Spatiotemporal evolution and diffusion pattern of the COVID-19 epidemic in Hainan Province, China

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Abstract

Within one month after the first case occurred in Hainan Province, the number of confirmed cases increased to 168, and there was no increase in nearly three months. As the southernmost province and a famous tourist destination, its frequent economic exchanges and high-intensity movements may affect the spread of epidemic. Therefore, it is of great theoretical and practical significance to examine the spatiotemporal evolution and diffusion pattern of the COVID-19 epidemic in Hainan Province.

Introduction

The COVID-19 epidemic has gradually evolved into a pandemic that threatens social security and human health and has become a focus and pain point of worldwide concern (Rachael et al. 2020; Annelies et al. 2020; Sarah et al. 2020). Suppression and elimination of the epidemic have become the core theme facing humankind in the beginning of the 2020s. Up to July 1, 2020, more than 10 millions laboratory-confirmed cases have been detected worldwide as reported by the World Health Organization (WHO). The US, Spain, Russia, the UK, as well as other countries, have become as new core areas of COVID-19, and the epidemic is still spreading rapidly. Presently, the global spread has not completely suppressed, and the situation of prevention is bleak.

Moreover, researchers in various disciplines quickly have approached this outbreak from different perspectives, mostly focusing on medicine, pathology, epidemiology and other fields. In terms of the clinical diagnosis, some studies pointed out the epidemiological characteristics, disease history, clinical symptoms and complications of confirmed cases by collecting information from the International Health Organization, RT-PCR or other statistical agencies (Huang et al. 2020; Chen et al. 2020), which provided a model for subsequent similar studies. As WHO indicated there is no virus treatment exists to kill or prevent COVID-19. In terms of clinical treatment, "after evaluating various antiviral drugs, radixivir and chloroquine phosphate were considered they can inhibit the virus in vitro" (Wang et al. 2020). TCM prevention programs were adopted in various regions of China and the author believed that the medicine should be used differently after considering conditions such as climate and population (Xu et al. 2020). Some studies have analyzed the effect of Favipiravir on experimental treatment of new coronary pneumonia from the perspective of pharmacokinetics (Du et al. 2020). Presently, many countries worldwide, including China, are also actively developing vaccines against the coronavirus (Paul et al. 2020; Gavin et al. 2020; Richard 2020; Lawrence 2020). In biomedicine and virus tracing research, bat was first considered the virus host through a genome control experiment (Zhou et al. 2020). Immediately, another studies estimated the recombinant genome based on the theory of systematic evolution and believed that the two genome sequences are different, but the bat is still possible to be a virus host (Paraskevis et al., 2020; Lu et al. 2020). Later, pangolins were considered as potential intermediate hosts for new coronaviruses (Xiao et al., 2020). Presently, the World Health Organization has confirmed that the new coronavirus originated from nature, and there is no trace of artificial changes. In terms of epidemiological modeling and prediction, some researchers compared the viral genome sequences in Bangkok and Wuhan City and believed that the epidemic began on November 9, 2019, and Wuhan City

was the main hub of spread (Li et al. 2020). After comparing the epidemic situation in Wuhan City and other cities, substantial public health interventions were considered essential to suppress the global outbreak (Wu et al. 2020). Many prediction models based on different theories appeared. For instance, based on 1,590 patients in China, LASSO regression was used to build a new model to predict critical coronary pneumonia, which can improve the efficiency of medical resource allocation (Liang et al. 2020). Due to the untimely prevention and treatment in many countries and regions, the COVID-19 epidemic has caused more than 510,000 deaths worldwide at the time of writing this paper, and it is crucial to prevent the spread of the epidemic in a timely manner.

China's epidemic prevention has achieved important results in stages, and the economy and society are accelerating to recover (Lai et al. 2020; Dennis 2020). At this critical stage, it is important to guard against the importation of confirmed cases overseas and the rebound of the internal epidemic. Data from the National Health Commission of the People's Republic of China (<http://www.nhc.gov.cn/>) clearly depicted that, up to July 1, 2020, there were 85,260 total confirmed cases and 4,648 deaths over China. China's success in epidemic prevention is obvious to all, and it provides a “Chinese model” for mankind to jointly respond to COVID-19.

Hainan is the second largest island in China, as well as a special economic zone, a free trade zone and a famous tourist attraction place. As of July 1, 2020, Hainan Province has reported 171 confirmed cases, ranking 20th in the country, with an epidemic density of 49.11 cases per 10,000 square kilometers, ranking 15th, and an infection rate of 0.18 cases per 10,000 people, and ranking 7th of the country. Recently, there are 2 new unhealed cases in the Hainan Island. First, Hainan is close to Guangdong Province, a region with a high incidence of epidemic in China. It is crucial to clarify the spatiotemporal evolution of the epidemic in this area to explore the spread at the provincial scale. Second, the special geographic location of Hainan Province makes it indicative of the prevention policies of other areas. Therefore, this research study used text analysis, spatial analyses and spatial statistical analyses to investigate the epidemiological characteristics of the confirmed cases in Hainan Province and to reveal the spatiotemporal evolution and spread of COVID-19 in Hainan Province.

Materials And Methods

Data collection

This study selected Hainan Province as the research area, and the secondary data were obtained from different data sources such as: (1) spatial data: digital administrative boundaries, derived from the 1:1,000,000 data obtained from the National Geomatics Center of China (<http://www.ngcc.cn/ngcc/>); (2) attribute data: statistical data, derived from Hainan Statistical Yearbook 2017 (<http://www.hainan.gov.cn/hn/zwgk/tjdc/hnnj/>); (3) epidemic data: collected from the Hainan Health and Wellness Committee website and its WeChat public account and other official medias report the epidemic situation of the study area. As of June 21, 2020, the detailed information of 168 confirmed cases obtained through the manual interpretation and collection methods (Table 1), including demographic information such as age and gender and spatial information such as activity trajectory

(Within one month of the outbreak, the number of confirmed cases rose to 168, and the 169th, 170th, 171th patient did not appear until May 15, 2020. Therefore, this study does not include these 3 confirmed cases.).

Table 1 Characteristics of baseline data of confirmed COVID-19 cases in Hainan Province (N = 168)

Age range in years	0~79
Average age in years	48.4
Median age in years	51
Age group in years	
A < 18 (%)	8 (4.7)
B 18~40 (%)	52 (31.0)
C 41~65 (%)	83 (49.4)
D > 65 (%)	25 (14.9)
Sex	
Female (%)	86 (51.2)
Male (%)	82 (48.8)
Long-term work or life in Wuhan City (imported cases)	113 (67.3)
Direct or indirect exposure to people from Wuhan City (transitioned cases)	43 (25.6)
internal diffusion (diffuse cases)	12 (7.1)

Note: The numbers in parentheses represent percentages.

Study area

Hainan Province is located in South China (Fig. 1), where borders Guangdong across the Qiongzhou Strait in the north, Guangxi Province and Vietnam across the Beibu Gulf in the west, Taiwan across the South China Sea in the east, and Malaysia, the Philippines and other countries in the south. It governs the following: 4 prefecture-level cities, Haikou City, Sansha City, Sanya City and Danzhou City; 5 county-level cities, Wuzhishan, Wenchang, Qionghai, Wanning and Dongfang; 4 counties, Ding'an, Tunchang, Chengmai and Lin'gao Baisha; 6 ethnic autonomous counties, Changjiang, Ledong, Lingshui, Baoting, Baisha and Qiongzhong; and the islands and sea areas of the Xisha Islands, Nansha Islands and Zhongsha Islands. The total land area is 35,000 square kilometers, and the sea area is approximately 2 million square kilometers. The topography of Hainan Province is high in the middle, low and flat all around, and mostly mountainous. The climate of the study area is a tropical marine monsoon climate, with warm and abundant rainfall throughout the year. The average annual temperature is 22~27°C, and the annual rainfall is about 1000~2600 mm. The vegetation is mainly tropical arbors and shrubs.

Methods

Text Analysis. Text analysis refers to quantifying information by extracting the features of language, words, images or other media. This research were used the manual interpretation of cases to extract age, gender, activity trajectory and other information to provide a data basis for further analysis.

Spatial autocorrelation analysis. Global Moran's I is an important indicator to measure spatial correlation and was used to measure the strength of the spatial autocorrelation of the epidemic in this article. The output values are varying from +1 to -1. The closer the value is to +1, the positive significant spatial correlation is, and the closer the value is to -1, the more negative spatial correlation is. The calculation formula can be drawn as follows:

$$\text{Moran's } I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n w_{ij} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (1)$$

Where; x_i and x_j represent the number of confirmed cases in regions i and j , w_{ij} is the corresponding value of the spatial weight matrix w , and n is the number of regions.

Kernel Density. By dividing the high, middle and low value areas to represent the distribution characteristics of geographical events in space, the core area of the epidemic can be presented in this article. The calculation formula can be depicted as follows:

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^n k\left[\frac{d_i(x, y)}{h}\right] \quad (2)$$

In addition, this study were used MS Excel 2018 for data sorting and preprocessing, ArcGIS 10.3 for epidemic distribution drawing and spatial analysis, SPSS 25.0 for statistical data analysis, and Origin Lab 2018 for Figures.

Results

Demographic characteristics of confirmed cases

In terms of gender, confirmed COVID-19 cases in Hainan Province showed a balanced distribution (Fig. 2) except for the last two segments, with 82 male cases and 86 female cases. The polynomial fitting results showed differences in the age structure of patients of different genders. The age structure of female diagnosed cases was approximately normal, with a median age of 50 years and an average age of 47.4 years. The age structure of male confirmed cases showed a negatively skewed distribution, with a median age of 54 years and an average age of 50.3 years, slightly higher than of women. The multiple regression equation for male-confirmed cases is $y_1 = 0.06 - 0.03x_1 - 4.98x_1^2 + 8.84x_1^3$ ($R_{1adj}^2 = 0.241$), and the multiple regression equation for female-confirmed cases is $y_2 = -0.37 - 0.08x_2 - 8.49x_2^2 + (1.63E-7)x_2^3$ ($R_{2adj}^2 = 0.270$). The age of the confirmed cases was

concentrated between 30 and 65 years, a total of 105 cases, accounting for 62.5% of the total. Overall, most of the confirmed cases in Hainan Province were middle-aged (41–65 years; 49.4%) and young adults (18–40 years; 31.0%), elderly (66 years; 14.9%) and adolescents (17%) and younger (4.7%), consistent with the age characteristics of confirmed cases nationwide (National Health Commission of the People’s Republic of China 2020). The middle-aged and young people are the main groups of social mobility. The characteristics of frequent social activities and outdoor life, as well as the long outdoor exposure time, make them vulnerable to infection.

Temporal process of the COVID-19 epidemic

Since January 23, 2020, the Hainan Health and Wellness Committee reported the first imported case, and then the number of confirmed cases have increased gradually. There were 18 confirmed cases on January 27, 2020, the highest number of confirmed cases on a single day so far (Fig. 3a). The number of confirmed cases in the next few days gradually declined. However, in the next ten days, this number increased rapidly again, reaching the second highest peak with 12 cases on February 12, 2020 and the average number of daily confirmed cases was 7.48.

Within approximately 10 days after the first imported case, the cumulative number of cured cases was small, and it rose rapidly after February 6. These two curves of the cumulative number of cured cases and confirmed cases form an approximately closed, centrally symmetric “lip” structure. Presently, the COVID-19 epidemic in Hainan Province has caused 6 deaths, with a mortality rate of 3.57%. The polynomial fitting results revealed that the number of daily confirmed cases showed a trend of “burst growth followed by slow decline”. There were not reported new confirmed cases after February 20.

The distribution of confirmed cases in various regions of Hainan Province is shown in two levels (Fig. 3b) (level 1, more than 20 cases; level 2, less than 20 cases). Sanya City and Haikou City are located in level 1, with 54 and 39 cases, respectively; the cumulative number of confirmed cases in other regions was fewer than 20 cases. As a well-known tourist city, external import is the main reason for the high incidence of the epidemic in Sanya City, and was more serious in the early stage than in other regions. By contrast, as the largest city and most populous city in Hainan Province, the number of confirmed cases in Haikou City has grown slowly, and it was notably higher than the other regions until early February. From February 20 until now, no new cases have been confirmed in Hainan Province. With the rising number of cured cases, the epidemic has been gradually controlled. Overall, the COVID-19 epidemic in Hainan Province showed a “burst growth followed by slow decline” in terms of time.

Infection groups and their evolution

Wuhan City, Hubei Province is the severest area of the COVID-19 epidemic in China, and the epidemic in other surrounding provinces may be related to Wuhan City. We manually interpreted the infection history and activity trajectory of the confirmed COVID-19 cases in Hainan Province, and divided them into three infection groups: confirmed cases who worked and lived long-term in Wuhan City or other cities in Hubei Province as imported

patients (Group 1). Nearly 40% of the imported patients can trace the infection trajectory in Wuhan City or other cities in Hubei Province (Fig. 4 Imported). More than 60% of imported patients lived in this area, but how they were infected remains unclear. Confirmed cases who had direct contact with imported infected persons or who had short-term trips to Wuhan City before and after the epidemic were defined as transitional patients (Group 2). Among the transitional patients, nearly half were infected by family members (Fig. 4 Transitional). Contact with confirmed cases and traveling to Wuhan City were also two routes of infection. Confirmed cases without a history of residence in Wuhan City and those who could not be identified as transitional patients were defined as diffuse patients (Group 3), and half of these patients live in Haikou City, the largest city on this island (Fig. 4 Diffuse).

The confirmed cases in Hainan Province were mainly external imported cases (Fig. 5a), with 113 cases, accounting for 67.3% of the total; mixed transitional cases numbered 43 cases, accounting for 25.6%; internal diffuse cases were fewer, totaling 12 cases, accounting for 7.1%. Due to untimely epidemic prevention, the number of external imported cases in a short period rose rapidly, reaching a peak of 17 cases on January 27, 2020 and reaching 10% of the total on this single day. From January 28 to February 12, 2020, the number of external imported cases increased first and then decreased, with an average of 4.2 confirmed cases daily, and then entered the stage of epidemic prevention. External imported cases decreased significantly from February 13 to 19, 2020 and 5 cases were confirmed. Mixed transitional cases were concentrated from February 4 to 12, 2020; 33 cases were confirmed during this period, accounting for 76.7% of this type and 19.5% of the total number of confirmed cases. Internal diffuse cases were concentrated from February 7 to 14, 2020; 9 cases were confirmed during this period, accounting for 75% of this type and 5.3% of the total.

Judging from the changes in the proportion of the three types of cases (Fig. 5b), external imported cases primarily comprised the confirmed cases from January 23 to February 3, 2020, accounting for 88.5%. This number gradually declined, accounting for 48.9% from February 4 to 19, 2020. The proportion of mixed transitional cases has gradually increased, accounting for 9.2% of the total before February 3, 2020 and has risen to 40.0% from February 4 to 19, 2020. With the active development of epidemic prevention and control, the proportion of internal diffuse cases has increased, but the number has gradually decreased.

In this paper, we used the diffusion ratio to measure the spread of the epidemic ($\text{diffusion ratio} = (\text{mixed transition cases} + \text{internal diffuse cases}) / \text{external imported cases}$). The diffusion ratio of COVID-19 in Hainan Province reached the first extreme value of 2.0 on January 28, 2020, indicating that an imported case can infect two patients. The diffusion ratio was at a low value from January 29 to February 3, 2020, with an average value of approximately 0.3. The diffusion ratio gradually increased after February 4, 2020 and reached a maximum value of 7 on February 9, 2020—i.e., the number of mixed transitional cases and internal diffuse cases were 7 times the number of imported cases in a single day. After that, the diffusion ratio dropped rapidly, with an average value of 1.56 from February 4 to 19, 2020. Thus, COVID-19 in Hainan Province was in the stage of external import before February 3, 2020 and began to spread after February 4, 2020. However, due to the implementation of prevention and control policies, the number of confirmed cases per day has gradually decreased, indicating that the COVID-19 epidemic in Hainan Province is dominated by external imported infections and has limited internal spread.

Spatial pattern of the COVID-19 epidemic

The outbreak of COVID-19 in Hainan Province began with three confirmed cases on January 23, 2020. A week later, by the last day of January, the whole island had already experienced outbreaks in all but the five regions of Wenchang, Baisha, Tunchang, Wuzhishan, and Baoting, (Fig. 6 Jan 31, 2020). As of February 5, 2020, the number of confirmed cases in Sanya City has gradually surpassed that in other regions, reaching 30 cases, followed by 16 cases in Haikou City, and the remaining uninfected areas comprise only three central regions (Fig. 6 Feb 5, 2020). As of February 10, 2020, the epidemic in Sanya City and Haikou City has been significantly more serious than the other regions. The confirmed cases in these two cities accounted for 52.1% of the province, especially in Sanya City, with 45 cases, accounting for 32%. In addition, the number of confirmed cases in Danzhou and Wanning gradually increased, reaching 11 and 13 cases, respectively (Fig. 6 Feb 10, 2020). Thus far, the spatial distribution pattern of the epidemic in Hainan Province has gradually formed. In the subsequent 10 days, 26 new cases were added across the whole island, mostly in Sanya City (6 new cases) and Haikou City (9 new cases), with no effect on the overall pattern. Within about a month of the outbreak, Sanya City and Haikou City were the regions with more confirmed cases and faster growth. The four regions of Sanya City, Haikou City, Danzhou City and Wanning City constituted an approximate cross-shaped spatial distribution pattern. Regardless of the number of confirmed cases or diffusion ratio, the reasons for the more serious epidemic situation in the coastal areas than the central area may be the following: First, the diffusion has developed from the edge to the middle. The timely implementation of policies has effectively prevented the spread of the epidemic. Second, the central part of the island is mostly mountainous with inconvenient transportation and a sparse population, slowing the outbreak.

The current distribution of confirmed cases (Fig. 7a) shows that the epidemic situation in Hainan Province is mainly serious at the north and south ends (Sanya City and Haikou City). The coastal areas were all affected, and the central region was less affected. The results of spatial autocorrelation analysis showed that Moran's I was 0.396, P was 0.005, and Zscore was 2.795, indicating the high spatial autocorrelation and significant clustering effect. The infection rate distribution (Fig. 7b) showed that Sanya City had the highest infection rate in Hainan Province, with 0.72 cases per 10,000 people, which was more than twice that of Changjiang with the second highest infection rate (0.30 cases per 10,000 people). In general, the infection rate in coastal areas is significantly higher than that in central areas. The density of confirmed cases (Fig. 7c) showed that Sanya City and Haikou City were the areas with the highest epidemic densities on the island, with 0.028 and 0.017 cases/km², respectively. The distribution density in other areas was small and scattered. Kernel analysis was conducted by collecting the latitude and longitude of the confirmed cases (Fig. 8), and the results showed that the confirmed cases were mainly distributed in the north and south ends of this island, namely, Haikou city and Sanya City, and the epidemic in coastal areas was more serious than that in central mountainous areas. The above results show that, there is an obvious spatial correlation and spatial agglomeration in the COVID-19 distribution.

Diffusion pattern of the COVID-19 epidemic

The diffusion in the north of Hainan Province was higher than that in the south ([Fig. 9a](#)), especially in Haikou City, with the highest diffusion ratio on the whole island. Thus, an imported confirmed case can infect more than one local patient. The diffusion ratio of the northern coastal areas were significantly higher than the other areas, and the diffusion ratios of Haikou City, Danzhou City, and Wenchang City all exceeded 0.5. Qiongzong, Changjiang and Baoting (shaded areas) had only diffuse cases, and no imported cases were found, indicating that the movement of people on the island promoted the spread of the epidemic. Currently, there are no confirmed cases in some areas of the central region (blank areas), so the diffusion ratio in these areas is 0. The cumulative diffusion ratio of various regions on the island ([Fig. 9b](#)) showed that, although Sanya City had the most imported cases, the local diffusion in Sanya City was not significant.

Since February 2020, as the largest city in Hainan Province, the diffusion in Haikou City has increased significantly, and eventually became the epidemic diffuse center, while Sanya City was the epidemic import center in Hainan Province. Among the confirmed cases in Hainan Province, 67.3% had lived or worked in Wuhan or other areas of Hubei Province for a long time, and 25.6% had short-term travel to Wuhan or had direct contact with confirmed cases returned from Hubei Province. More than half patients in these two groups were detected in Sanya City. The tourism industry in Sanya city is developed, which increases the import risk of confirmed cases and inevitably becomes the import center (67.3% of imported cases were detected in Sanya City.). As the largest city and transportation center in Hainan Province, Haikou's diffusion ratio increased rapidly in the latter half of the period and became the epidemic diffusion center (50.0% of diffuse cases were detected in Haikou City.). These two cities constitutes a dual-core model for the spread of the epidemic in Hainan Province ([Fig. 10](#)). This diffusion model may be applicable to some countries or regions with similar geographical characteristic as Hainan Province. Generally, tourist cities with a large number of migrant population provide a channel for the entry of the confirmed cases, while the capital or the central city as a transportation hub provides a diffusion path for the spread of the epidemic.

Prevention and control measures for the COVID-19 epidemic

China has experienced SARS in 2003 and MERS in 2012 of the coronavirus outbreak, providing invaluable experience for the current COVID-19 epidemic control ([Tian et al. 2020](#)). Notably, the contradiction now is that faster information transmission has improved the efficiency of policy implementation, but the increase in the frequency and range of activities between people has strengthened the spread of the epidemic. The rapid decision-making of the government and rapid response of all sectors of society are the main reasons for the control of the epidemic in China. China's epidemic prevention has achieved tremendous achievements, for which it has paid a painful price ([Lai et al. 2020](#); [Tian et al. 2020](#)). The number of daily confirmed cases in Hubei Province, the most severe province in China, has dropped to 0, indicating that China's epidemic prevention is nearing completion. Nonetheless, in the face of the grim situation of epidemic development worldwide, the normalization of epidemic prevention policies is crucial. Restoring social order and economic development based on preventing the import of overseas cases and the rebound of the domestic epidemic situation is the current main task for the Chinese government.

Hainan is close to Guangdong Province, where the epidemic is more severe (cumulative cases: 1,641, as of July 1, 2020, ranked 2nd only to Hubei Province in China) (<http://www.nhc.gov.cn/>), placing high demands on the epidemic prevention work of the island. The cumulative number of confirmed cases in Hainan Province ranks 25th in this country (Fig. 11), and it is one of the regions with relatively stable epidemic control. The special geographic location makes its epidemic control work of reference value for many countries. The fatality of patients infected by COVID-19 in Hainan Province was 3.6%, significantly higher than the whole national average level and that in other provinces, mainly due to the difference in the number of confirmed cases.

Therefore, we propose to further contain and eliminate the epidemic from the following aspects. First, real-time, daily monitoring should be implemented in time. Emphasis should be placed on monitoring the gathering places of people with high mobility, such as communities and enterprises. Additionally, the health status and travel information of each resident and employee should be recorded and updated in a timely manner. At present, the spread of the epidemic globally persists, and the entry of confirmed cases abroad should be avoided, especially in tourist destinations and border zones, such as Hainan. The government can provide corresponding assistance to those former patients and their families to alleviate their psychological and life pressures. Furthermore, the government can focus on the progress of epidemic prevention in various regions, as well as optimize and adjust strategies in a timely manner according to the actual situation. Second, in terms of space, prevention work should be continuously refined according to different levels such as community, county, and city, to ensure higher efficiency. On the community scale, management departments should keep abreast of the health status and living needs of each household resident, which can be done through a health brochure or register. Additionally, the public space of the community should be periodically disinfected and inspected. Online work and communication can be used to reduce crowd contact and avoid crowd formation. Regarding shopping malls and other public places that have resumed, normal safety inspections should be conducted, and the latest epidemic situation needs to be reported in a timely manner. If there are new confirmed cases, the distribution of social resources should be adjusted in a timely manner, and under the premise of preventing further spread, to ensure that patients can be quickly treated. Humans are the core carriers of virus transmission and spread of the epidemic and are the key to eliminating the virus and preventing and controlling the epidemic. Therefore, in this critical period, for everyone, regulating individual behavior is the most basic but also crucial for epidemic prevention. The regulation of individual behavior depends on the strength of epidemic prevention awareness and effective supervision of all social departments. The media platform can disseminate the epidemic situation, policies and regulations through publicity methods to improve the efficiency of the individual's timely access to information.

Discussion

The demographic characteristics of 168 confirmed cases in Hainan Province were consistent with the statistical results of other regions in China (Tian et al. 2020; Wang et al. 2020). The COVID-19 epidemic did not show gender orientation, and patients mainly were middle-aged and young adults. Thus, there is no specific regional directivity in this epidemic, and patients in all regions have consistent gender and age characteristics (National Health Commission of the People's Republic of China 2020). The outbreak in Hainan Province lasted about a month, consistent with the remaining provinces of China except for the

worst area, Hubei Province. However, the current situation in Hubei has improved, and no more than 10 uncured cases remain in the area (<http://www.nhc.gov.cn/>).

One of the most southern cities in China, Sanya City, where millions of tourists flock every year, has led to foreign patients entering the island at the beginning of the outbreak. During the first month of the outbreak, Sanya City has been the city with the largest number of confirmed cases in this province. Compared with capital Haikou City, the spread in Sanya City has remained at a low level. This shows that Sanya City is the import center for external cases, and Haikou, the provincial capital with a dense population and convenient transportation, is the diffuse center of the outbreak in this island; other areas may have the same dual-core spread pattern.

Furthermore, we divided the outbreak period into two parts at an intermediate time point, and the functions are fitted with the first part and whole, respectively (Fig. 12). Calculation of the definite points shows that the implementation of the isolation policy has reduced the spread of the epidemic by more than 40%. Considering that the outbreak freely developed much faster than linearly, and the implementation of the isolation policy is earlier than the midpoint, 40% is the most conservative estimate. The outbreak of COVID-19 in the early 2020s exceeded the boundaries of countries and continents and became a pandemic affecting human health and social development. China has actively and quickly implemented policies to effectively prevent the spread of the epidemic in China, providing much experience for other regions that are conservatively affected by the outbreak (Lai et al. 2020). Therefore, preventing external infections from entering the region is crucial and reducing population movement to avoid the spread of the epidemic has proven to be effective in China (Moritz et al. 2020).

This study has some limitations. First, the characteristics of the confirmed cases alone cannot completely reflect the law of the epidemic. A comprehensive analysis of the confirmed cases, close contacts, suspected cases and other special groups will provide more accurate conclusions. Second, it is difficult to estimate the degree of policy suppression of the epidemic. This article only used the most conservative approach to calculate the efficiency of the policy. Additionally, due to the small number of confirmed cases in Hainan, the estimated results do not apply to other regions.

Conclusion

Based on the basic information and spatiotemporal trajectory of confirmed COVID-19 cases reported by official media, this article used text analysis, spatial analysis, evolutionary mapping and other methods to analyze the demographic characteristics, temporal evolution, spatial distribution, diffusion pattern of confirmed cases in Hainan Province, and provides suggestions on prevention policies and regulations based on the current epidemic situation. The main conclusions are as follows: (1) The gender distribution of confirmed cases is balanced without obvious gender preference. Middle-aged and young adults are the main groups, exceeding 80% of the total. (2) The development of the COVID-19 epidemic in Hainan Province has shown the trend of “burst growth followed by slow decline”. The spatial heterogeneity of epidemic distribution is significant, the coastal areas, especially the north and south ends, were the severe

areas in the islands. (3) The confirmed cases in Hainan Province were mainly imported cases, and the diffusion was relatively limited on this island. Sanya City was the import center of confirmed cases, and Haikou City was the diffusion center, which two constitutes a dual-core spread model of COVID-19 epidemic. (4) The previous prevention policies have achieved remarkable results. In the future, strategies should be continuously adjusted according to changes in the epidemic, and work efficiency can be improved at all levels of government, community, and individuals.

Declarations

Compliance with ethical standards

This study used the official published website data in general information and we conducted in accordance with the Declaration of Helsinki.

Conflict of interest

There are no conflicts of interest.

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References

Chen N, Zhou M, Dong X, et al. (2020) Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *The Lancet*, 395(10223), 507-513

Du Y X, Chen X P (2020) Favipiravir: pharmacokinetics and concerns about clinical trials for 2019-nCoV infection. *Clinical Pharmacology & Therapeutics*. <https://doi.org/10.1002/cpt.1878>

Gavin Y, Marco S, Richard H, et al. (2020) Ensuring global access to COVID-19 vaccines. *The Lancet*. 395(10234), 2-8

Huang C, Wan Y, Li X, et al. (2020) Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*. 395(10223), 497-506

Lai S, Ruktanonchai N W, Zhou L, et al. (2020) Effect of non-pharmaceutical interventions for containing the COVID-19 outbreak: an observational and modelling study. *medRxiv* 2020

- Lawrence C, John R M, Anthony S F, et al. (2020) A strategic approach to COVID-19 vaccine R&D. *Science*. <https://doi.org/10.1126/science.abc5312>
- Li X, Zai J, Wang X, et al. (2020) Potential of large “first generation” human-to-human transmission of 2019-nCoV. *Journal of medical virology*. 92(4), 448-454
- Liang W H, Liang H R, Ou L M, et al. (2020) Development and validation of a clinical risk score to predict the occurrence of critical illness in hospitalized patients with COVID-19. *JAMA Internal Medicine*. <https://doi.org/10.1001/jamainternmed.2020.2033>
- Lu R, Zhao X, Li J, et al. (2020) Genomic characterization and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *The Lancet*. 395(10224), 565-574
- Moritz U G, Kraemer, Chia H Y, et al. (2020) [The effect of human mobility and control measures on the COVID-19 epidemic in China](https://doi.org/10.1126/science.abb4218). *Science*. [https://doi.org/ 10.1126/science.abb4218](https://doi.org/10.1126/science.abb4218)
- Normile D. (2020) www.sciencemag.org/news/2020/03/can-china-return-normalcy-while-keeping-coronavirus-check. *Science*. Accessed 14 May 2020
- Paraskevis D, Kostaki E G, Magiorkinis G, et al. (2020) Full-genome evolutionary analysis of the novel corona virus (2019-nCoV) rejects the hypothesis of emergence as a result of a recent recombination event. *Infection, Genetics and Evolution*. 79:104212
- Paul N N, Katherine C Bond (2020) COVID-19 and risks to the supply and quality of tests, drugs, and vaccines. [The Lancet Global Health](https://doi.org/10.1016/S2214-109X(20)30136-4). [https://doi.org/10.1016/S2214-109X\(20\)30136-4](https://doi.org/10.1016/S2214-109X(20)30136-4)
- Richard L (2020) Sarah Gilbert: carving a path towards a COVID-19 vaccine. *The Lancet*. 395(10232), 18-24
- Tian H, Liu Y, Li Y, et al. (2020) An investigation of transmission control measures during the first 50 days of the COVID-19 epidemic in China. *Science*. 368(6491), 638-642
- Tian S, Hu N, Lou J, et al. (2020) Characteristics of COVID-19 infection in Beijing. *Journal of Infection*. 80, 401-406
- Wang M, Cao R, Zhang L, et al. (2020) Remdesivir and Chloroquine effectively inhibit the recently emerged novel coronavirus (2019-nCoV) in vitro. *Cell research*. 30(3), 269-271
- Wang R R, Pan M, Zhang X M, et al. (2020) Epidemiological and clinical features of 125 hospitalized patients with COVID-19 in Fuyang, Anhui, China. *International Journal of Infectious Diseases*. 95, 421-428
- Wilder S A, Chiew C J, Lee V J. (2020) Can we contain the COVID-19 outbreak with the same measures as for SARS? *The Lancet infectious Disease*. 20(5), e102-e107

Wu J T, Leung K, & Leung G M (2020) Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. *The Lancet*. 395(10225), 689-697

Xiao K P, Zhai J Q, Feng Y Y, et al. (2020) Isolation of SARS-CoV-2-related coronavirus from Malayan pangolins. *Nature*. <https://doi.org/10.1038/s41586-020-2313-x>

Xu X, Zhang Y, Li X, et al. (2020) Analysis on prevention plan of corona virus disease-19 (COVID-19) by traditional Chinese medicine in various regions. *Chinese Traditional and Herbal Drugs*. (in Chinese)

Yong S E, Anderson D E, Wei W E, et al. (2020) Connecting clusters of COVID-19: an epidemiological and serological investigation. *The Lancet infectious Disease*. [https://doi.org/10.1016/S1473-3099\(20\)30273-5](https://doi.org/10.1016/S1473-3099(20)30273-5)

Zhou P, Yang X L, Wang X G, et al. (2020) A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*. 579(7798), 270-273

Figures

Figure 1

Location map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Age and gender structure of confirmed COVID-19 cases in Hainan Province

Figure 3

Trends of the COVID-19 epidemic in Hainan Province (a, provincial; b, regional)

Figure 4

Infection groups and their classification

Figure 5

Infection groups and diffusion ratios of confirmed cases in Hainan Province (a, number; b, proportion)

Figure 6

Spatial evolution of the COVID-19 epidemic in Hainan Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Spatial distribution of confirmed COVID-19 cases in Hainan Province (a, number; b, infection rate; c, density). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 8

Kernel analysis of the distribution of confirmed COVID-19 cases in Hainan Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of

any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 9

Diffusion ratio of the COVID-19 epidemic in Hainan Province (a, current; b, evolving). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 10

Path model of epidemic spread in Hainan Province

Figure 11

Cumulative confirmed cases for all provinces in China

Figure 12

Impact of quarantine policy implementation on the development of the epidemic