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Original Article

Socio-Economic Factors Affecting the Regional Spread and Outbreak of COVID-19 in China

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Abstract

Background: This study investigated the impact of socio-economic factors on the spread and outbreak of COVID-19 based on Chinese data.

Methods: Cumulative confirmed cases were collected and divided into the First-stage cases cluster dominated by imported cases, and the Second-stage cases cluster dominated by secondary cases, according to the time of emergency state and Wuhan city lockdown. The linear regression was used for data analysis.

Results: A total of 12,877 cases in 30 provinces were analyzed in the study. The First-stage cases cluster included 675 cases and Second-stage cases cluster included 12,202 cases. The socio-economic factors were significantly associated with the cases (P<0.05). The GDP and proportion of population moving out of Wuhan were associate with the First-stage dominated by imported cases (β>0, P<0.05). The First-stage cases cluster, proportion of population moving out of Wuhan and urban population were associate with the Second-stage dominated by secondary cases (β>0, P<0.05).

Conclusion: Socio-economic factors had impacts on the spread and outbreak of COVID-19. The combination of different socio-economic indicators at different stages of the epidemic may help control the epidemic.

Keywords: Socio-economic; COVID-19; Epidemic; Spread; Outbreak; China

Introduction

Since Dec 2019, novel coronavirus disease (COVID-19) emerged in the world and has been become a global pandemic. In the early stage, Wuhan City, Hubei Province of China reported confirmed cases (1). COVID-19 spread and broke out across China rapidly during a few days before the Spring Festival. The WHO declared that COVID-19 was a Public Health Emergency of International Concern on February 5th, 2020 (2). As of Jan 2nd, 2021, COVID-19 has swept more than 200 countries, and the cumulative global confirmed cases was more than 84,000,000 and more than 1,800,000 patients (including health-care workers) died, of which the United States, India, Brazil, Russia, France and Britain were more serious (https://ncov.dxy.cn/ncovh5/view/pneumonia). To prevent the further development of COVID-19, most countries declared a state of emergency and took a lockdown, residents segregated themselves at home. The pandemic has brought a huge blow to social stability, global economy and a great threat to people's health.

In the early stage, people lacked enough knowledge in characteristics of the novel coronavirus and its' early situation. COVID-19 spread across China along with population migration and transportation before the Spring Festival. As Jasmina suggested, we also ought to view socio-economic driving factors as parts of a puzzle that needs to be built to give the full picture of how best to tackle COVID-19 spread (3). But few researches about COVID-19 paid attention to the socio-economic driving factors for the spread and outbreak of the epidemic.

Epidemic diseases are not only medical but also social events, it's necessary to involve socio-economic factors in analysis (4, 5). We found that the distribution of COVID-19 in China was quite different among provinces except for Hubei province (the epidemic area). This distribution seemed to be related to the economic conditions among provinces. Research also found that Chinese GDP growth are closely related to the incidence of Class B notifiable diseases (5). We hypothesized that socio-economic factors may influence the spread of COVID-19. And the transportation network has been an important factor in the spread of SARS, MERS and so on (6, 7). But are there any other regional characteristics affect the spread and development of COCID-19?

In this study, we aimed to investigate the relationship between socio-economic factors and the spread of COVID-19 and establish quantitative relationships between them. We hoped our findings could reveal the important factors affecting the spread of COVID-19 and help to prevent and control the epidemic.

Materials and Methods

Study Design

A data analysis among 30 provinces and 100 cities in China was conducted to explore the impact of socio-economic factors (economy, population and transportation) on the spread and outbreak of COVID-19 across China, based on the actual situation on population movement during Spring Festival Travel Rush (the annual population movement from workplace to domicile for family reunion during Spring Festival) and epidemic control. The National Health Commission of the People's Republic of China has determined that data collection and analysis of cases and close contacts of COVID-19 to be part of a continuing public health outbreak investigation and were thus considered exempt from institutional review board approval (8).

Data collection

Confirmed cases

The public data of confirmed cases (n=78 064) regarding COVID-19 as of 24:00 February 25, 2020, was collected from the National Health Commission of the People's Republic of China (http://www.nhc.gov.cn).

Socio-economic factors

Socio-economic factors were obtained from China Statistical Yearbook(2019) of the National Bureau of Statistics of China (http://www.stats.gov.cn/tjsj/ndsj/) and Chinese Baidu Map (https://map.baidu.com) that were recorded as **A.** Gross Domestic Product (GDP, Ten Billion Chinese Yuan, refer to final output results of the economic production activities in a certain period (2018) in a region). **B.** Passenger Traffic (Ten Thousand Persons, refer to the actual number of passengers transported by railway, highway and waterway within a certain period (2018) in a region). **C.** Passenger Traffic of Railways (Ten Thousand Persons). **D.** Passenger Kilometers (100 Million Passenger-Kilometer, refer to the product of the number of passengers was transported and the average distance traveled by region in a certain period (2018)). **E.** Passenger Kilometers of Railway (100 Million Passenger-Kilometer). **F.** Urban Population (Ten Thousand Persons, refer to the total number of people living in cities and towns (2018) of a region). **G.** Population Density (population number Per Square Kilometer, refers to the number of population (2018) per unit area (square kilometers)). **H.** Distance (Kilometers, refer to the shortest highway mileage (January 2020) from a region's administrative Center to Wuhan. **I.** The Proportion of Population Moving Out of Wuhan (percentage (%), the ratio of the population moved out from Wuhan in provinces or cities divided by the total number of people moved from Wuhan from Jan 1 to Jan 23, 2020).

The data of Statistical Yearbook (2019) in the research belong to 2018, and the latest data in 2019 has not been released. Hence, socio-economic factors of China Statistical Yearbook on GDP, Passenger Traffic, Passenger Kilometers, Urban Population and Population Density in the recent five years were collected and were used to analyze the stability of data in Yearbook and representativeness of the data in 2018.

Data classification

The main analysis was conducted in 30 provinces of China. Taiwan, Hong Kong and Macao were excluded because of special management policy, and Hubei province was excluded as an epidemic area. Then the data verification among100 cities was conducted (including 85 cities out of Hubei province and 15 cities in Hubei province except for Wuhan city). Data on GDP and the proportion of population moving out of Wuhan were fully collected (100%) in all cites. The rest factors could not be fully collected.

Analysis for 30 provinces

The actual imported cases and secondary cases among provinces cannot be obtained. The total cases were divided into the First-stage cases cluster dominated by imported cases and Second-stage cases cluster dominated by secondary cases.

First-stage cases cluster

The cases cluster was dominated by imported cases. In the early stage of COVID-19 before strictly epidemic control, the cases out of Hubei province were mainly imported cases from epidemic areas, which determined the later epidemic development. On Jan 23, 2020, China announced the lockdown of Wuhan city. With the majority of provinces under the state of emergency of the highest level in China, people began to be quarantined at home and the cases import were almost stopped after January 23, 2020. Combining the median incubation period of COVID-19 (4.8 days) and the median days from the onset to the diagnosis (1 day) after Janu 22 (8, 9), the accumulative confirmed cases as of 24:00 Jan 29 among provinces were regarded as First-stage cases cluster in the study.

Second-stage cases cluster

The cases cluster was dominated by imported cases, which closely related to the contact with imported cases. On Feb 19, a related apartment in China formulated "Relevant Opinions on Adjusting the Emergency Response of COVID-19 Prevention and Control at the Region below Provincial Level", and more than 80% of provinces have completed the production resumption on Feb 26. So, the accumulative confirmed cases from Jan 29 to Feb 25 were regarded as Second-stage cases cluster in the study.

Ethical approval

The National Health Commission of the People's Republic of China has determined that data collection and analysis of cases and close contacts of COVID-19 to be part of a continuing public health outbreak investigation and were thus considered exempt from institutional review board approval.

Statistical Analysis

R software, version 3.6.2 was used for statistical analysis. The Scatter plot was used to analyze the trend between cases and socio-economic factors. Natural log (Ln) transformation in population density was performed (data were not shown). Then linear regression analysis was adopted to explore the associations between the socio-economic factors and cases. Collinearity analysis was used to examine the multicollinearity. The best subset model selection method was used to find a suitable multi-factor model, and the goodness-of-fit was validated. *P* value < 0.05 was considered as statistically significant. The outliers were excluded in sensitivity analysis to verify the robustness of the results. The specific data processing and analysis are shown in Fig. 1.

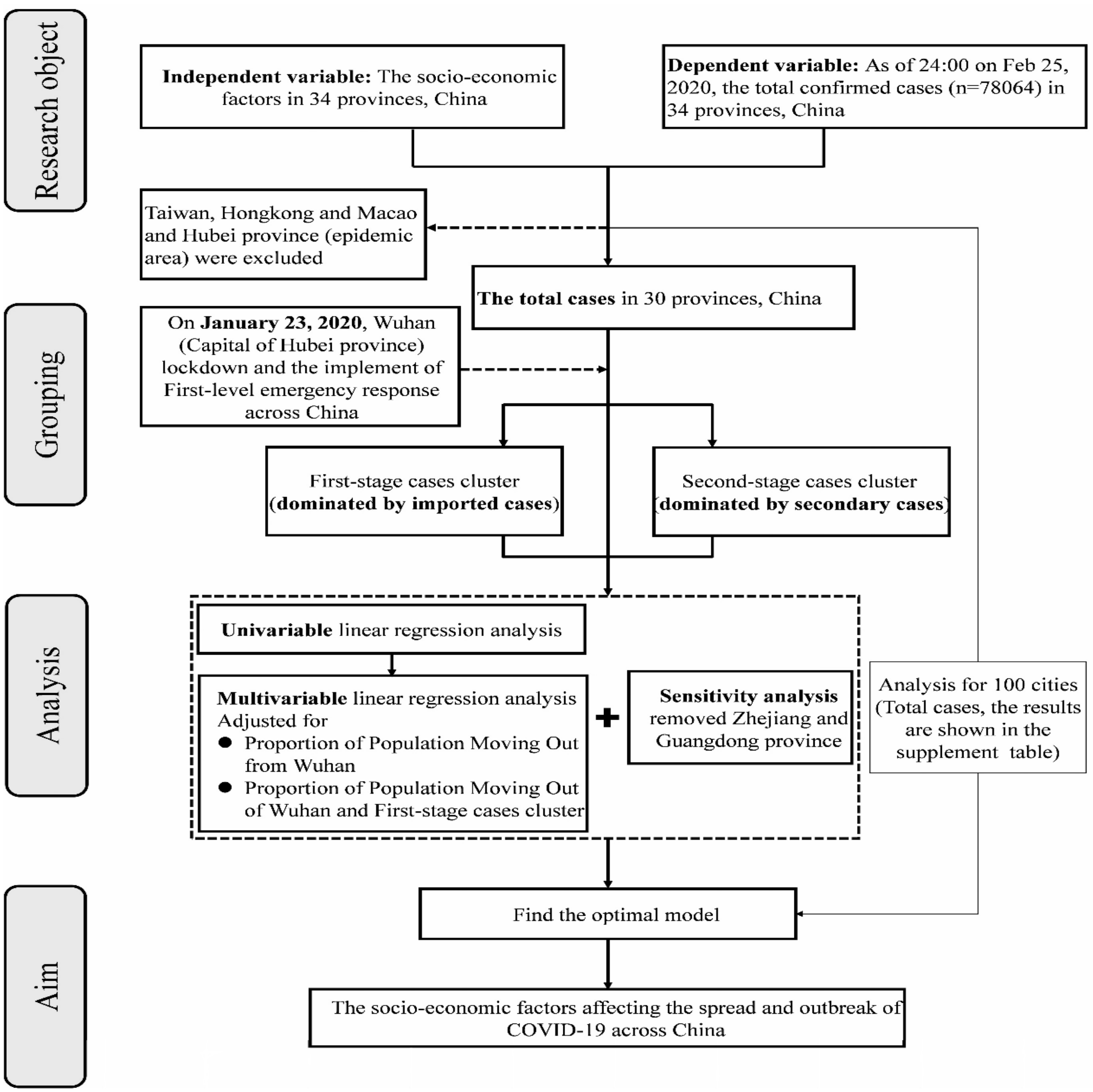

Fig. 1: Flow Chart of this Study

Results

Analysis for 30 provinces

As of 24:00 Feb 25, 2020, there were 78,064 cases of COVID-19 in China and 12,877 cases in 30 provinces. First-stage cases cluster included 675 cases and Second-stage cases cluster included 12,202 cases (Fig. 2).

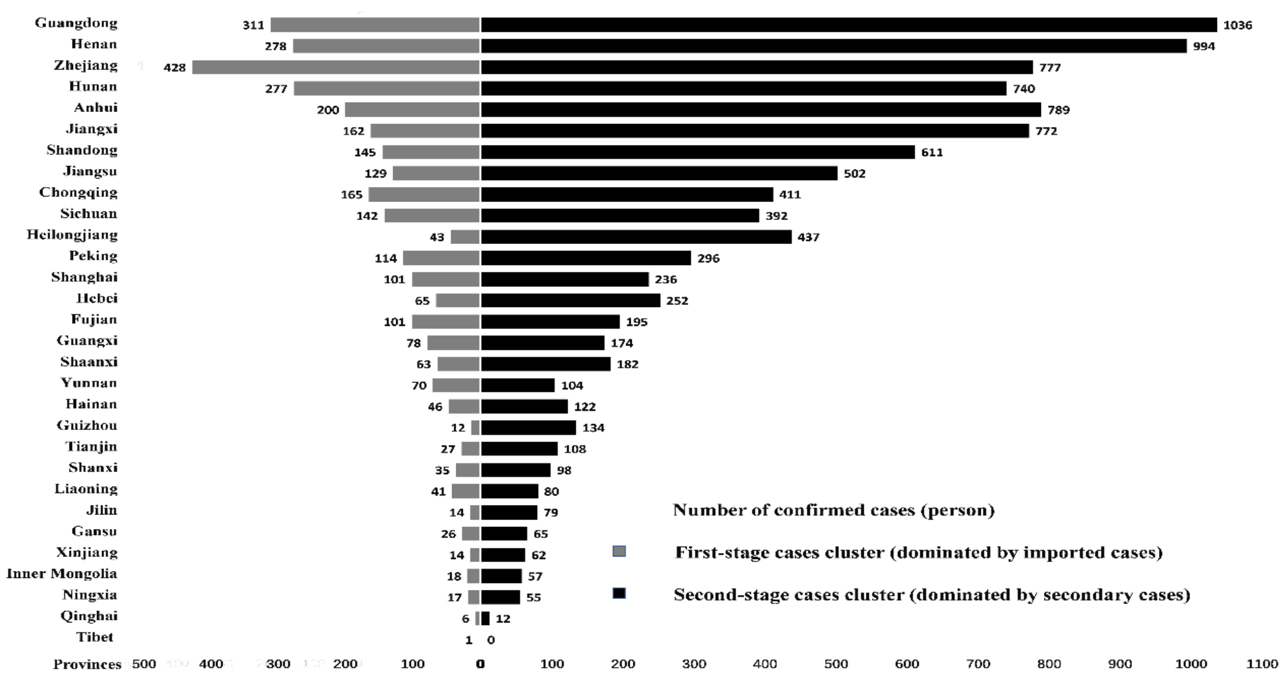

Fig. 2: The number of confirmed cases (person) of the total cases, First-stage and Second-stage cases cluster among 30 provinces, China

The gray bar graph represents the First-stage cases cluster (dominated by imported cases), the black bar graph represents the Second-stage cases cluster (dominated by secondary cases)

Table 1 presents the median and interquartile range (IQR) of socio-economic factors and univariate analysis for provinces. There were significant linear relationships between cases and socio-economic factors. The distance to Wuhan was negatively associated with Total cases, First-stage and Second-stage cases cluster ($\beta_{\text{Total cases}}$: -0.312, 95%CI: -0.481, -0.143. $\beta_{\text{First-stage cases cluster}}$: -0.079, 95%CI: -0.123, -0.035. $\beta_{\text{Second-stage cases cluster}}$: -0.233, 95%CI: -0.363, -0.103), while other factors were positively associated with the Total cases, First-stage and Second-stage cases cluster (all $\beta>0$, $P<0.05$).

After adjusted for the Proportion (proportion of population moving out of Wuhan), the GDP, passenger traffic, passenger traffic of railways, passenger kilometers, passenger kilometers of railway and urban population were also positively associated with Total cases and Second-stage cases cluster. Except for the passenger kilometers of railway, population density and distance to Wuhan, the rest factors were still positively associated with First-stage cases cluster. After adjusted for the Proportion and First-stage cases cluster, the GDP, passenger traffic of railways, passenger kilometers, urban population were positively associated with more cases of total cases. In sensitivity analysis for the First-stage cases cluster, the trend of results was consistent with original analysis adjusted for Proportion.

Table 1: Univariate Linear Regression between cases of COVID-19 and social-economic factors in 30 provinces of China

Variables	*Median (IQR)*	*Total cases*	*First-stage cases cluster*	*Second-stage cases cluster*
		β (95%CI)	β (95%CI)	β (95%CI)
GDP	211.740 (211.066)	1.194 (0.737,1.650) *	0.290 (0.166,0.415) *	0.903 (0.553,1.254) *
Passenger Traffic	48018.000 (56678.000)	0.008 (0.006,0.011) *	0.002 (0.001,0.003) *	0.006 (0.004,0.008) *
Passenger Traffic of Railways	11026.500 (8920.500)	0.045 (0.031,0.059) *	0.011 (0.008,0.015) *	0.034 (0.023,0.044) *
Passenger Kilometers	617.350 (796.678)	0.614 (0.438,0.790) *	0.140 (0.087,0.194) *	0.474 (0.342,0.605) *
Passenger Kilometers of Railway	354.010 (555.480)	0.943 (0.626,1.260) *	0.214 (0.120,0.307) *	0.729 (0.493,0.966) *
Urban Population	2256.858 (2395.820)	0.171 (0.117,0.224) *	0.040 (0.024,0.055) *	0.131 (0.091,0.171) *
Population Density [a]	277.003 (448.609)	129.045 (39.153,218.937) *	33.202 (9.912,56.493) *	95.842 (26.777,164.908) *
Distance [b]	1097.950 (730.825)	-0.312 (-0.481, -0.143) *	-0.079 (-0.123, -0.035) *	-0.233 (-0.363, -0.103) *
Proportion [c]	0.670 (0.948)	286.29 (203.437,369.143) *	65.162 (39.767,90.556) *	221.128 (159.481,282.775) *

Notes: [a] Population Density was transformed by Ln. [b] Distance: the distance from the provincial capital of provinces to Wuhan (the provincial capital of Hubei province). [c] Proportion: the proportion of population moving out of Wuhan. * $P<0.05$

Analysis for 100 cities

Within the cities of Hubei, the higher Proportion was associated with increased cases (β: 231.910, 95%CI: 192.958, 270.861). The increased GDP (β: 1.130, 95%CI: 0.901, 1.359) and Proportion were positively related to the cases (β: 182.003, 95%CI: 144.859, 219.146) for cities out of Hubei province in sensitivity analysis. And the increased urban population (β: 0.144, 95%CI: 0.104, 0.183), passenger traffic of highway (β: 0.008, 95%CI: 0.006, 0.010) were also associated with increased cases in cities out of Hubei province in sensitivity analysis.

Best subset model selection

The suitable multi-factors models are shown in Table 2**.** Model 2 was closely associated with the total cases, can well explain the variation for total cases ($\beta_{urban\ population}$:0.043, 95%CI: 0.012, 0.074. $\beta_{Proportion}$:86.466, 95% CI: 35.561, 137.371 and $\beta_{First\text{-}stage\ cases\ cluster}$:2.441, 95% CI: 1.815, 3.067, R^2=0.932). For First-stage cases cluster, Model 1 was closely associated with the cases after sensitivity analysis (β_{GDP}:0.132, 95%CI: 0.067, 0.197. $\beta_{Proportion}$: 51.815, 95%CI: 38.248, 65.381. R^2=0.832). For Second-stage cases cluster, Model 2 were closely related to the cases ($\beta_{urban\ population}$:0.043, 95%CI: 0.012, 0.074. $\beta_{Proportion}$: 86.466, 95%CI: 35.561, 137.371 and $\beta_{First\text{-}stage\ cases\ cluster}$: 1.441, 95%CI: 0.815, 2.067. R^2=0.883). In addition, Model 1 was closely positively associated with the cases in cities (β_{GDP}: 0.767, 95%CI: 0.522, 1.012 and $\beta_{Proportion}$: 208.861, 95%CI: 146.888, 270.834. R^2=0.637). All variables in models were significant ($P<0.05$), there was no significant multicollinearity (all tolerance>0.1).

Table 2: The best subset model analysis in regression analysis for cases in 30 provinces and 100 cities of China

Model	Variables	Parametric for cases in best subset model		
		β (95%CI)	Tolerance	Adjusted R^2
		Total cases cluster in 30 provinces		
Model 1	GDP	0.731 (0.391,1.072) *	>0.10	0.776
	Proportion [a]	214.815 (142.297,287.333) *	>0.10	
Model 2	Urban Population	0.043 (0.012,0.074) *	>0.10	0.932
	Proportion [a]	86.466 (35.561,137.371) *	>0.10	
	First-stage Cases cluster	2.441 (1.815,3.067) *	>0.10	
		First-stage cases cluster (dominated by imported cases) in 30 provinces [b]		
Model 1	GDP	0.132 (0.067,0.197) *	>0.10	0.832
	Proportion [a]	51.815 (38.248,65.381) *	>0.10	
Model 3	Passenger Traffic of Railways	0.005 (0.003,0.008) *	>0.10	0.863
	Proportion [a]	47.896 (35.215,60.577) *	>0.10	
		Second-stage cases cluster (dominated by secondary cases) in 30 provinces		
Model 1	GDP	0.541 (0.287,0.768) *	>0.10	0.785
	Proportion [a]	168.248 (114.072,222.424) *	>0.10	
Model 2	Urban Population	0.043 (0.012,0.074) *	>0.10	0.883
	Proportion [a]	86.466 (35.561,137.371) *	>0.10	
	First-stage Cases	1.441 (0.815,2.067) *	>0.10	
		Cases in cities		
Model 1	GDP	0.767(0.522,1.012) *	>0.10	0.637
	Proportion [a]	208.861(146.888,270.834) *	>0.10	

Notes: Proportion [a]: the proportion of population moving out of Wuhan. [b] the results for First-stage cases cluster in 30 provinces in sensitivity analysis exclude the data in Zhejiang and Guangdong province

Discussion

This research explored and quantify the influence of socio-economic factors on the COVID-19 situation for the first time. The results showed that socio-economic factors had important impacts on the confirmed cases. Model 2 (urban population, Proportion and First-stage cases cluster), Model 1 (GDP and Proportion) and Model 2 had more impact on the total cases, the First-stage cases cluster (dominated by imported cases) and Second-stage cases cluster (dominated by secondary cases), respectively.

The influences of COVID-19 on global society

As of Dec 2020, the cumulative confirmed case was more than 84,000,000 and died case was more than 1,800,000 worldwide. The global pandemic of COVID-19 brought multiple impacts, such as economic recession, the stock market fell, industrial chain interruption, commodity supply difficulties. It has been estimated economic losses caused by a major influenza as high as $7.3 trillion—a downturn on par with the Great Depression (10). Researchers are making contributions to control COVID-19. However, researches mainly focused on clinical characteristics, treatment and epidemiological study (1, 9, 11-13), less discussed the impact of socio-economic drivers on COVID-19 but mitigating the risks from infectious diseases requires preemptive measures against their social drivers.

The effects of socio-economic factors on the First-stage cases cluster dominated by imported cases

We found that Model 1 combined GDP and Proportion was closely related to the First-stage cases. GDP is a core indicator of regional productivity, could effectively reflect regional infrastructure (such as transportation), government management and industrial structure. A region with higher GDP represents a higher level of salary, transportation development and tertiary industry. The demand for talents and labor force is greater (14-16), then the imported cases from epidemic area are more. Researches confirmed that population movement sets a condition for the spread of infection, which was consistent with SARS and MERS, the primary mechanism for the spread of infection from a city to other cities is population movement (4, 17). This explains well the great effect of model 1 on the First-stage cases cluster. Although Model 3 (R^2=86.6%) also significantly related to First-stage cases cluster with better goodness of fit than model 1. But GDP as a comprehensive indicator, it is more proper to explain the influence compared to other factors such as passenger traffic of railways population in Model 3.

The results of the sensitivity analysis for First-stage cases cluster after excluding Zhejiang and Guangdong province were similar to the primary results. Zhejiang and Guangdong province were the top 2 in China's GDP for many years, the mobile population accounted for 1/3 in total provincial population. Guangdong province concentrated the cities of Guangzhou, Shenzhen and Zhuhai with huge scale of economy and population (18, 19), which contributed to increased risk of COVID-19. For Zhejiang provinces, the industry of manufacturing, traffic and logistics are developed, many people are businessmen with frequent traveling. It is reported that 33,000 people of Wenzhou city (a city in Zhejiang province) returned from Wuhan and surrounding areas (20). And businessmen had more social activities were more likely to be infected (21), which may explain so many cases in Zhejiang Province.

The effects socio-economic factors on the Second-stage cases cluster dominated by secondary cases

Results pointed that model 2 combined urban population, Proportion and First-stage cases cluster was considered suitable to the Second-stage cases cluster.

The Proportion and First-stage cases represent the basis of cases import that influenced the further development of epidemic. Urban population also played an essential role in epidemic development and reflects region's population density and mobility. As urbanization deepens, more population is concentrated in cities, which provides a hotbed for infection such as the outbreak of Ebola virus in African cities, SARS in Hongkong and Pearl River Delta in China (10). But finally, the population density did not make sense in the study, the difference may be caused by that the population density was calculated in units of provinces rather than cities. In addition, the higher prevalence of other diseases in cities also increases vulnerability to infection. This also explains why the patients of COVID-19 are mostly elderly (9). Overall, the risk of epidemic is exacerbated by the concentration and interconnectedness of human populations associated with urbanization.

The effects of socio-economic factors on total cases

We found model 2 combined urban population, Proportion and First-stage cases also had more influence on total cases across 30 provinces. Model 1 influenced the cases import mostly, which impacts the spread of epidemic at the later stage. As a result of timely measures taken in China, the imported cases accounted for a small proportion and the secondary cases accounted for a greater proportion in the total cases. This partly explains why model 2 closely related to the total cases but model 1.

Recommends for epidemic prevention and control

Based on these results, we put forward the simple and visual influencing factors on epidemic spread. For regions suffering from epidemic that couldn't control the imported cases well, related agencies should be taken to strengthen monitoring and management for population flow, especially the region with high GDP. For regions control the case's import of epidemic well, more strict measures should be adopted to curb the population contact to prevent further outbreak of epidemic, while to control the cases import from other epidemic areas. In the future, when a new epidemic emerges, at the initial stage dominated by imported cases, related departments should combine population monitoring from epidemic area and visual GDP to predict the spread of an epidemic, promote regional prevention measures, restrict population import as early and more strictly. At the later stage dominated by secondary cases, the areas with many imported cases and urban populations should strengthen inner population contact control to curb the further outbreak of the epidemic.

Strengths and Limitations

The study explored and quantified the impact of socio-economic factors on COVID-19. And the data in the research was from authority agency, which reduces the error. The study promoted simple and visual indicators to prevent and control the epidemic. It is helpful to avoid the loss in life and health due to insufficient prevention and control of epidemic. It is not only provided phased and regional prevention and control suggestions for the prevention and control of COVID-19, but also provided prevention suggestions for epidemics in the future.

But there were limitations in the study. First, some socio-economic factors were not the actual data during the epidemic of COVID-19. But the analysis of the recent 5 yr data showed that data in Statistical Yearbook of different yr are highly correlated. We will conduct more analysis when data be updated. Second, the sample number of provinces was small, which affected the robustness of analysis results. But there are only 34 provincial administrative units in China, and socio-economic factors in smaller administrative units may be incomprehensive. Hence, the analysis in 100 cities was adopted for verification analysis. We hoped to obtain more comprehensive data for analysis in the future to improve the robustness of the results.

Conclusion

Socio-economic factors had an important impact on the COVID-19 situation and should be considered to prevent and control the COVID-19 and an emerging epidemic. Socio-economic factors contribute to the precise, phased and regionalized prevention and control measures.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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