



OPEN Spatial-temporal evolution patterns of influenza incidence in Xinjiang Prefecture from 2014 to 2023 based on GIS

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Using GIS technology, this study investigated the spatiotemporal distribution pattern of influenza incidence in Xinjiang from 2014 to 2023 based on influenza surveillance data. The study revealed a noticeable fluctuation trend in influenza incidence rates in Xinjiang, particularly notable spikes observed in 2019 and 2023. The results of the 3-year moving average showed a significant long-term upward trend in influenza incidence rates, confirmed by Theil-Sen method ($MAD = 2.202$, $p < 0.01$). Global spatial autocorrelation analysis indicated significant positive spatial autocorrelation in influenza incidence rates from 2016 and from 2018 to 2023 (Moran's $I > 0$, $P < 0.05$). Local spatial autocorrelation analysis further revealed clustering patterns in different regions, with high-high clustering and low-high clustering predominating in northern Xinjiang, and low-low clustering predominating in southern Xinjiang. Hotspot analysis indicated a progressive rise in the number of influenza incidence hotspots, primarily concentrated in northern Xinjiang, particularly in Urumqi, Ili Kazakh Autonomous Prefecture, and Hotan Prefecture. Standard deviation ellipse analysis and the trajectory of influenza incidence gravity center migration showed that the transmission range of influenza in Xinjiang has been expanding, with the epidemic center gradually moving northward. The spatiotemporal heterogeneity of influenza incidence in Xinjiang highlights the need for differentiated and precise influenza prevention and control strategies in different regions to address the changing trends in influenza prevalence.

Keywords Influenza, Spatiotemporal analysis, GIS

Influenza, commonly known as the flu, is an acute respiratory infectious disease caused by influenza viruses, affecting individuals of all ages with varying susceptibility to the virus¹. The rapid spread and extensive impact of influenza epidemics pose significant threats to public health and societal stability². According to data from the World Health Organization (WHO), approximately 10% of the global population is affected by influenza annually, leading to a large number of cases and around 500,000 deaths³, thereby imposing a substantial disease burden and economic losses.

Globally, influenza epidemics exhibit a distinct seasonal pattern, with winter and spring often being peak periods for influenza activity⁴. To effectively combat influenza epidemics, the WHO actively promotes the establishment and enhancement of a global influenza surveillance network to monitor influenza activity levels and trends in real-time, aiming to identify and address potential health risks promptly⁵. The annual influenza reports published by the WHO provide essential references for countries to develop targeted prevention and control strategies.

In China, influenza is also a significant public health issue⁶. The Chinese Center for Disease Control and Prevention (CDC) and other relevant departments actively conduct influenza surveillance, collecting and analyzing vast amounts of data to understand the dynamic changes in influenza epidemics⁷. However, due to the large population, vast territory, and diverse climates, the influenza epidemic situation in China is complex and variable⁸, necessitating more nuanced and targeted influenza prevention and control strategies. The Xinjiang Uygur Autonomous Region (Xinjiang) presents a unique case due to its distinct geographical location and climatic conditions. The Tianshan Mountains divide Xinjiang into northern and southern regions, each

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exhibiting significant climatic differences. Such a varied situation calls for more precise monitoring and control measures.

In recent years, the application of Geographic Information Systems (GIS) in infectious disease research has become increasingly widespread. GIS offers advantages in spatiotemporal analysis, providing new insights and methods for monitoring and controlling influenza epidemics⁹. By utilizing GIS technology, influenza surveillance data can be spatially visualized and quantitatively analyzed, allowing for a more intuitive understanding of the spatiotemporal distribution patterns of epidemics, revealing disease transmission pathways and influencing factors. Previous studies have successfully used GIS technology to analyze the spatiotemporal distribution patterns of influenza in various regions of China¹⁰, identifying high-risk areas¹¹ and providing scientific bases for targeted prevention and control measures.

In the vast and climatically diverse region of Xinjiang, utilizing GIS technology for spatiotemporal analysis of influenza epidemics is particularly crucial. Identifying high-risk areas and transmission pathways can provide scientific evidence for developing targeted prevention and control measures. This study uses influenza surveillance data from Xinjiang to analyze the spatial heterogeneity of influenza incidence at the county level, explore the spatiotemporal distribution characteristics and evolution trends of the epidemic, and identify high-risk areas. The aim is to provide theoretical support and practical guidance for influenza epidemic surveillance, early warning, risk assessment, and precise control.

Methods

Data and sources

Data source

The influenza incidence data for 96 counties in Xinjiang from 2014 to 2023 were obtained from the China Infectious Disease Surveillance System, ensuring data reliability. The map data were obtained from the Xinjiang Uygur Autonomous Region Geological Survey Institute. The map used in this study has a scale of 1:100,000, which shows the administrative subdivisions of the region in detail. To ensure the accuracy of the map boundaries, we compared them with the data from the Xinjiang Uygur Autonomous Region Platform for Common Geospatial Information Service (https://xinjiang.tianditu.gov.cn/bzdt_code/bzdt.html). This comparison confirmed that the maps are accurate and free of any sensitive geographical information, making them suitable for use in our spatial analysis.

Spatial correlation

The influenza incidence data for each county were linked to electronic maps of Xinjiang county boundaries. Using the mapping function of ArcGIS, thematic maps of influenza incidence rates were created. Global Moran's I was calculated to describe the spatial characteristics of influenza incidence rates across Xinjiang using the formula:

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

where n represents the number of counties, x represents the influenza incidence rates of different counties,

\bar{x} represents the mean incidence rate, w represents spatial weight.

Moran's I ranges from -1 to 1 . At a significance level of $\alpha=0.05$, values near 1 indicate positive spatial autocorrelation, near -1 indicate negative spatial autocorrelation, and zero indicates randomness. We used Local Moran's I to analyze spatial autocorrelation patterns at spatial unit levels and conducted LISA to identify clustered areas. Four clustering patterns were identified: HH (high-high), HL (high-low), LL (low-low), and LH (low-high).

The Getis-Ord G statistic was utilized as a measure to identify influenza incidence hotspots and cold spots using the formula:

$$G_i = \frac{\sum_{j=1}^n w_{ij} x_j}{\sum_{j=1}^n x_j} \quad (2)$$

where the meanings of the variables are the same as in Formula (1). Under the $\alpha=0.05$ significance level, a positive G_i value suggests a hotspot area of influenza incidence, while a negative G_i value suggests a cold spot area.

Gravity center shift model and standard deviation ellipse

The influenza incidence database was linked with the coordinates of each county. The influenza incidence gravity center model was employed to calculate the coordinates of influenza incidence gravity centers for different periods. The formula for calculating the gravity center (\bar{X}, \bar{Y}) is as follows:

$$\bar{X} = \frac{\sum W_i x_i}{\sum W_i} \quad \bar{Y} = \frac{\sum W_i y_i}{\sum W_i} \quad (3)$$

where x_i and y_i represent the coordinates of the i th county, and W_i represents the weight of the i th county, which in this study is the influenza incidence rate.

The standard deviation ellipse method simultaneously analyzes the direction and distribution of data. The size of the ellipse reflects the concentration of influenza incidence reports in Xinjiang on a spatial scale. The

length of the major axis indicates the direction of data distribution, while the length of the minor axis represents the range of data distribution. The greater the difference between the lengths of the major and minor axes (i.e., the larger the eccentricity), the more pronounced the directionality of the data. Conversely, if the lengths of the major and minor axes are closer, it indicates less pronounced directionality.

Statistical methods

Excel 2019 was used to establish the influenza incidence database. R 4.3.2 software for trend analysis and plotting line graphs. ArcGIS 10.8 software was utilized for map visualization and spatial analysis. Spatial exploratory analysis included global spatial autocorrelation analysis, local spatial autocorrelation analysis, and hotspot analysis. Spatial descriptive analysis employed gravity center analysis and standard deviation ellipse analysis methods.

Results

Incidence characteristics

From 2014 to 2023, a total of 96 counties in Xinjiang reported 103,887 cases of influenza, with annual incidence rates of 9.86/100,000, 3.85/100,000, 10.16/100,000, 26.01/100,000, 88.80/100,000, 20.06/100,000, 7.78/100,000, 16.5/100,000, and 234.61/100,000. Over the past decade, the incidence rate has shown significant fluctuations. In 2015, the incidence rate reached its lowest point at 3.85/100,000, while in 2019, it significantly increased to 88.80/100,000, and then sharply rose to 234.61/100,000 in 2023. To better understand the long-term trend, a 3-year moving average was calculated, revealing a long-term upward trend in the incidence rate. The Theil-Sen method confirmed that this upward trend is statistically significant ($MAD = 2.202$, $V\text{-value} = 54$, $p < 0.01$). Detailed results are presented in Fig. 1.

The thematic maps of influenza incidence in 96 counties of Xinjiang from 2014 to 2023 show the influenza incidence rates across the entire region. From 2014 to 2017, the incidence rates in various counties were generally low, mostly below 20 per 100,000, and remained at that level, especially in southern Xinjiang where the rates remained low with little variation. Starting in 2018, the incidence rates in counties located in northern and eastern Xinjiang began to rise steadily, exceeding 50 per 100,000, until they started to decline in 2021. However, in 2023, the incidence rates increased significantly again, affecting the entire region, especially in northern Xinjiang. Five counties in Urumqi City (Tianshan, Toutunhe, Terrazzo, Xinshi, Shaybak), two counties in Altay Region (Burqin, Hoboksar), as well as Yizhou in Hami Region and Yanqi in Bayingolin Region had incidence rates exceeding 500 per 100,000. Detailed results are presented in Fig. 2.

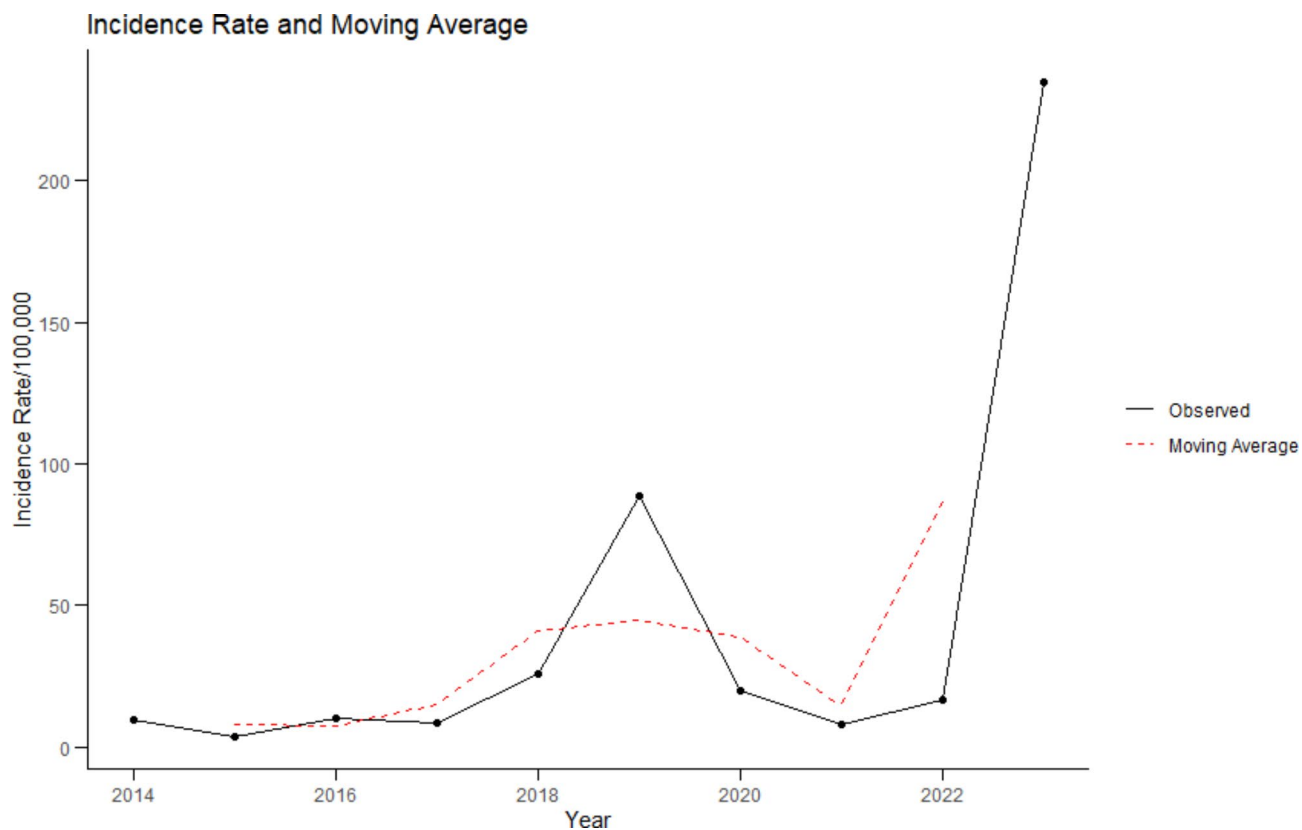


Fig. 1. Incidence Rate and Moving Average line graph of influenza incidence from 2018 to 2023 in Xinjiang.

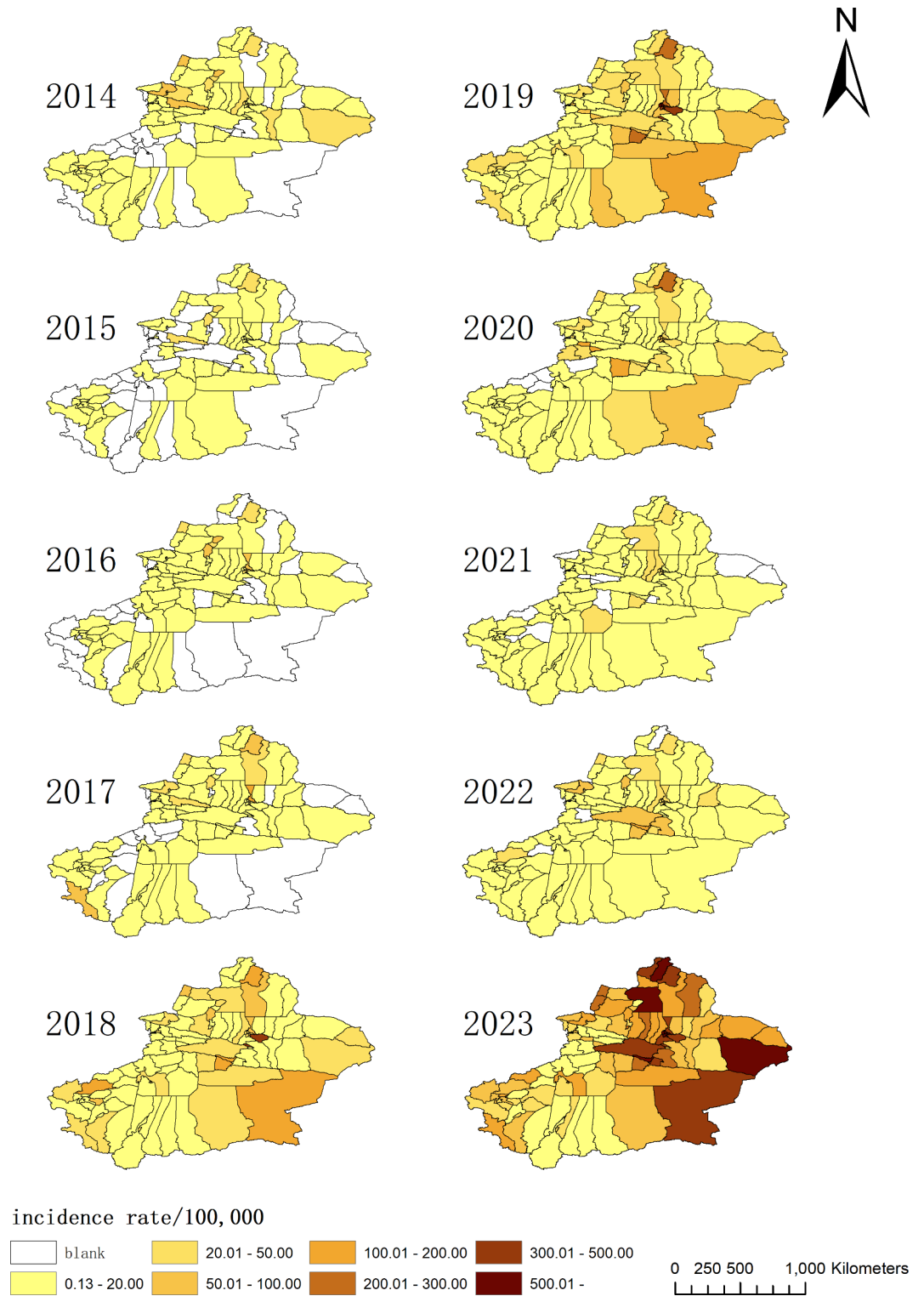


Fig. 2. The thematic maps of influenza incidence from 2018 to 2023 in Xinjiang.

Spatial correlation analysis

The global spatial autocorrelation analysis of influenza incidence rates in 96 counties of Xinjiang shows that, except for the years 2014, 2015, and 2017, the incidence rates from 2014 to 2023 exhibited positive spatial autocorrelation. The Moran’s I values were all greater than 0, with *P* values less than 0.05. The strongest clustering occurred in 2023, followed by 2021. Detailed results are presented in Table 1. The local spatial autocorrelation analysis was conducted for influenza incidence rates from 2018 to 2023, which exhibited positive spatial autocorrelation. Significant clustering patterns were identified. In northern Xinjiang, the predominant patterns were high-high

Year	Rate	Moran's I	Z-score	P-value
2014	9.68	0.079	1.438	0.075
2015	3.85	0.001	0.196	0.422
2016	10.16	0.125	2.265	0.012
2017	8.66	0.036	0.796	0.213
2018	26.01	0.064	2.233	0.026
2019	88.80	0.445	12.581	<0.001
2020	20.06	0.149	4.671	<0.001
2021	7.78	0.626	17.400	<0.001
2022	16.50	0.279	8.181	<0.001
2023	234.61	0.980	27.325	<0.001

Table 1. Global spatial autocorrelation of influenza incidence from 2014 to 2023 in Xinjiang (1/100,000).

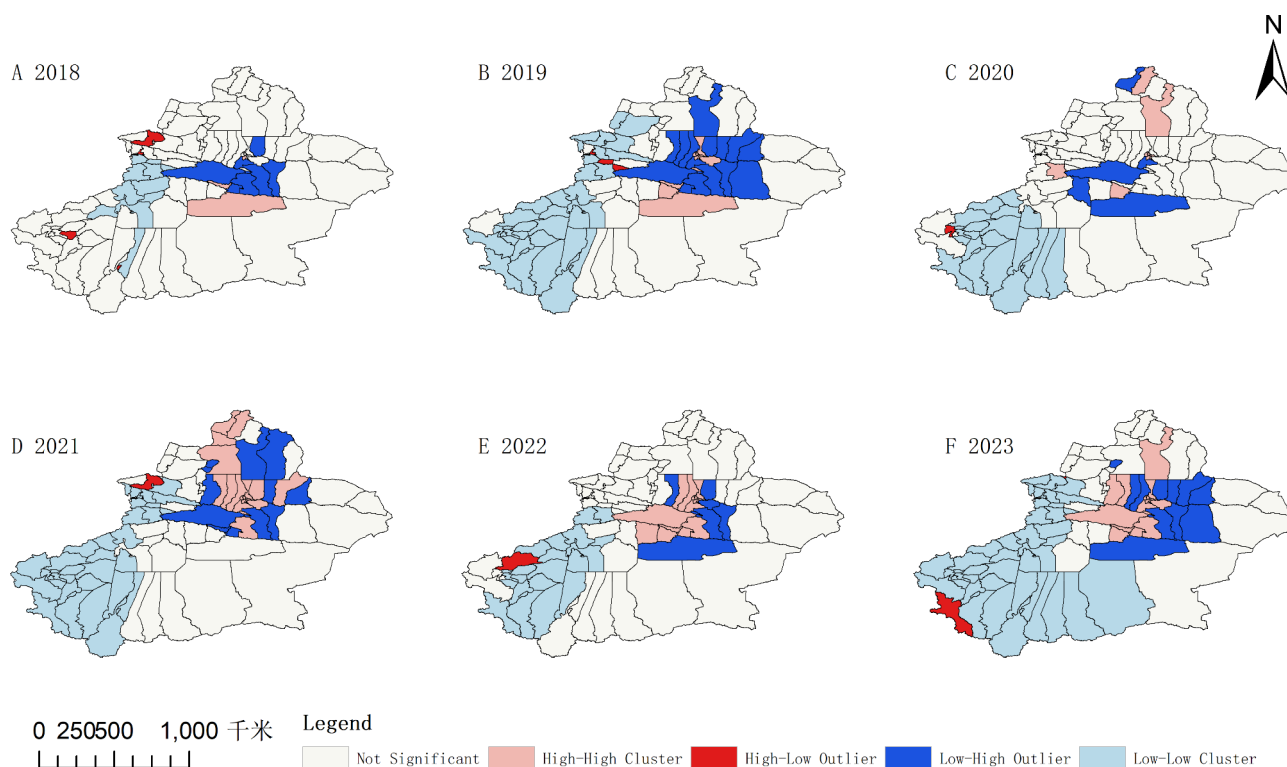


Fig. 3. The LISA cluster maps of influenza incidence from 2018 to 2023 in Xinjiang.

clustering and low-high clustering, while in Southern Xinjiang, low-low clustering predominated. The number of high-high clustering patterns observed each year increased from 3 to 16, indicating a strengthening of local spatial relationships and an increased influence of influenza incidence rates among counties. See Fig. 3 for details.

Hotspot analysis

The results of the hotspot analysis of influenza incidence in 2018–2023 showed that hotspot areas were identified in 22, 34, 16, 38, 30 and 34 counties for each respective year. These hotspots were mainly concentrated in northern Xinjiang, particularly in three regions: Urumqi, Ili Kazakh Autonomous Prefecture, and Hotan Prefecture, accounting for 72.73%, 64.71%, 50%, 55.26%, 63.33%, and 64.71% of the total hotspots for each year, respectively. The hotspot areas increasingly concentrated in northern Xinjiang from 2018 to 2023. Additionally, the number of hotspot counties exhibited a fluctuating upward trend, indicating an increasing trend in influenza incidence rates in northern Xinjiang and an expanding trend. See Fig. 4 for detailed information.

Standard deviation ellipse analysis and gravity center migration

The standard deviation ellipses, centered around the influenza incidence gravity center for each respective year. In 2018, the standard deviation ellipse covered the largest area, encompassing almost all of northern Xinjiang and parts of southern Xinjiang, indicating widespread transmission. In 2019, the standard deviation ellipse

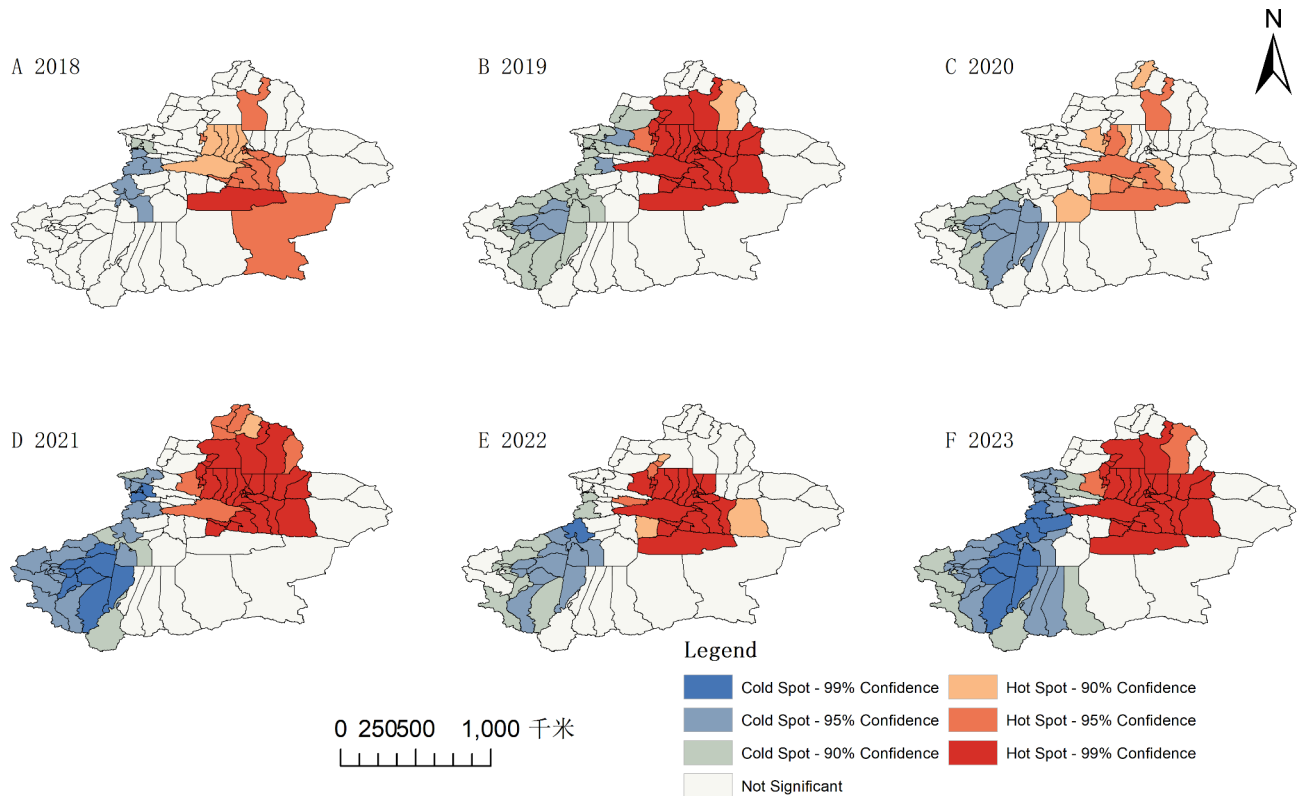


Fig. 4. Hot spots of influenza incidence from 2018 to 2023 in Xinjiang.

significantly shrank, concentrating in northern Xinjiang, suggesting a more localized spread. From 2020 to 2022, the standard deviation ellipse gradually elongated amid fluctuations, reflecting the further expansion of the influenza transmission range. In 2023, the standard deviation ellipse slightly decreased in size but remained highly concentrated in northern Xinjiang, indicating a significant clustering effect in influenza incidence in this region.

The trajectory of influenza incidence gravity center migration in Xinjiang from 2018 to 2023 reflects the spatial evolution process of influenza development and diffusion in the region. In 2018, the gravity center of influenza incidence was located in Hejing County, in the central region of northern Xinjiang. In 2019, the gravity center shifted eastward by 134.55 km to Changji City, indicating a trend of influenza incidence spreading eastward. In 2020, the gravity center moved further northwest by 85.71 km to Shawan County, showing an expanded transmission range in northern Xinjiang. In 2021, the gravity center continued to move north by 50.31 km to Manas County, reflecting a significant increase in influenza incidence in the northern region. In 2022, the gravity center shifted back to Hejing County, moving 118.24 km, indicating repeated fluctuations of the epidemic between northern and eastern Xinjiang. In 2023, the gravity center moved northeast again by 122.84 km to Manas County, reflecting a continued high incidence of influenza in northern and eastern Xinjiang. Overall, from 2018 to 2023, the gravity center of influenza incidence remained in northern Xinjiang, moving from Hejing County (115.5020° N, 43.2640° E) northeast to Hutubi County (86.3827° N, 43.7019° E), with a direct movement distance of 141.31 km. Each year, the incidence gravity center shifted around Urumqi and its surrounding areas. See Fig. 5 for detailed information.

Discussion

Between 2014 and 2023, the incidence rate of influenza in Xinjiang exhibited significant fluctuations, with an overall upward trend ($MAD = 2.202$, $p < 0.01$). From 2014 to 2018, the incidence rate remained low, below 30 per 100,000. However, in 2019, it surged to 88.80 per 100,000, an increase of 241.41%. During the period from 2020 to 2022, the incidence rate of influenza significantly decreased to between 7.78 per 100,000 and 20.06 per 100,000. This significant decline in influenza incidence during this period is likely because both COVID-19 and influenza are respiratory diseases. Multiple studies conducted during this time showed that non-pharmaceutical interventions (NPIs) implemented to control COVID-19, such as social distancing, mask-wearing, and enhanced hygiene practices, effectively reduced the incidence of influenza^{12,13}. In regions where lockdown measures were implemented due to the COVID-19 pandemic, the reduction in influenza incidence was particularly noticeable. For instance, one study indicated that influenza incidence decreased by 79-fold after nine months of lockdown¹⁴.

However, in 2023, the incidence rate of influenza sharply rebounded to 234.61 per 100,000, marking a 164.20% increase from 2019 and a 1321.88% increase from 2022. This significant rebound occurred in contrast to the period of the COVID-19 pandemic, suggesting that the relaxation of COVID-19 preventive measures led

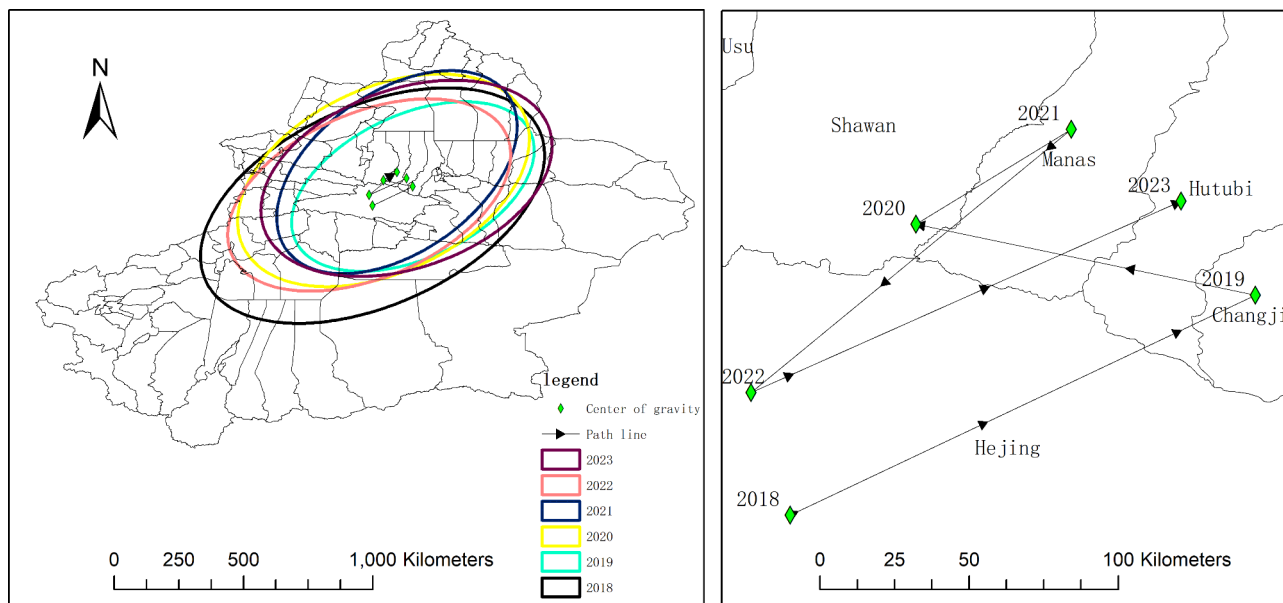


Fig. 5. Gravity center of influenza incidence from 2018 to 2023 in Xinjiang.

to increased opportunities for influenza virus transmission¹⁵. In the post-pandemic era, it is imperative to guard against the alternating or simultaneous epidemic trends of various respiratory diseases such as COVID-19, influenza, and pneumonia caused by *Mycoplasma pneumoniae*¹⁶.

According to the global spatial autocorrelation analysis, the influenza incidence rate in Xinjiang exhibited positive spatial correlation in 2016 and from 2018 to 2023. The local spatial autocorrelation analysis from 2018 to 2023 revealed distinct clustering patterns in different regions of Xinjiang. In northern Xinjiang, the predominant patterns were high-high clustering (HH) and low-high clustering (LH), while in southern Xinjiang, low-low clustering (LL) was more common. The high-high clustering in northern Xinjiang indicates that counties with high influenza incidence rates are surrounded by neighbors also experiencing high rates, suggesting strong local transmission. The low-high clustering indicates that counties with low influenza incidence rates are surrounded by neighbors with high rates, implying potential risk areas. There was a fluctuating upward trend in the number of high-high clusters, increasing from 3 in 2018 to 16 in 2023, a rise of 433.33%. This indicates a strengthening of local spatial relationships and an increased influence of influenza incidence rates among counties.

The hotspot analysis results corroborate this finding, showing a fluctuating upward trend in the number of influenza hotspots, with hotspot counties increasing from 22 in 2018 to 34 in 2023, a rise of 54.55%. These hotspots were primarily concentrated in Urumqi, Ili Kazakh Autonomous Prefecture, and Hotan Prefecture. This indicates that the high prevalence of influenza is in northern Xinjiang, with an increasing and expanding trend in incidence rates.

Throughout 2018 to 2023, the gravity center of influenza incidence remained in northern Xinjiang, shifting between five counties: Hejing County, Changji City, Hutubi County, Manas County, and Shawan County. The incidence rates in northern Xinjiang increased rapidly, leading to an overall southwest to northeast shift in the gravity center. The standard deviation ellipses exhibited a northeast-southwest pattern, with its area fluctuating over time, reflecting the degree of concentration of influenza incidence. These results further indicate significant differences in incidence rates between counties in northern and Southern Xinjiang. Overall, the incidence rates in northern Xinjiang were significantly higher than those in Southern Xinjiang, making it a hotspot and primary region for the migration of the incidence center. The spread of influenza in northern and eastern Xinjiang showed a trend of continuous expansion. Over six years, the center of influenza incidence gradually moved towards Urumqi and its surrounding areas. Particularly in 2023, the influenza incidence in northern Xinjiang became more concentrated.

Spatiotemporal analysis techniques have significant advantages in revealing the development trends of influenza epidemics and accurately predicting risks¹⁷. By analyzing the dynamic changes of influenza in temporal and spatial dimensions, high-risk areas and potential development trends can be accurately identified¹⁸. In-depth studies at the county level are of great importance for improving the precision and effectiveness of influenza prevention and control. This study analyzes the spatiotemporal evolution of influenza incidence rates at the county level in Xinjiang, further highlighting the critical role and practical utility of spatiotemporal analysis in epidemic prevention and control.

This study reveals that influenza in Xinjiang is on the rise, with an accelerated growth rate in the post-pandemic era. Spatial analysis methods have identified northern Xinjiang as a high-risk area for influenza, showing an increasing trend in incidence and spread. The significant difference in influenza outbreaks between northern and southern Xinjiang may be attributed to various social factors, including population density, medical

resources, and transportation accessibility¹⁹. Studies have shown that areas with higher population density and better transportation networks tend to experience higher rates of influenza transmission^{20,21}.

Xinjiang, divided into northern and southern regions by the Tianshan Mountains, exhibits significant climatic differences. The climate in northern Xinjiang is colder and more humid, which are driving factors for influenza epidemics²². Studies have shown that colder temperatures and higher humidity can facilitate the spread of influenza viruses by promoting virus stability and transmission^{23,24}. Additionally, this may suggest that potential epidemics in southern Xinjiang have not yet been detected.

Therefore, the prevention and control of influenza in Xinjiang require the formulation of differentiated and precise prevention strategies based on the clustering patterns and spatiotemporal characteristics of different regions. Northern Xinjiang is a high-incidence area for influenza, thus requiring more prevention and control resources to address this challenge. Measures such as increasing vaccine supply, strengthening the construction of medical facilities, and enhancing the professional capabilities of healthcare workers are necessary^{25,26}. Additionally, targeted health education activities should be conducted to improve public awareness and prevention of influenza. Although the incidence rate of influenza in southern Xinjiang is relatively low, there still exists a certain level of risk, necessitating the establishment of a more comprehensive influenza monitoring system²⁷ to promptly detect and respond to potential influenza outbreaks. By strengthening influenza prevention and control efforts in northern Xinjiang, enhancing influenza monitoring capabilities in southern Xinjiang, and addressing issues related to the allocation of medical resources between the two regions, we can better address public health challenges posed by influenza epidemics and ensure the health and safety of the people.

This study primarily conducted spatial description and analysis of influenza incidence rate data. However, it is worth noting that the study did not delve into the various factors influencing influenza incidence rates, resulting in a significant deficiency in causal analysis. The causes of influenza incidence are complex and diverse, potentially including environmental factors, socioeconomic conditions, population structure, distribution of medical resources, and other aspects. Future research should expand in this area to achieve a more comprehensive and in-depth understanding of the epidemiological patterns of influenza. Additionally, this study was limited to the geographic scope of Xinjiang, which somewhat restricted the study's generalizability. Given the vast territory and uneven population distribution in Xinjiang, there may be significant differences in influenza incidence rates across different regions. Therefore, future research could consider expanding the study scope to cover the entire country or more regions. Moreover, at the county level, research units could be further refined to the level of streets or communities to enhance the study's generalizability and representativeness. This approach would be more conducive to revealing the epidemiological characteristics of respiratory diseases such as influenza, thereby providing a more scientific and accurate basis for the formulation of prevention and control measures.

Conclusions

This study presents a comprehensive analysis of the spatiotemporal dynamics of influenza incidence in Xinjiang from 2014 to 2023 using GIS technology. The findings highlight significant fluctuations in influenza incidence rates over the study period, with notable increases observed in 2019 and 2023. Spatial autocorrelation analysis revealed a spatially positive correlation of influenza incidence rates, with increasing high-high clustering areas. Hotspot analysis indicated a progressive rise in the number of influenza incidence hotspots, primarily concentrated in northern Xinjiang. The centroid migration analysis showed a consistent movement of the influenza incidence centroid towards northern Xinjiang, reflecting a higher incidence rate in this region. Moreover, the study underscores the importance of strengthening influenza prevention and control measures, particularly in high-risk areas such as northern Xinjiang, while also emphasizing the need to enhance influenza surveillance capabilities in southern Xinjiang. These insights contribute to a better understanding of influenza epidemiology and provide valuable guidance for public health interventions and resource allocation strategies to mitigate the impact of influenza epidemics in Xinjiang and beyond. Further research is warranted to delve deeper into the multifaceted factors influencing influenza incidence rates and to broaden the geographical scope of analysis for more comprehensive insights.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

F.W. conceptualized and designed the study, and revised the manuscript. Z.Y. conceived and designed the study, and wrote the article. Y.D., Q.W. and Y.M. participated in the statistical analysis. L.Z., X.A.1, X.A.2, Z.C., R.Q. participated in data collection and maintenance. All authors reviewed the manuscript.

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Competing interests

The authors declare no competing interests.

Additional information

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