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The spatial and temporal pattern of COVID-19 and its effect on humans development in China

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ABSTRACT

The coronavirus disease 2019 (COVID-19) has been identified as the main cause of the outbreak of the respiratory disease in Wuhan, Hubei Province of China in December 2019. Since then, the epidemic has spread rapidly throughout China and many other countries in the world. This study, therefore, examines the spatiotemporal distribution of the confirmed cases of COVID-19 and its effect on human development in China, and suggested social and non-pharmaceutical preventive interventions to help curb the further spread of the disease. The public open data available from January to February 2020, from the National Health Commission of the People's Republic of China and a medical knowledge sharing website were used, and spatial analysis was performed to visualize the spatial distribution pattern of COVID-19 in China. The results showed among others that COVID-19 had entered a dispersed spatial pattern, resulting in increased pressure to control the spread of the disease. In early March, there was a significant reduction in the existing number of cases, and the number of deaths also decreased. At the provincial level, the spatial distribution of the number of cumulative confirmed cases in China was divided into four patterns: Hubei was the initial core region; the eastern provinces adjacent to Hubei formed the second concentrated pattern; the western provinces adjacent to Hubei and the northeastern and southeastern provinces which were separated from Hubei by one province belonged to the third distribution pattern; while the rest of the provinces in the north, south and west showing sporadic distribution patterns formed the fourth. It has been estimated that about 80% of students' online learning at all schools were not effective due to lack of access to reliable and uninterrupted internet services especially in the rural areas of China.

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INTRODUCTION

Since the first case of the pneumonia linked to the new coronavirus was found in Wuhan city, Hubei Province, in December 2019, the epidemic has spread rapidly throughout China (Zhu *et al*., 2019; Ma *et al.,* 2020). The confirmed cases were also found in many foreign countries (Michelle *et al.,* 2019; CDC Newsroom, 2020a) within a short period of time. On January 12, 2020, the World Health Organization (WHO) named the new virus causing pneumonia as coronavirus disease 2019 (COVID-19) as indicated by Jiang *et al.* (2020). On January 20, 2019, COVID-19 was included on the list of class B infectious diseases in China, and class A control measures were taken according to the Law of the People's Republic of China on Prevention and Control of Infectious Diseases (SHCPRC, 2020). On January 30, the WHO defined COVID-19 as a public health emergency of international concern. To respond to the emerging epidemic, China has taken decisive and powerful measures to control the spread of COVID-19. However, due to the lack of early understanding, China has paid a heavy price. Wuhan had to stop the operation of urban public transport, including the subway, ferry and long-distance passenger transport, starting at 10:00 am on January 23, 2020, and closed the airport and railway stations (cutting the city off from the rest of China). Subsequently, other cities in Hubei Province and then some areas in other provinces also announced lockdowns. Comprehensive measures such as closures of supermarkets, gas stations, hotels and restaurants, and schools, among others, have also been taken in many cities. Many studies have been conducted on the large-scale of this diseases in foreign countries (Holshue *et al.,* 2020; CDC Newsroom, 2020b) in an attempt to find the causes and ways to control its widespread. The genomic characteristics and epidemiology of COVID-19 (Lu *et al*., 2020), clinical characteristics (Chen *et al.,* 2020), and radiologic characteristics (Huang *et al.,* 2020) were studied. Data from the first 425 confirmed cases in Wuhan indicated that human-to-human transmission has occurred among close contacts since mid-December 2019 (Li *et al.,* 2020). Alternative traditional Chinese medical treatments were taken and guidance and treatment suggestions were issued (Wang *et al., 2020).* New antiviral drugs are also being developed, and the clinical effect might be obvious in patients according to the report on the treatment process of the first case in the United States (Michelle *et al.,* 2019). The Markov Chain Monte Carlo model simulation showed that the basic reproductive number of COVID-19 was 2.68, which implied that epidemics were already growing exponentially in multiple major cities of China (Wu *et al*., 2020). Furthermore, Chan *et al.,* (2020) even pointed out that one asymptomatic child had radiological ground-glass lung opacities. The virus carriers might have a long incubation period and could be asymptomatic and infectious, thus becoming super spreaders, which makes COVID-19 more dangerous and more serious than severe acute respiratory syndrome (SARS) as indicated by Peiris *et al.,* (2004) which broke out from Guangdong province in 2003 and spread to Southeast Asia and even the world. The Spring Festival just passed, which was China's largest traditional festival. A large number of population that returned to work moved from city to city and from countryside to urban areas, which accelerated the spread of the virus, creating severe pressure to prevent and control transmission. It is helpful to understand the situation of epidemics by using maps to visualize them and; analyze their geographical patterns. However, until now, there have been few reports on the spatial distribution pattern of COVID-19. To guide epidemic prevention and control and to fight against the virus on the front line (China's Ministry of Science and Technology, 2020), public data from COVID-19 until February 21, 2020 were collected, and the current situation and spatiotemporal pattern were analyzed by means of geospatial analysis to provide prediction and early warning for prevention and control. This study has been carried out in China in 2020. It mainly seeks to determine the national distribution pattern of confirmed cases of COVID-19 at the provincial level in the country, and the factors influencing the spread of the disease. In addition, a brief study on the possible effect of the disease on human development has been discussed and some suggestions have been put forward to help in the control and prevention of the virus in China.

Brief background of COVID-19

Coronaviruses were first identified in the 1960s. The coronavirus belongs to a large family of viruses that cause respiratory infections, and they range from the common cold to serious diseases that include

Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS), according to Fehr *et al.* (2017) and Guo *et al.* (2020). The COVID-19 is a novel coronavirus which was first detected during an investigation into an outbreak in Wuhan of Hubei Province of China (Xu *et al.,* 2020; Ou *et al.,* 2020; and WMHC, 2020). The COVID-19 is a respiratory disease that can be transmitted by zoonotic means, that is by animals or from an infected person to another. In other words, the mode of transmission includes respiratory droplets produced when an infected person sneezes and/or coughs; touching surfaces or objects (for instance, doorknobs, tables) that have the virus on them and then using the same hand to touch one's mouth, nose, eye without first washing one's hands with alcohol-based sanitizing soap under running water.

Characteristics, incubation period and incidence of COVID-19

According to the Chinese Center for Disease Control and Prevention (CDC, 2020c), 585 environmental samples were taken from the Huanan Seafood Market in Wuhan, Hubei province of China, and 33 of the samples were detected to contain COVID-19. This indicates that the disease possibly originated from the sale of wild animals in the market. In China, people at risk of contracting the virus were observed to be those who travelled from Wuhan-the epicenter to other parts of the country during the Spring Festival, also called the 'Chinese New Year'. In addition, people who came into contact with infected persons were also highly likely to contract the disease. Some studies have also showed that persons with compromised immune systems such as the elderly were more susceptible to the disease (NHC, 2020). It has been established that the incubation period of COVID-19 from about 14 days, and up to even 24 days. This situation makes everyone a potential carrier of the virus since asymptomatic persons pose as a threat to the further spread of the virus in many places. The virus affects all ages and gender of persons, probably due to decreased immunologic response to the infection and the metabolic alterations linked with aging in China. Currently, the risk of COVID-19 to children in the transmission process is still unclear, although there has so far been a low rate of confirmed cases among children.

Symptoms, control and preventive measures

In general, the symptoms of COVID-19 have been identified to include the following but not limited to: fever, persistent dry coughs, pneumonia, and shortness in breath, acute runny nose, sore throat, severe headache, and body weakness and/or fatigue. It is important to state that some infected people may not show any of the above-listed signs at all, while others may show mild forms of them and for which they can easily recover. There is currently no vaccine for COVID-19, but good medical care can help treat most of the symptoms. As part of measures to control the disease, persons diagnosed with the virus are required to be quarantined or do self-isolation at their homes until they recover fully. To prevent contracting COVID-19, some of the measures outlined by WHO include avoid making close contacts with infected or potentially infected persons by observing reasonable social distancing, avoid touching one's eyes, nose and mouth with unwashed hands, washing of hands regularly with soap under running water, use of alcohol-based sanitizers on hands often, avoiding overcrowded places, limit travels or movements to likely infected places, eating nutritious food and performing regular physical exercises to boost one's immune system, covering of mouth with a tissue when one coughs or sneezes, and the wearing of face/nose masks when it is needful to visit public places such as shopping malls, or hospitals. In China, some of the measures adopted to control COVID-19 include but not limited to the following: Entry of people into many places such as train and bus stations, subways, seaports and airports, in and supermarkets, premises of companies, and educational institutions require the scanning of a health code. In addition, the temperature of such persons are taken at such places using Thermal infrared imager. These measures are designed to check persons suspected of the disease. The use of face masks when going to public places by individuals has become mandatory. Finally, if a person shows any of the symptoms of the virus, a national ambulance service is immediately contacted to provide the needed assistance, with treatment of the disease being free of charge. To ensure proper disposal of biomedical wastes from hospitals in China during the COVID-19 period, the MEEPRC, (2020) issued guidelines for emergency management and technical treatment for medical wastes on January 28, 2020. In this regard, all medical wastes were

to be collected, transferred, and disposed of with high priority on the same day. The guidelines also stipulated that medical wastes must be collected with yellow bags, and each transshipment vehicle must be equipped with global navigation satellite system (GNSS), and the transportation route must be far away from crowded places. These medical wastes are then incinerated for about 16 hours after being subjected to high temperatures. This study has been carried out mainly to determine the national distribution pattern of the confirmed cases of COVID-19 in China using geospatial analysis. In particular, the study sought to analyze the diffusion spatial pattern of COVID-19, as well as examine at the provincial and prefecture levels, the spatial distribution of the number of cumulative confirmed cases. In addition, the study discussed the potential effect of COVID-19 on human development in the country and has put forward suggestions toward the control and prevention of the disease. The study was conducted in China in 2020.

MATERIALS AND METHODS

Data sources

Public open data collected from the State Health Commission of the People's Republic of China and the Beijing Daily real-time national data on medical knowledge were used in this study.

Method

The COVID-19 real-time data were sorted in spreadsheets and then linked to the national administrative division map through the join command in Geographic Information System (GIS), and the provincial spatial distribution map and the prefecture spatial distribution map were created for spatial analysis. The coordinate system of the map for the density calculation was in the Albers equal-area projection.

RESULTS AND DISCUSSION

Analysis of the current situation

As of 10:00 am on February 22, 2020, the national COVID-19 real-time data statistics were as indicated in Table 1.

Table 1 shows that after almost two months of transmission, the number of confirmed cases was quite large, and the number of existing severe cases is far greater than 10,000, which would cause the deaths to increase dramatically, although the death rate is currently almost as low as 3%. This indicates that the treatment cost was very heavy, and the therapeutic methods need to be improved urgently.

Compared with the 2003 SARS epidemic in China in Table 2, the confirmed cases have exceeded the SARS cases by 14 times, and the number of deaths is almost 7 times that of SARS. Such serious consequences might result from two reasons: on the one hand, human beings were not aware of the features of the virus, such as the long incubation period and the ability for a patient to be asymptomatic and infectious. Another more important aspect was that the early preventive control measures were not in place and data were not made public. The spatiotemporal pattern analysis of COVID-19 was performed here to provide suggestions for preventive control measures to reduce transmission as people returned to work after the Spring Festival.

Fig. 1 shows that before February 9, 2020, the existing confirmed cases and suspected cases continued to increase, and the two were close to equal. By February 12, the number of new cases had increased rapidly, leading to a significant reduction in the suspected cases. To date, existing cases have maintained high values. According to statistics from the National Health Commission of the People's Republic of China (NHC, 2020), the average hospitalization days of discharged patients

Table 1: Real-time national data statistics for COVID-19

Confirmed cases	Suspected cases	Deaths	Cured cases	Existing severe cases
76,392	5,365	2,348	20,673	11,477

Table 2: SARS data statistics (Ministry of Health, 2003)

Confirmed cases	Deaths	Cured cases	Death of other diseases
5327	349	4959	19

nationwide was 9 days, and the average hospital stay of patients in Hubei Province was 20 days. Therefore, it was estimated that at the end of February, it was difficult to reduce the number of confirmed cases on a large scale. Further statistics also showed that more than 80% of the deaths had been in patients treated for less than two weeks. Therefore, we inferred that after two weeks, that is, in early March, there would be a significant reduction in the existing number of cases, and the number of deaths might increase. A higher number of suspected cases would have a greater risk of missed treatment and transmission probability. To ensure the safety of resumption of work, a comprehensive investigation of the suspected cases should be conducted as much as possible to minimize the suspected cases and prevent the spread of the epidemic. Door-to-door screening by people has been necessary until now, and the overall geographical distribution analysis could provide a more macro-scale vision and an overall organized layout.

Province-level spatial distribution

The cumulative number of COVID-19 cases until February 2 were collected for every province and mapped using GIS software, as shown in Fig. 2. A

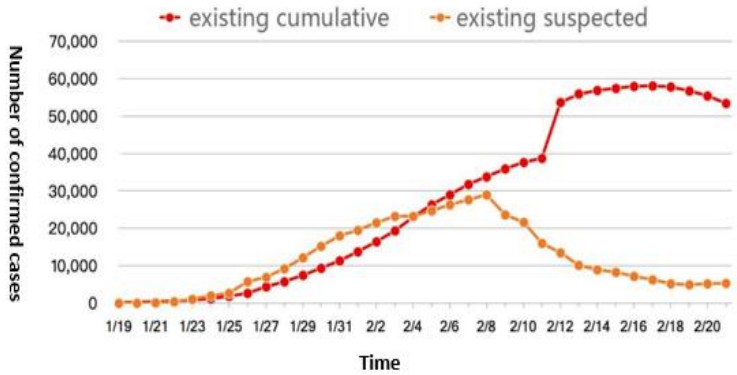

Fig. 1: Trends in the existing confirmed and suspected cases of COVID-19

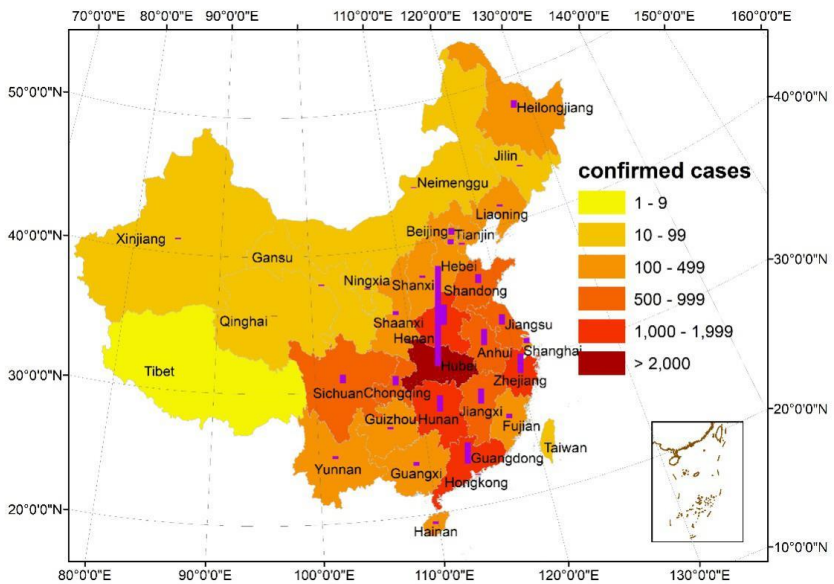

Fig. 2: Provincial spatial distribution of the cumulative confirmed COVID-19 cases (Note: the color indicates the relative level of confirmed numbers, the purple histogram indicates the confirmed number, and the number of cases in Hubei has been divided by 10)

gradient of six colors that moved from yellow to red were used to represent the classification level of the case numbers, and the purple bars are proportional to the numbers of cases, except the number for Hubei, which was divided by 10 because its original value was too large to display.

Fig. 2 shows that the number of confirmed cases of COVID-19 in Hubei Province was the largest. By the end of writing this paper (February 21, 2020), there was a total of 62,031 cumulative confirmed cases in Hubei Province and 12,642 in the rest of China, so Hubei accounted for 83% of the total cases of China. The provinces adjacent to Hubei in the north, south, and east, including Hebei, Hunan, Anhui, and Jiangxi, had many cumulative confirmed cases. Among them, the number in Hunan and Henan was more than 1,000. These two provinces are located on the main artery of the Beijing-Guangzhou line. It could be seen that the closer the distance, the more convenient the traffic, and the more frequent the circulation and exchange of people, which increased the probability of the spread of the virus. The provinces with a large number of confirmed cases that are far away from Hubei Province were mainly Zhejiang and Guangdong. They are two major economic provinces in China and are inhabited by many migrant workers. This also indicates that the prevention and control measures in the early stage were not timely and that the measures were not suitable. Now, the COVID-19 has spread across provinces and has entered into a proliferating pattern, which has brought serious challenges to national prevention and control and will therefore bring a heavy cost. With Hubei as the geographical center, the number of confirmed cases spread to all provinces in China. The spread to the east was faster than that to the northwest and southwest. It was estimated that this spatial pattern had much to do with the traffic and economic conditions because the superior economic conditions in the eastern region had formed an obvious attraction for the potential population flow, and the convenient traffic provided a corridor for actual population flow.

With natural breaks as the classification method for the pattern of confirmed cases, the spatial pattern map in Fig. 3 shows that China could be divided into 4 spatial distribution pattern regions, which are described in Table 3: Hubei was the first-level core region. The provinces to the east and south of Hubei, including Hunan, Henan, Jiangxi, Anhui, Zhejiang and Guangdong, formed the second concentrated region. The provinces to the west of Hubei, including Chongqing and Sichuan, and the provinces in the northeast and southeast, such as Shanghai, Jiangsu, Shandong, Hebei, Tianjin, Beijing and Fujian, comprised the third buffer distribution region. The rest of the provinces the north, south and west

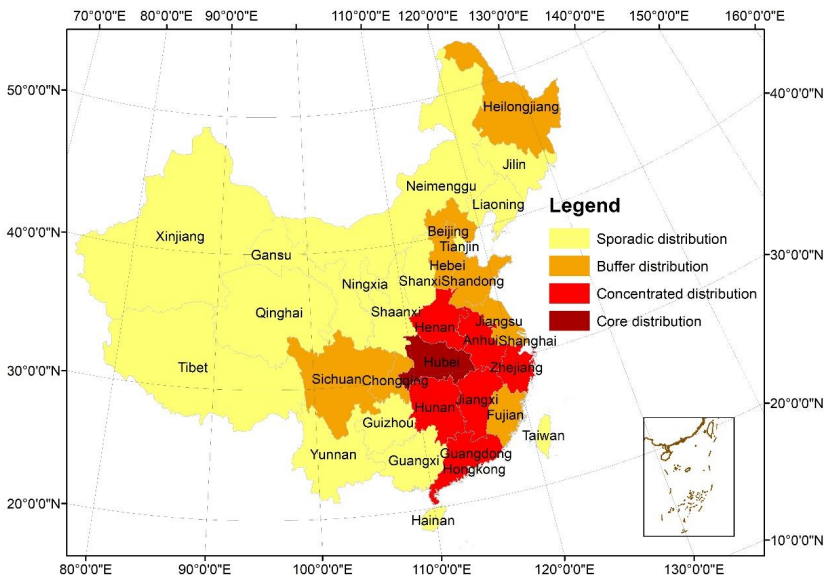

Fig. 3: Provincial spatial pattern of the cumulative confirmed COVID-19 cases

comprised the fourth sporadic distribution region. One abnormality was that Heilongjiang had a relatively large number of confirmed cases, although it was far from Hubei and had low economic attractiveness. This might have resulted from factors such as older age, a higher prevalence of lung diseases caused by cold climates, and a more serious traditional habit of reunion. However, specific scientific reasons require further research, and more attention should be paid to avoid agglomerative transmission.

Prefecture spatial distribution

Fig. 4 indicates the spatial distribution of density (people per 100 km^2) of cumulative confirmed cases COVID-19 at the prefecture-level with color indicating case density and the purple bars indicating total cases (the cases in Wuhan had been divided by 10).

As can be seen in Fig. 4, (a) COVID-19 spatial pattern in Hubei Province, (b) Hunan Province prevention and control schematic diagram, (c) national spatial pattern respectively. Fig. 4 shows that in Hubei Province, there were many confirmed cases in the east, which gradually decreased to the western part of the province. Wuhan had the largest numbers, and the statistical data showed that Wuhan, which had a density of 525 cases per 100 km^2 by the end of February 2020, actually had 45,027 cases in total, accounting for 73% of the number of cumulative confirmed cases in Hubei Province. For the areas outside of Wuhan, Ezhou, which had a density of 84

Table 3: National spatial distribution pattern of the cumulative confirmed COVID-19 cases

Level	Pattern	Provinces	Description
1	Core distribution	Hubei	Hubei
2	Concentrated distribution	Hunan, Henan, Jiangxi, Anhui, Zhejiang, Guangdong	Adjacent to Hubei, or close economic and traffic connection with Hubei
3	Buffered distribution	Chongqing, Sichuan, Shanghai, Jiangsu, Shandong, Hebei, Tianjin, Beijing and Fujian	Not many economic and traffic connections with Hubei
4	Sporadic distribution	Other provinces	Far from Hubei or with fewer economic and traffic connections with Hubei

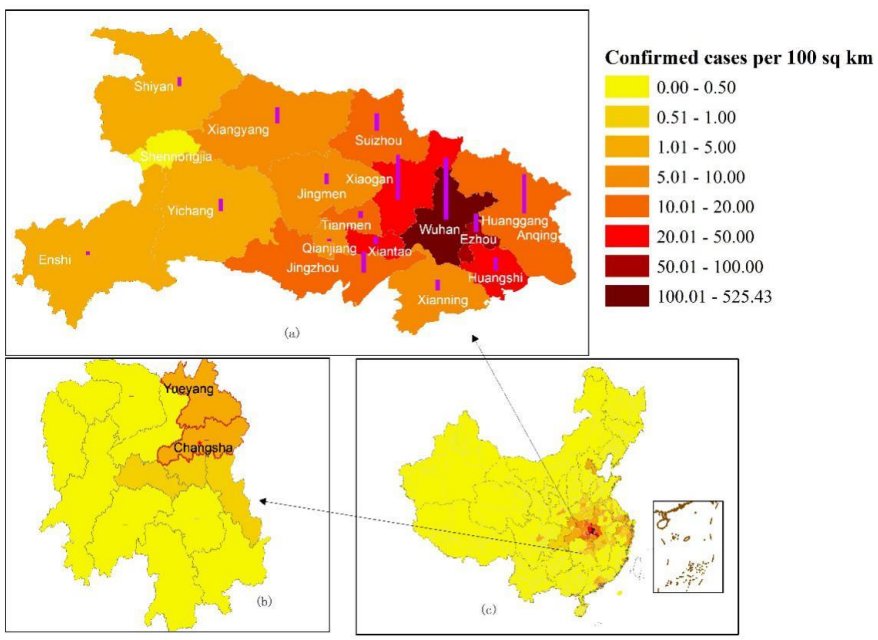

Fig. 4: Spatial distribution of density (people per 100 km^2) of cumulative confirmed cases

cases per 100 km^2, had the second largest density of cumulative confirmed cases, and Xiaogan, which had 3329 cases in total, had the second largest number of cases. Based on absolute cumulative confirmed cased, density and spatial position, the distribution pattern of the confirmed cases in Hubei Province also showed four classifications in Fig. 5. Wuhan was the most severe region, the eastern provinces were a relatively severe region, the middle provinces were a generally severe region and the western provinces were a sporadic region. Each region is further described in Table 4. The surrounding areas of Wuhan require considerable attention to avoid large human-to-human transmission (Wei and Ren, 2020; Zhou *et al.,* 2020).

Due to the closure of transportation, people in Hubei were most likely to go out to other provinces by private cars. Because of the superior factors of short distance, warm climate, and low prices, southern Hunan Province became the most attractive destination for population flow from Hubei. Therefore, Yueyang city, which was close to Hubei Province, and Changsha city, the capital of Hunan Province, had a larger trend of population flow and faced great pressure for prevention and control, as shown in Fig. 5.

Influence of population distribution pattern on the confirmed cases of COVID-19

The Huanyong Hu line (Hu, 1987) also known as 'Ai Hui-Tengchong line' has been widely used to differentiate between the natural and human regions in China the line was proposed by Huanyong Hu and has been shown by many theories and practices (Chen *et al.,* 2016). Figure 6 below shows that east of the Hu Huanyong line, the population density was high, and all provinces and even almost all prefectures had confirmed cases and showed a clustering distribution.

However, to the west of the Hu Huanyong line, the population density was small, and most areas had no confirmed cases, showing a sporadic distribution pattern as shown in Fig. 6. The population was a

Table 4: Classification of COVID-19 cumulative confirmed case in Hubei Province

Level	Classification	Prefectures	Position
1	Most severe	Wuhan	Wuhan
2	Quite severe	Xiantao, Xiaogan, Huanggang, Ezhou, Huangshi, Xianning	East
3	Generally, severe	Xiangyang, Suizhou, Jingmen, TianMen, Qianjing, Jingzhou, Yichang	Middle
4	Less severe	Enshi, Shiyan, Shennongjia	West

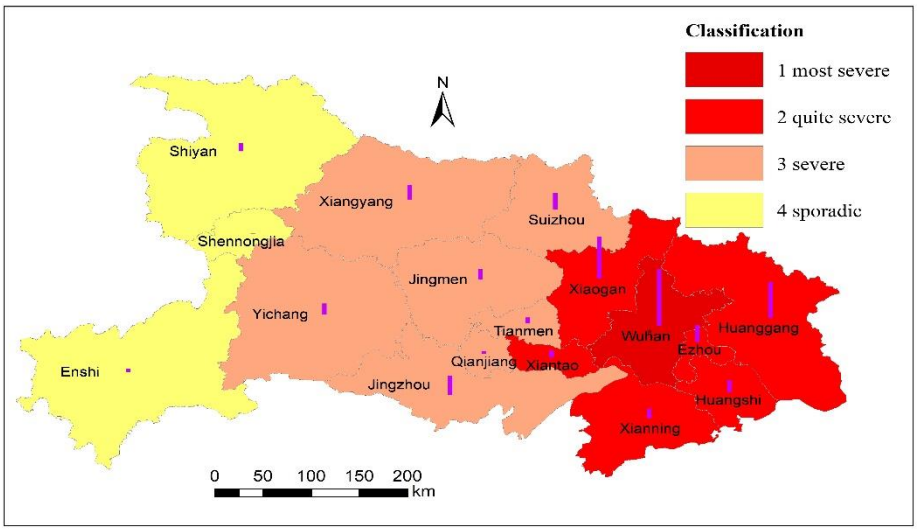

Fig. 5: Spatial pattern of cumulative confirmed cases in Hubei province

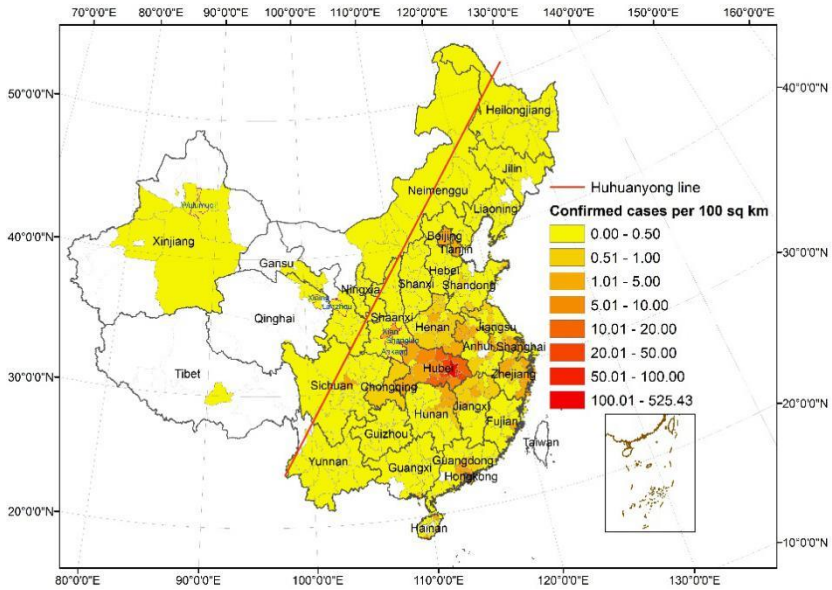

Fig. 6: Influence of the population distribution pattern on the cumulative confirmed cases based on the Huanyong Hu line

substantial factor influencing the density of COVID-19 cases. Therefore, we could infer that the cities near the Hu Huanyong line were important prevention and control nodes that had strategic significance for blocking the transmission of COVID-19.

Potential effect of COVID-19 on human development

Although, it might seem still early for researchers and development partners to quantify the negative effect of the COVID-19 on various aspect of human life in China, there appear some indicators of worrying concerns. On education, re-opening of basic schools and have colleges have been delayed by some four months (February-May, 2020). Even though, the use of online learning became necessary, it is estimated that about 80% of children at the basic schools were not effective due to lack of access to reliable and uninterrupted internet services especially in the rural areas of China. At the College level, many students also experienced intermitted breaks during online teaching sessions, it is even worse for international students who have returned to their home countries during the Spring Festival holidays or Winter holidays. Further still, the national per capita income of China in the current year is projected to decline to all-time low figures since the reforms era. Therefore, global human development, measured in terms of basic education, primary healthcare and living standard are likely to decline for the first, especially in developing countries like China, since the introduction of the concept in 1990 (UNDP, 1990). Livelihoods of many Chinese could be affected negatively (Waren *et al.,* 2020). The informal sector of the economy could also be negatively affected as found out in other countries (Amoah-Nuamah *et al.,* 2020). Some other effects of COVID-19 on human development has been found to be the quality of air to human survival in developing countries (Isaifan, 2020).

CONCLUSION

China, as the most populous country in the world and the first nation affected with the COVID-19, this paper studied the spatiotemporal pattern of COVID-19 from the time it started until February 21, 2020. This is to provide a clearer understanding of the spread of COVID-19 and its potential effect on development, and to provide theoretical support for epidemic prevention and control. Comprehensive means, such as delaying work and school and promoting online office work and teaching, among others, must be taken to fight against the spread of the infection after the Spring Festival, especially for geographical areas with mass distributions of confirmed cases. Open information about the geographical distribution of the

epidemic and scientific decision-making will play an important role in defeating COVID-19. The treatment process of the first confirmed case of COVID-19 in the United States demonstrated the importance of close coordination and rapid dissemination between clinicians and public health authorities at the local, state, and country levels. The distribution pattern of confirmed cases provided spatially explicit information to carry out scientific prevention and control measures and to implement large-scale public health interventions. We will continue to track the progress of the epidemic in a timely manner, conduct spatiotemporal analyses, and analyze the geographic process of transmission. On some of the ways to help reduce the effect of COVID-19 on human development of the people of China, the following suggestions have been put forward. There is the need for the government of China to begin to implement equity-focused approaches that are affordable, by narrowing the gap in access to internet for rural dwellers. This can help improve online learning, online-medicine and working from home. In addition, special interventions that can help the economy and rural communities to mitigate the far-reaching effect of the COVID-19 epidemic should be quickly rolled out. This study is contributed significantly to the literature on COVID-19 in developing countries such as China, by expanding the knowledge on the distribution pattern of the disease. In addition, the study reveals the role played by traffic due to population as a precautionary measure in controlling the spread of the disease in China.

AUTHOR CONTRIBUTIONS

X. Xie and E.Y. Naminse designed the study and X. Xie was responsible for the initial paper write up. E.Y. Naminse was also responsible for the literature searches, data analysis and editing. S. Liu and Q. Yi assisted with the manuscript's subsequent writing and revisions. Finally, all authors have read and approved of the final manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no potential conflicts of interests regarding the publication of this work. The ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

CDC	Chinese center for disease control
COVID-19	Coronavirus disease 2019
Fig	Figure
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
km²	square kilometer
MEEPRC	Ministry of Ecology and Environment of the People's Republic of China
MERS	Middle East Respiratory Syndrome
NHC	National Health Commission
%	percent
SARS	Severe Acute Respiratory Syndrome
SHCPRC	State Health Commission of the People's Republic of China
UNDP	United Nations Development Programme
WHO	World Health Organization
WMHC	Wuhan Municipal Health Commission

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