses population mobility to reflect The vulnerability of Hazard-affected carriers. The stronger the regional population mobility, the higher the transmission rate will be, and the new coronavirus comprehensive risk will be higher. Population mobility is represented by the number of travel per capita (passenger volume / average population) and the per capita travel distance (passenger turnover / average population).

The third edge is emergency management, which is designed to ensure public health and safety. The outbreak of COVID-19 has shown us the importance of building a strong public health system. Li Liming (2021) believes that public health is the guard of national health, and the comprehensive public health capacity is an important symbol of the government's modern disease construction system and the fine social management. This research reveals the importance of reform and improvement of the public health system. For example, in early January 2020, the mortality rate in Wuhan was much higher than in other rest of China. This distorted mortality rate was due to the serious lack of hospital care among many infected people, and the lack of disease control resources seriously affected the control of the epidemic.

The study adopts three secondary indicators, including emergency medical facilities, emergency command facilities and emergency support effect. The differences in population base and medical levels in different regions are the impact of the epidemic. Emergency medical facilities adopt the number of beds in medical institutions per 10,000 people(units), the number of medical and health institutions (units), the number of health personnel per 10,000(10,000 person), the number of outpatient and inpatient medical assistance (10,000 person-times).

The emergency command facilities adopt the number of community service institutions and facilities per 10,000 people, the total number of real-name volunteers (10,000), and the number of emergency equipment (units) as its indicators.

Since the outbreak of the COVID-19 epidemic, the community has played a role as a "battle fortress" in the epidemic prevention and control for external import and internal proliferation. The work of community service agencies is relatively trivial, including door-to-door investigation, urging gatherings, banquets and other gathering activities, disinfection, providing materials during home observation or isolation, errands, psychological counselling and other services. Volunteers in COVID-19 are a "red barrier" for epidemic prevention and control, and have become a beautiful scenery for epidemic prevention and control. Technical and equipment support is also very important, which can effectively improve the response and deal with emergencies. Such as crawler intelligent disinfection campaign robot, outdoor epidemic prevention disinfection robot, family epidemic prevention emergency package, multi-functional intelligent protection all-in-one machine, new energy health epidemic prevention elimination vehicles, epidemic prevention mass fog elimination robot, fire emergency fire prevention vehicles, hospital centre attract system emissions inactivation device, folding aluminium magnesium alloy equipment box material handling box, unmanned aerial vehicles, etc.

The effect of emergency support is reflected by the number of cured and discharged people / the number of confirmed patients, which reflects the scientific response and treatment effect of the epidemic. Considering the difficulty of obtaining some data and the systematicness and integrity of the whole index system, based on the principles of comprehensiveness, typicality, operability and so on, the selection of indicators at all levels is as shown in Table 1. The weight of each layer index is obtained by fuzzy analysis method. The calculation formula of Novel Coronavirus Comprehensive Risk Evaluation Index (short for CREI) is:

Comprehensive Risk Evaluation Index of COVID-19= (Virus outbreak risk ×The vulnerability of disaster victims) / effectiveness of emergency guarantee

Table1: Comprehensive risk evaluation index system of COVID-19

First-level Indicators	Second-level Indicators	Third-level Indicators
Virus outbreak risk	Prevalence rate of 10,000	Number of confirmed cases/Resident Population (10,000)
	The fatality rate	Number of deaths/confirmed cases
The vulnerability of Hazard-affected carriers	Proportion of aged population	Population over 60 years old/total population at year-end
	Population mobility	travel per capita = passenger volume/average population
		Per capita travel distance = passenger turnover / average population
Effectiveness of emergency support	Emergency medical facilities	Number of beds in medical institutions per 10,000 people (sheet)
		Number of Medical and health institutions
		Number of health workers per 10,000 (10,000)
		Number of outpatient and inpatient medical assistance (10,000 person-times)
	Emergency command facility	Number of community service agencies and facilities per 10,000 people
		Total number of real-name volunteers (10,000)
		Number of Emergency equipment (units)
	Emergency support effect	Number of cured and discharged patients/number of confirmed patients

4 RESEARCH METHODS AND DATA SOURCES

4.1 Research Methods

This paper uses an exploratory spatial data analysis method. The Exploratory Spatial Data Analysis (ESDA) includes global and local auto-correlation analysis, which focuses on spatial correlation measures to describe and display the spatial distribution of the studied objects, and to reveal spatial connections as well as spatial patterns. And the global auto-correlation analysis is the dependence and heterogeneity of a research object on the regional space, and the formula is as followed:

$$\text{Moran I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (1)$$

In equation (1), variety $S^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \overline{Y})\overline{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$. n is the total number of study regions, Yi represents the observation of the I region, that is Comprehensive Risk Evaluation Index of COVID-19 of the *i* region, W_{ij} is the spatial weight matrix, and *i,j* represents the region *i* and regional *j*. In this paper, if Moran's I >0, it indicated that areas with similar comprehensive risk levels tend to gather together. If Moran's I <0, it indicates that areas with high and low comprehensive risk levels exist in the same region, with great spatial differences. If Moran's I =0, there is no spatial dependence between regions.

Local auto-correlation analysis often uses Moran scatter map (or Moran plot) that can refine the local characteristics and changes of the analysis space. The scatter map is divided into four quadrants, the first of which is high-high agglomeration (HH), indicating a high comprehensive risk level in both the region itself and the surrounding areas. The second quadrant is low-high agglomeration (LH), indicating that areas with lower COVID-19 comprehensive risk levels are surrounded by areas with higher peripheral risk levels. The third quadrant is low-low agglomeration (LL), with the low comprehensive risk level in the region itself and the surrounding areas. The fourth quadrant is high and low agglomeration (HL), where areas with high risk level of comprehensive coronavirus are surrounded by areas with lower risk levels. The first and three quadrants are typical regions, while the second and four quadrants are atypical regions (spatial outlier).

4.2 Data Source

The sample is from 31 provinces (cities and autonomous regions) of China, and the data comes from the National Health Commission, the National Bureau of Statistics, China Emergency Information Network, Public Health Science Data Centre, the 7th National Census Bulletin, and local social statistics bulletin, China Statistical Yearbook, China Yearbook of Civil Affairs Statistics and China City Statistical Yearbook. And data on COVID-19 cases were available as of June 30, 2021. The proportion of the elderly population adopts the seventh census data in 2021. The total number of real-name volunteers and the number of emergency equipment are the latest statistical data of the emergency information network, and the other indicators are the data of 2020.

5 RESULTS ANALYSIS

5.1 Space and Temporal Distribution

As of June 30, 2021, the region with the largest number of confirmed cases in China was concentrated in Hubei (68,162). As showed in Table 2, Wuhan, Hubei, is the most severe city, followed by Guangdong (2,759), Shanghai (2,222 cases), Heilongjiang (1,612), Zhejiang (1,386), Henan and Hebei (all 1,317), Sichuan (1,109), Beijing (1,078), Hunan (1,061), Anhui (1,008), and the total number of cases in other regions were below 1,000.

The spread of novel coronavirus is increased due to its geographical proximity to Hubei Province, especially the closest cities to Wuhan, such as Henan Xinyang, Zhengzhou, Nanyang, Zhumadian, Hunan Changsha, Yueyang, Anhui Hefei, Bengbu, Bozhou, Fuyang, Jiangxi Nanchang, Shangrao, Xinyu, Jiujiang and Chongqing Wanzhou district. In addition, as an economically developed trade centre, a transportation centre, and a political and cultural centre, they are often the centre of the spread of the epidemic. Due to the large number of migrant workers in Wuhan, Hubei Province, its flow with Guangzhou, Shenzhen, Wenzhou, Hangzhou, Ningbo is very frequent. Therefore, the number of COVID-19 infections in Beijing, Shanghai, Guangdong, Zhejiang and so forth are larger.

Table 2: The cumulative number of confirmed COVID-19 cases (As of June 30,2021).

Region	Number of Confirmed cases （person）	Region	Number of Confirmed cases （person）	Region	Number of Confirmed cases （person）	Region	Number of Confirmed cases （person）
Beijing	1078	Heilongjiang	1612	Shandong	883	Chongqing	601
Tianjin	402	Shanghai	2222	Henan	1317	Sichuan	1109
Hebei	1317	Jiangsu	743	Hubei	68162	Guizhou	147
Shanxi	253	Zhejiang	1386	Hunan	1061	Yunnan	446
Inner Mongolia	394	Anhui	1008	Guangdong	2759	Tibet	1
Liaoning	430	Fujian	688	Guangxi	276	Shaanxi	629
Jilin	573	Jiangxi	937	Hainan	188	Gansu	195
Qinghai	18	Ningxia	76	Xinjiang	980		

Data sources: Public Health Science Data Center

According to CREI of COVID-19 calculated by the comprehensive index system, 31 provinces and autonomous regions in China are divided into 5 levels, with lowest-risk, lower-risk, medium-risk, higher-risk and highest-risk. Highest-risk areas (risk index 0.2657-1.0465) include Tianjin, Hubei, Sichuan, Liaoning, Shanghai and Hainan; The higher-risk areas (risk index 0.1779-0.2657) include Gansu, Hunan, Chongqing, Heilongjiang, Jilin and Beijing; Medium-risk areas (risk index 0.1503-0.1779) include Shanxi, Inner Mongolia, Anhui, Jiangxi, Guizhou and Shandong; Lower-risk areas (risk index 0.1121-0.1503) include Hebei, Jiangsu, Fujian, Henan, Guangxi and Zhejiang; Lowest-risk areas (risk index 0.0243-0.1121) are Guangdong, Yunnan, Tibet, Shaanxi, Qinghai, Ningxia, and Xinjiang. The COVID-19 risk area at all levels has the characteristics of spatial agglomeration. In general, the comprehensive risk in the northwest and southwest regions is relatively low, and the comprehensive risk in the eastern and central regions is high(showed in Fig.2).

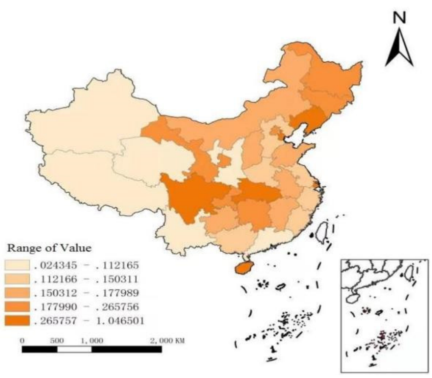

Figure 2: Spatial distribution of CREI of COVID-19.

Note: Based on the standard under-drawing GS(2016) 2892 map review system of Natural Resources, not modified. Due to data difficulties, this study does not include Hong Kong, Taiwan and Macau

Combined with the index system and original data, the difference between the regions of comprehensive risk level is related with public health service system construction, medical service system organization imbalance and emergency service supply capacity. For example, some regional hospitals and community service institutions is less in quantity and small in scale, and health technical personnel reserve is backward with talent draining. Therefore, the areas in the process of the epidemic, measures such as diagnosis and treatment, comprehensive isolation and cut off the transmission channels was unable to meet the demand of confirmed treatment and isolation.

5.2 Correlation Analysis

The Moran index of CREI is 0.2417 and the P value is 0.01. As showed in Fig.3, it implies that the spatial distribution is not completely random state, but a spatial agglomeration between similar values, that is, a positive spatial correlation, which shows that the areas of higher and high-tech comprehensive risk are close to each other, and the regions with low high-tech comprehensive risk are also close to the spatial relationship structure, and the regions are relatively concentrated.

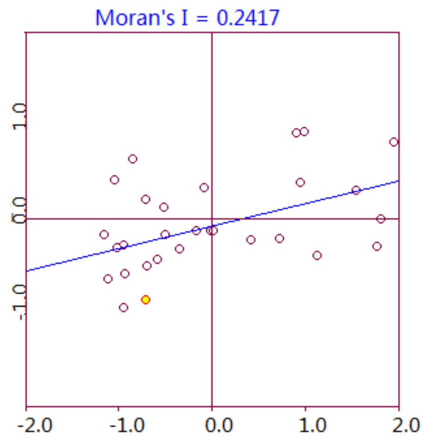

Figure 3: Moran plot of CREI of COVID-19.

About 58% of the regions are typical areas in positive correlation (including HH and LL), among which the high-high agglomeration mode (HH) includes Heilongjiang, Jilin, Liaoning, Guangxi and Yunnan, which have a relatively high comprehensive risk and the surrounding areas. There are many areas belonging to the low-low agglomeration mode (LL), including Xinjiang, Tibet, Qinghai, Gansu, Hebei, Shaanxi, Shaanxi, Shanxi, Zhejiang, Jiangsu, Shanghai, Shandong, Henan and Tianjin. The comprehensive risk level of these regions and neighbouring areas is low, forming a low-risk agglomeration belt. Belonging to the low-high agglomeration mode (LH) are Inner Mongolia, Fujian, Hunan, Chongqing and Jiangxi, which have low comprehensive risk and are surrounded by the high-risk areas. Ningxia, Guangdong, Anhui and Hubei are the High and Low Cluster Mode (HL). The comprehensive risk of the new regions is high and the risk level of the surrounding areas is relatively low. Sichuan, Beijing and Hainan are across two quadrants, belonging to the LL and HL modes, and Guizhou across the HH and HL quadrants. The HL and LH regions are atypical regions, namely spatial outlier states, showing that the degree of spatial difference in the new coronavirus risk is relatively large (showed in Table.3).

Table 3: Distribution of Moran scatter plots

Type	Provincial Administrative Regions
HH	Heilongjiang, Jilin, Liaoning, Guangxi, Yunnan
LH	Inner Mongolia, Fujian, Hunan, Chongqing, Jiangxi
LL	Xinjiang, Tibet, Qinghai, Gansu, Hebei, Shaanxi, Shanxi, Zhejiang, Jiangsu, Shanghai, Shandong, Henan, Tianjin
HL	Ningxia, Guangdong, Anhui, Hubei
Across Quadrants	Sichuan, Beijing, Hainan（LL&HL）, Guizhou（HH&HL）

6 CONCLUSIONS

Considering the influence of spatial factors, we established a Comprehensive Risk Evaluation Index system of COVID-19 with using exploratory spatial data analysis, and calculated the index of 31 provinces (cities, autonomous regions), to drew the following conclusions: Tianjin, Hubei, Sichuan, Liaoning, Shanghai, Hainan are areas with high comprehensive risk, while Guangdong, Yunnan, Tibet, Shaanxi, Qinghai, Ningxia and Xinjiang are the low-risk areas. In general, the comprehensive risk of COVID-19 in the northwest and southwest is relatively low, and the risk in the east and central regions is high. China's CREI presents a significant positive correlation in space. The CREI in most regions is a typical region of (HH and LL), forming high-high agglomeration and low-low agglomeration modes. The CREI of Shanghai, Zhejiang, Jiangsu, Anhui, Henan, Hunan and other places follows the geographical proximity law with the outbreak centre in terms of geographical and spatial distribution. The comprehensive risks of Shanghai, Zhejiang, Jiangsu, Anhui, Henan, Hunan and other places follow the geographical proximity to in terms of geospatial distribution.

For high-risk areas, relevant departments should pay more attention at the epidemic prevention and emergency response, and implement strict control strategies such as non-proliferation internally, and export-prevention externally, especially in the areas with a developed economy, large personnel mobility and density, where should also pay attention to the risk control of the epidemic. In addition, after the outbreak of COVID-19, it also exposed the problems in the medical and health service facilities and public health emergency management system. We need to learn from it and improve the major epidemic prevention and control system and mechanism, regular the national public health emergency management system, and perfect the incentive mechanism, cultivate more health technicians, and to the end to improve the response ability and management level of major public health emergencies.

The deficiency in this paper is that we just mainly analyse the spatial distribution pattern and aggregation pattern of Comprehensive risks of COVID-19, and some other factors that may affect COVID-19does not take account into the research system, such as urbanization process, regional economic development level, fiscal expenditure, population migration and migration and adjacent to other countries and so on. In future research, we will further consider and incorporate the above relevant factors to simulate and predict the outbreak risks and trends of COVID-19.

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