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Research Article

Impact of Population Emigration from Wuhan and Medical Support on COVID-19 Infection in China

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ABSTRACT

Background: The novel Coronavirus Disease 2019 (COVID-19) infection broken out in Wuhan. We aimed to analyse the impact of medical support and population emigration from Wuhan on the cure rate and mortality of COVID-19 infection in China and to provide early warning on the developmental trend of the epidemic.

Methods: Data were obtained from The National Health Commission of People's Republic of China, Chinese Center for Disease Control and Prevention and The National Health Commission of People's Republic of Hubei Province. The Poisson distribution and normal approximate were used to analyse the relationship between population emigration from Wuhan and the probability of outbreaks and to predict the developmental trend of the epidemic situation.

Results: The outbreak were related to population emigration from Wuhan in 87% of the cities in Hubei. The result of developmental trend indicated that 95% confidence intervals of confirmed case in Xiaogan and HuangGang were 3301.678–3526.042 and 3201.189–3422.17, respectively. For province outside of Hubei, the outbreak in 76% of the provinces were related to population emigration from Wuhan. Hot spot provinces for epidemic prevention included GuangDong and HeNan. Medical support significantly improved the cure rate of patients with COVID-19 ($r = 0.852$, $p < 0.001$).

Conclusion: Population emigration from Wuhan has a certain impact on the probability of outbreaks COVID-19 in Hubei and the whole country, medical support improved the cure rate of patients with COVID-19.

1. INTRODUCTION

In early December 2019, a new type of coronavirus named severe acute respiratory syndrome-coronavirus-2 (SARS-CoV-2) was found to cause cases of viral pneumonia in Wuhan [1,2]. By March 8, 2020, 80,955 laboratory-confirmed cases and 3162 deaths had been documented in China. Fortunately, the epidemic in China has been effectively controlled. However, Coronavirus Disease 2019 (COVID-19) is currently prevalent worldwide and has not been effectively controlled. Therefore, the effective measures taken by China in this epidemic have certain guiding value. The aim of this study was to analyse the impact of population emigration from Wuhan and medical support on COVID-19 infection in China and explore the effectiveness of the corresponding measures.

Since the outbreak of COVID-19, the Chinese government has taken a series of measures to prevent the epidemic from further exacerbation. The Wuhan government officially announced that public transport, subway, ferry, and long-distance passenger transport operations have been suspended, the airport and railway station from the Han channel have also been temporarily closed since 10:00 hours on January 23, 2020. However, before that time, a considerable number of people from Wuhan had migrated to other cities [3,4]. Evidence has pointed to person-to-person transmission [5–7]. Therefore, we aimed to study the impact of Wuhan population migration on COVID-19 infection in China. In addition, the response of medical support in this epidemic situation was swift, and 42,000 medical staff have supported Wuhan to date. Therefore, the relationship between medical support and cure rate is also worthy of attention.

2. MATERIALS AND METHODS

2.1. Date Collection

Date from January 11 to March 8, 2020 were obtained. Confirmed cases, deaths, severe cases and cure rates of patients with COVID-19 infection were obtained from The National Health Commission of People's Republic (http://www.nhc.gov.cn/xcs/yqfkdt/gzbd_index.shtml), China Chinese Center for Disease Control and Prevention (http://2019ncov.chinacdc.cn/nCoV/) and The Health Commission of Hubei Province (http://www.hubei.gov.cn/fbjd/dtyw/). Date regarding Wuhan population mobility were obtained from the Baidu migration map (http://qianxi.baidu.com/). The amount of medical support was assessed using data from the Press Conference of the joint prevention and Control Mechanism of the State council (https://news.youth.cn/jsxw/202002/t20200207_12188577.htm). Two researchers independently reviewed the data.

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Data availability statement: The data that support the findings of this study are available from the corresponding author, [Shengyu Wang], upon reasonable request.

2.2. Grouping

According to the time of "Closing Wuhan" on January 23, 2020, and medical support at January 24, 2020, we used January 24 as the point at which to divide the period into two time intervals: January 11–24, and January 25–March 8.

2.3. Date Model

2.3.1. Poisson distribution

Poisson distribution is a kind of distribution that describes the occurrence regularity of small probability events. It can be used to study the distribution of the number of rare events per unit time (or unit space, volume). The outbreak or aggregation of infectious diseases is considered a rare event in unit time (space) [8]. The statistical data were assumed to follow a Poisson distribution, as follows:

$$P(X) = \frac{\mu^X}{X!} e^{(-\mu)}, \quad X = 0, 1, 2, 3, \ldots$$

where $P(X)$ is the probability of outbreak caused by Wuhan migration, μ is the average migration rate that triggers each confirmed case in certain cities in Hubei during the study period. To calculate μ, the first step is to calculate the average emigration rate that triggers each confirmed case in Hubei. We define it as A.

$$A_{\text{Hubei}} = \frac{\text{The sum of the migration rate of Wuhan in Hubei}}{\text{The sum of confirmed cases in Hubei}} = 0.003815$$

$$\mu_{\text{City}} = A_{\text{Hubei*}}\text{Migration rate in certain cities}$$

$P(X)$ can be obtained by the above formula. $e \approx 2.7182$, which is a constant. The $P(X)$ of each province in China is the same as that of the city in Hubei Province.

$$A_{\text{Country}} = \frac{\text{The sum of migration rate of Wuhan in the whole country}}{\text{The sum of confirmed cases in the whole country}} = 0.006475$$

$$\mu_{\text{Province}} = A_{\text{Country*}}\text{Migration rate in certain provinces.}$$

2.4. Normal Approximate

When μ is large, $x - n\ (\mu, \mu)$. Therefore, when x is large ($x > 50$), the confidence interval of μ can be estimated by a normal approximation. Then, we use the normal approximation method to estimate the 95% confidence interval of the total number of confirmed cases in a certain city of Hubei.

$$(X - \mu_{a/2}\sqrt{X}, X + \mu_{a/2}\sqrt{X})$$

$\mu_{a/2} = 1.96$ is a constant, and X is the average number of confirmed cases caused by 1% of population emigration from Wuhan in a certain city of Hubei. To calculate X, the first step is to calculate the average number of confirmed cases caused by 1% of population emigration from Wuhan in Hubei province. We define it as E.

$$E_{\text{Hubei}} = \frac{\text{The sum of confirmed cases in Hubei}}{\text{The sum of the migration rate of Wuhan in Hubei}} = 262$$

$$X_{\text{City}} = E_{\text{Hubei*}}\text{Migration rate in certain cities.}$$

The 95% confidence interval of the total number of confirmed cases in a certain area of Hubei can be obtained from normal approximate formula. The 95% confidence interval of the total number of confirmed cases in a certain province is the same as that of a city in Hubei Province

$$E_{\text{Country}} = \frac{\text{The sum of confirmed cases in the whole country}}{\text{The sum of migration rate of Wuhan in the whole country}} = 154$$

$$X_{\text{Province}} = E_{\text{Country*}}\text{Migration rate in certain provinces.}$$

2.5. Statistical Analysis

The data were analysed using SPSS software 18.0 (SPSS Inc., Chicago, IL, USA). The Pearson correlation coefficient was used to evaluate the degree of linear relationship between two variables. Categorical variables are expressed as numbers (%) and means (minimum − maximum), and $p < 0.05$ was considered statistically significant.

3. RESULTS

3.1. Current Situation of COVID-19 Infection in China

Hubei was the worst-hit region for COVID-19 infection followed by Guangzhou, Henan, Zhejiang, Hunan and Anhui. From January 11 to March 8, 2020, there were 67,773 confirmed cases, 49,062 cures and 3046 deaths in Hubei. While 10910 confirmed cases, 1774 cured cases and 42 deaths out of Hubei Province. Figure 1 shows that the provinces with high confirmed cases are adjacent to Hubei.

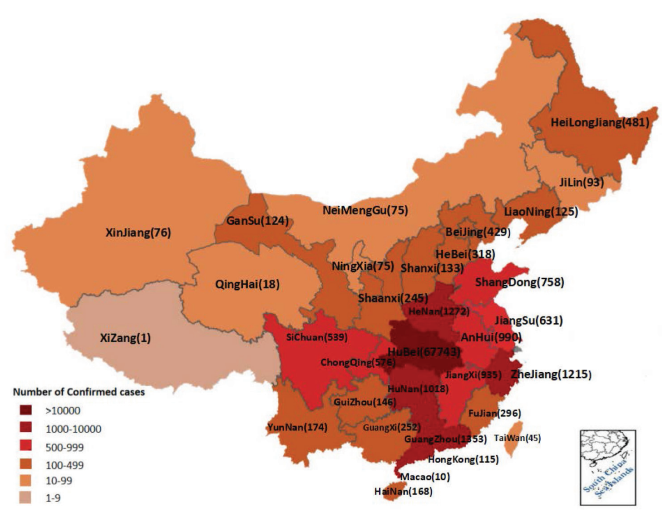

Figure 1 | Confirmed cases in China.

The cure rate and death rate were 68.5% and 4.4% in Hubei Province, and 93.6% and 0.86% outside of Hubei Province, respectively (Table 1). The number of confirmed cases increased rapidly from January 22 to February 13. In particular, on February 12, 15,152 new confirmed cases were found, including 13,332 clinical cases in Hubei Province. Since February 14, the growth trend has slowed down, and the number of confirmed cases has been basically stable since February 27. At the same time, the number of cured cases increased significantly. However, the number of deaths was relatively few. The first mortality occurred on January 11 in Wuhan (Figure 2 and Table 2).

3.2. Relationship between Population Emigration from Wuhan and the Probability of Outbreaks in Hubei and the Developmental Trend

As shown in Table 3, for cities in Hubei, Xiaogan and HuangGang were the two cities with the largest population emigration from Wuhan, with emigration rate of 13.03% and 12.64%, respectively. The number of confirmed cases in these two cities was second only to Wuhan in Hubei Province. QianJiang had the lowest emigration rate and the lowest number of confirmed cases in Hubei Province. The relationship between population emigration and outbreak probability in Hubei Province was calculated bases on Poisson distribution. As indicated in Figure 3, in 13 of the 15 cities in Hubei Province, more than 50% of the outbreak probability is related to the population emigration from Wuhan. The detailed outbreak probability is shown in Table 3. The outbreak were related to population emigration from Wuhan in 87% of the cities in Hubei. We also predicted the development trend of the epidemic situation in Hubei. As depicted in Figure 4 and Table 3, Xiaogan and HuangGang appeared to be the worst hit areas in Hubei Province. The 95% confidence intervals of the confirmed case were 3301.678–3526.042 and 3201.189–3422.17, respectively.

Table 1 The date of COVID-19 infection from January 11 to March 8, 2020 in Hubei and out of Hubei

	In Hubei	Out of Hubei
Confirmed (*n*)	67,743	12,992
Cure (*n*)	46,433	12,167
Cure ratio (%)	68.5	93.6
Death (*n*)	3007	112
Death ratio (%)	4.4	0.86

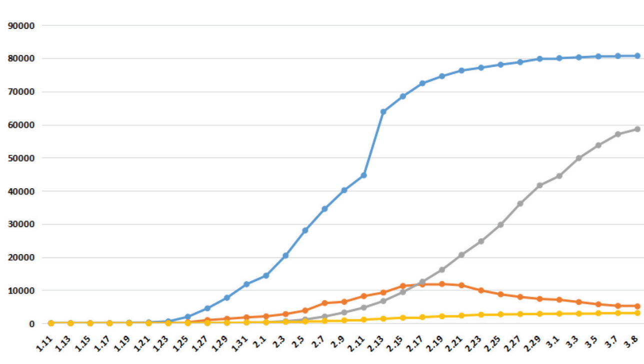

Figure 2 The number of confirmed, severe, death and cured cases of COVID-19 in China from January 11 to March 10, 2020. Since February 14, the growth trend has slowed, and the number of confirmed cases has remained basically stable from February 27. At the same time, the number of cured cases increased significantly.

Table 2 The number of confirmed, severe, death and cure cases of COVID-19 infect in China from January 11 to March 8, 2020

Date	Confirmed (*n*)	Severe (*n*)	Cure (*n*)	Death (*n*)	Cure (*n*)
1.11	41	7	2	1	2
1.13	41	6	6	1	6
1.15	41	6	7	1	7
1.17	45	5	15	2	15
1.19	198	35	25	3	25
1.21	291	78	25	6	25
1.23	571	95	34	17	34
1.25	1975	324	49	56	49
1.27	4515	976	60	106	60
1.29	7711	1370	124	170	124
1.31	11,791	1795	243	259	243
2.1	14,380	2110	328	304	328
2.3	20,438	2788	632	425	632
2.5	28,018	3859	1153	563	1153
2.7	34,546	6101	2050	722	2050
2.9	40,171	6484	3281	908	3281
2.11	44,653	8204	4740	1113	4740
2.13	63,859	9278	6723	1380	6723
2.15	68,500	11,272	9419	1665	9419
2.17	72,436	11,742	12,552	1868	12,552
2.19	74,576	11,864	16,155	2118	16,155
2.21	76,288	11,477	20,659	2345	20,659
2.23	77,150	9915	24,734	2592	24,734
2.25	78,064	8752	29,745	2715	29,745
2.27	78,824	7952	36,117	2788	36,117
2.29	79,824	7365	41,625	2870	41,625
3.1	80,026	7110	44,462	2912	44,462
3.3	80,270	6416	49,856	2918	49,856
3.5	80,552	5737	53,726	3042	53,726
3.7	80,695	5264	57,065	3097	57,065
3.8	80,735	5111	58,600	3119	58,600

3.3. Impact of Population Emigration from Wuhan on the Epidemic Outbreak Rate in Provinces Out of Hubei and the Development Trend

For province outside of Hubei, as shown in Table 4 and Figure 5, more than 50% of the outbreak probability was related to population emigration from Wuhan in 23 of the 30 provinces, and the outbreaks were related to population emigration in 76% of provinces outside of Hubei. GuangDong, HeNan and ZheJiang appeared be the worst hit areas in provinces outside of Hubei (Figure 6). The 95% confidence intervals of the confirmed cases were 2467.46569–2661.934, 1138.44806–1271.752 and 1048.36289–1176.437, respectively (Table 4). Therefore, we can draw a preliminary conclusion that the movement from Wuhan correlated positively with the outbreak in each province.

3.4. Relationship between Medical Support and the Cure Rate, and Death Rate of COVID-19 Infection

As shown in Figure 7 and Table 5, before the first medical support arrived in Wuhan on January 24 (New Year's Eve), the mortality

Table 3 | The probability of epidemic outbreak and 95% confidence interval of confirmed cases in cities of Hubei

City in Hubei	Emigration ratio from Wuhan (%)	Confirmed number (*n*)	Probability of outbreak (%)	95% confidence interval of confirm case	
				Lower	Upper
XiaoGan	13.03	3518	52.648	3301.678	3526.042
HuangGang	12.64	2907	77.2611	3201.189	3422.171
JingZhou	6.34	1580	60.1613	1582.828	1739.332
XiangNing	5.04	836	89.5713	1250.71	1390.25
EZhou	4.1	1394	38.6337	1011.272	1137.128
XiangYang	3.87	1019	65.0618	952.8025	1075.077
HuangShi	3.74	1015	65.3595	919.7782	1039.982
JinMen	3.07	928	52.7769	749.8871	858.7929
SuiZhou	2.99	1307	26.6793	729.6413	837.1187
XianTao	2.86	575	82.0497	696.7625	801.8775
YiChang	2.79	931	52.5316	679.0696	782.8904
TianMen	2.02	496	70.5688	485.07	573.41
EnShi	1.86	252	92.6621	444.9354	529.7046
ShiYan	1.79	672	52.7424	427.4006	510.5594
QianJiang	1.12	198	82.4671	260.5502	326.3298

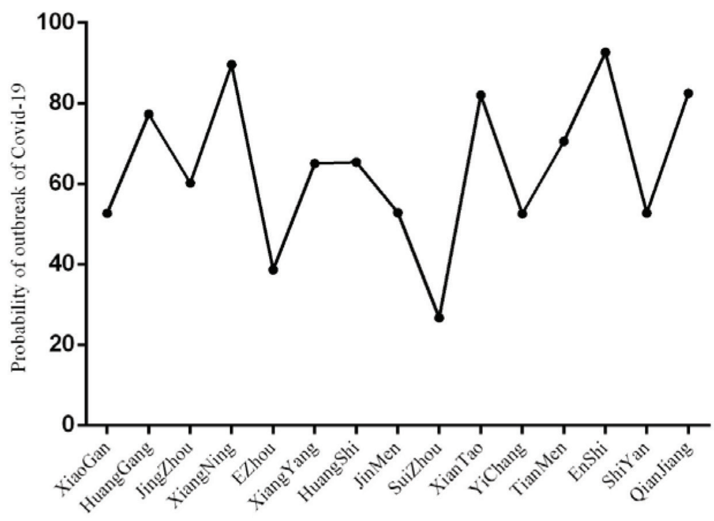

Figure 3 | The probability of disease outbreaks caused by population emigration from Wuhan in Hubei.

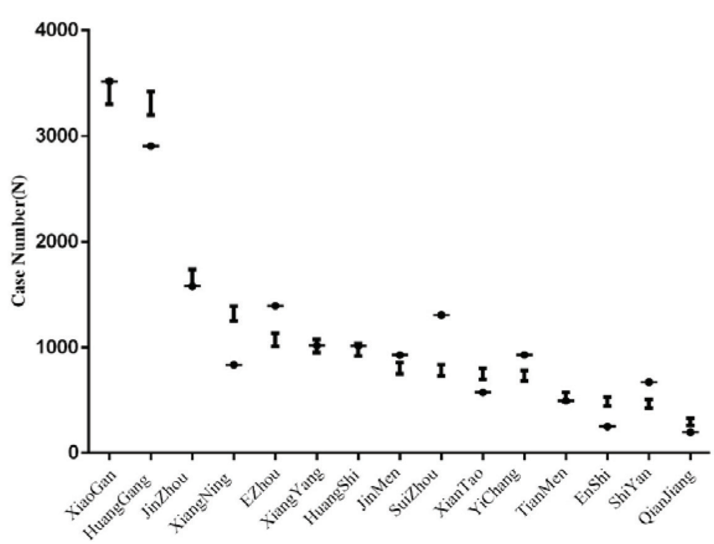

Figure 4 | Confirmed case 95% confidence intervals for Hubei.

Table 4 | The probability of epidemic outbreak and 95% confidence intervals of confirm case in Provinces of China

Province	Emigration ratio from Wuhan (%)	Confirmed number (*n*)	Probability of outbreak	95% confidence interval of confirm case	
				Lower	Upper
GuangDong	8.3	1352	96.562	2467.46569	2661.934
HeNan	3.9	1272	60.7762	1138.44806	1271.752
ZheJiang	3.6	1215	64.3712	1048.36289	1176.437
JiangSu	3.3	631	85.0236	958.389136	1081.011
HuNan	3.3	946	63.4888	958.389136	1081.011
BeiJing	2.5	428	94.8259	719.135742	825.8643
ShangHai	2.5	342	97.3925	719.135742	825.8643
AnHui	1.8	990	38.0487	510.918926	601.4811
JiangXi	1.7	935	41.8817	481.294706	569.3053
FuJian	1.5	296	92.7623	422.164224	504.8358
ShanDong	1.1	758	29.8144	304.502156	375.2978
SiChuan	1.0	539	48.0712	275.24948	342.7505
ChongQing	1.0	576	44.5168	275.24948	342.7505
HeBei	0.8	318	72.5834	217.012617	277.3874
GuangXi	0.8	252	80.3811	217.012617	277.3874
ShaanXi	0.72	133	93.0361	193.841734	251.1183
YunNan	0.56	174	89.0467	147.783424	198.2966
GuiZhou	042	146	62.4061	107.907163	151.6528
LiaoNing	0.41	125	66.7853	105.079123	148.3009
HaiNan	0.4	168	58.1261	102.254297	144.9457
TianJin	0.37	136	64.4544	93.8003602	134.8596
ShanXi	0.34	133	65.0819	85.3802341	124.7398
HeiLongJiang	0.2	481	21.153	46.7063086	76.89369
XinJiang	0.2	76	78.2359	46.7063086	76.89369
JiLin	0.17	93	74.0564	38.6143041	66.4457
GanSu	0.17	124	67.0013	38.6143041	66.4457
NeiMengGu	0.15	75	78.4889	33.2784798	59.42152
NingXia	0.08	75	78.4889	15.1739114	34.26609
QingHai	0.05	18	94.3526	7.9031543	22.99685
XiZang	0.02	1	99.6776	1.40695569	10.95304

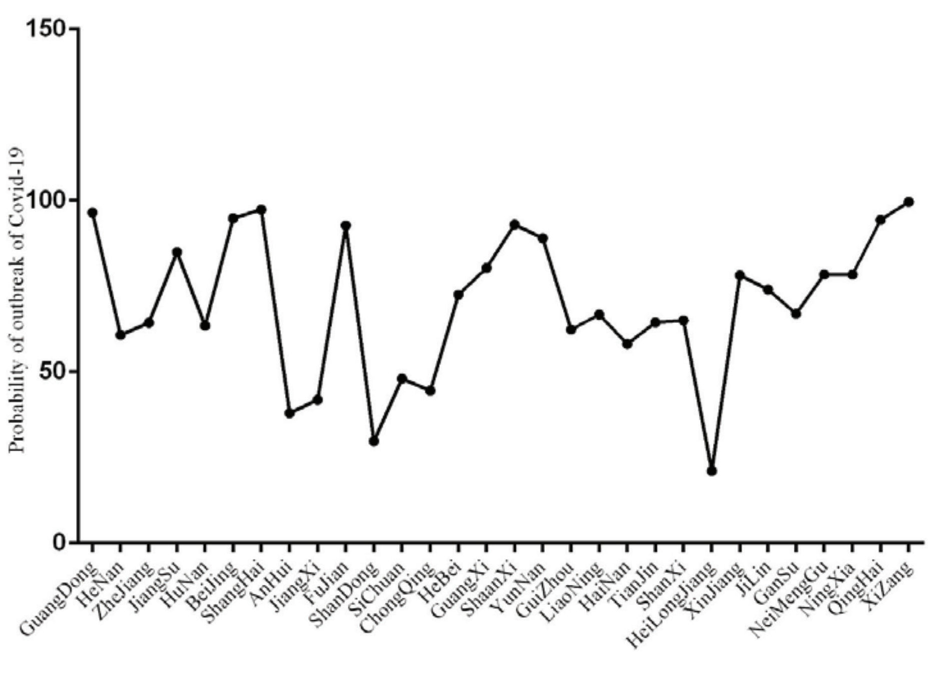

Figure 5 | The probability of disease outbreak caused by population emigration from Wuhan in Province out of Hubei.

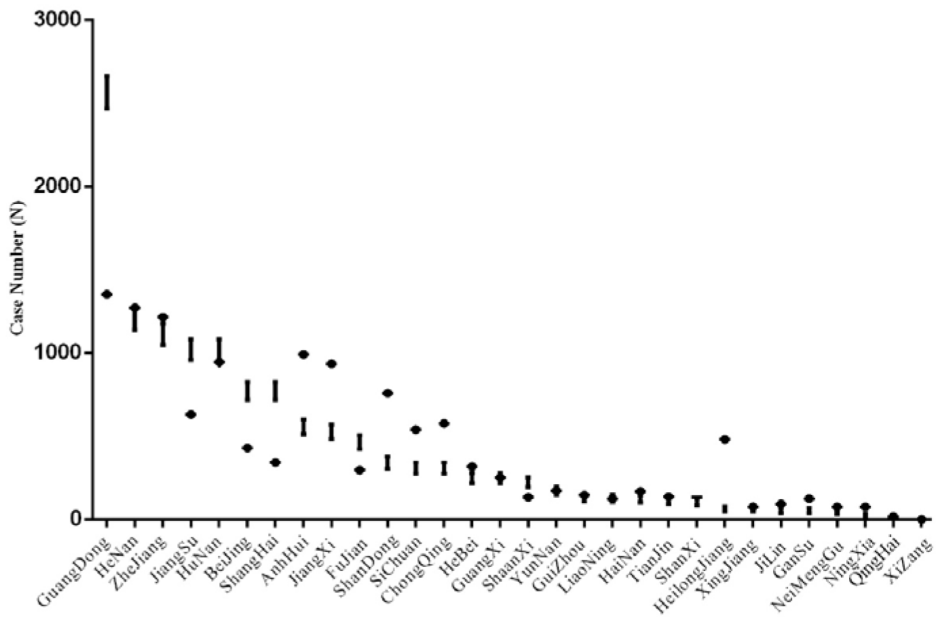

Figure 6 | Confirmed case 95% confidence intervals for in province outside of Hubei.

Table 5 | The date of number of Health care works support and cure rate, mortality in Hubei

Date	Hubei mortality (%)	Cure rate (%)	Health care workers support (*n*)
1.20	1.1	9.2	
1.22	3.8	5.6	
1.24	5.5	4.4	675
1.26	5.3	3.1	
1.28	3.5	2.4	5930
1.30	3.5	2.0	
2.2	3.1	2.6	8130
2.4	2.9	3.1	
2.6	2.8	3.7	10,596
2.8	2.8	5.3	
2.10	3.1	7.0	13,905
2.12	2.7	7.1	
2.14	2.7	8.8	25,633
2.16	2.9	11.4	
2.18	3.1	14.8	32,572
2.20	3.4	18.8	
2.22	3.7	23.8	38,000
2.24	4.0	29.1	
2.26	4.0	35.3	42,000
2.28	4.1	43.6	
3.2	4.2	53.8	42,322
3.4	4.3	60.0	
3.6	4.4	64.2	
3.8	4.4	68.5	

rate in Wuhan continued to increase and the cure rate continued to decline. The obvious change occurred on January 27. Although there was fluctuation on January 28, the overall cure rate showed an upward trend, especially in the last 2 weeks of January. The mortality was stable. The cure rate and mortality between January 21 and 24 were 5.60% (4.40–9.20) and 3.8% (1.1–5.5), respectively, and 11.4% (2.0–68.5) and 3.5% (2.7–5.3) from January 25 to March 8, 2020. ($p = 0.867$ and 0.248). The difference between medical support and cure rate was statistically significant ($r = 0.852$, $p < 0.001$). However, significant for mortality was not observed ($r = 0.145$, $p = 0.637$). The overall cure rate and mortality trends showed improvement.

4. DISCUSSION

In December 2019, a series of pneumonia cases of unknown cause emerged unexpectedly in Wuhan and spread rapidly across the country. The disease was named COVID-19 [4,9]. By March 8, 2020, more than 80,000 confirmed cases had been confirmed in China. COVID-19 infection has become a legal class B infectious disease under the law of the People's Republic of China for the prevention and control of infectious diseases and is managed as a Class A infectious disease. The WHO has declared the new coronavirus epidemic as a Public Health Emergency of International Concern (PHEIC). The COVID-19 spreads through respiratory droplets when infected individuals cough, talk loudly or sneeze [10–12]. Close contact is also a source of transmission. Wuhan is the most serious epidemic area in China. Evidence has confirmed that COVID-19 infection in other cities can be traced to Wuhan. Before this feature was discovered, some potentially infected people in Wuhan had already travelled to other cities. However, few studies focused on the relationship between movement from Wuhan and medical support in COVID-19 cases.

This study found that population emigration from Wuhan was related to the probability of outbreaks in Hubei and other provinces. This conclusion is consistent with Chen et al. [13], who found that population movement from Wuhan was the main infection source in other cities and provinces. By establishing a scale free network, Nishiura et al. [14] also found that migration from Wuhan could partially explain the seriousness of the epidemic in Hubei Province and other regions. However, their research mainly focused on the early stage of the epidemic, time span was from January 16 to 30, and factors of medical staff support were not analysed. Fortunately, the Chinese government

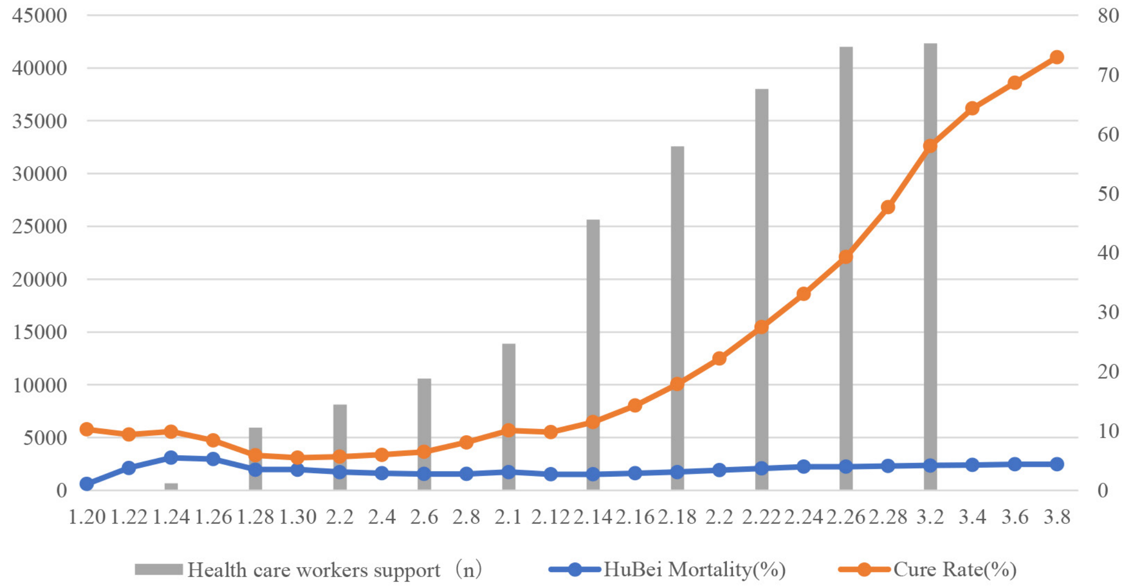

Figure 7 | The relationship between the number of medical support, cure and mortality rates in Hubei. There was a positive correlation between medical support and cure rate ($p < 0.01$).

responded quickly. At 10:00 h on January 23, 2020, the policy of "Closing Wuhan" was implemented. We believe that this policy has played an important role in controlling the spread of the epidemic to some extent.

In addition to controlling population migration, medical support is another important measure to prevent the deterioration of the epidemic situation, medical support from all over the country went to Wuhan on January 24, 2020 (New Year's Eve), as of March 8, the number of medical staff reached 42,000. Through our analysis, we found that medical support significantly improved the cure rate of patients with COVID-19. When interpreting these results, the following issues should be taken into consideration. The unexpected outbreak of COVID-19 in Wuhan resulted in a serious imbalance between doctors and patients. Medical support alleviated the doctor–patient rate. In addition, medical support provide more manpower for early disease screening, facilitating early intervention and treatment. Furthermore, with more medical support, exhausted personnel were relieved, and both diagnosis and treatment were improved. Medical support also provided a large amount of medical supplies, which ameliorated shortage. Finally, increase in the number of medical staff provided confidence for patients to overcome the disease. This study also indicated that medical support had little effect on mortality, which may be because the majority of cured patients had mild disease, and the number of severe cases was not significantly reduced.

In general, we should control the spread of the epidemic from the source and strengthen medical support from all regions. These two measures have a certain role in controlling the epidemic of COVID-19.

This study has several limitations. First, due to limited information, laboratory indicators were not valuated in this study. Second, the sample size was small, and a large sample size is needed to reach more reliable conclusions. Third, the data involved in this study were all from public websites. Therefore, no detailed data were obtained.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

AUTHORS' CONTRIBUTION

YY and TY designed the study, conducted analysis, and drafted the work; ZJ made substantial contribution to design of the work, interpretation of the work, and revising the draft for important intellectual content; CBG, DX, LY and DLG helped with access to the data and provided information and consulting; WSY made substantial contributions to the conception of the work, revising the draft for important intellectual content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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ETHICS APPROVAL

Formal ethical approval is not required as no primary data will be collected.

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