Vital Surveillances

The Spatiotemporal Epidemiology and Influencing Factor Analysis of Leptospirosis — Anhui Province, China, 2004–2023

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ABSTRACT

Introduction: Leptospirosis has historically been a severe public health concern across multiple Chinese provinces. Despite an overall decline in incidence in recent years, the disease continues to exhibit fluctuations and occasionally triggers localized outbreaks. This study aimed to characterize the demographic and spatiotemporal patterns of leptospirosis in Anhui Province — a historically significant epidemic region — from 2004 to 2023, to investigate potential climatic and environmental risk factors, and to identify critical targets for disease prevention and control.

Methods: Spatiotemporal cluster analysis was conducted using SaTScan software. Spearman correlation analysis was performed using SPSS to examine the short-term lagged effects of rainfall, temperature, and normalized difference vegetation index (NDVI) on leptospirosis incidence in the high-risk counties of Huaiyuan and Jingde.

Results: A total of 458 leptospirosis cases were reported across Anhui Province during the 20-year study period. Middle-aged individuals (40–59 years), males, and agricultural workers constituted the primary high-risk populations. Spatiotemporal scanning identified nine adjacent hotspots in southern Anhui during 2004–2012, with a subsequent shift to Huaiyuan County in the northern Huaihe River Basin during 2016–2021. Significant associations were observed between leptospirosis cases and temperature, rainfall, and NDVI in both Huaiyuan and Jingde counties.

Conclusion: This study revealed significant spatial heterogeneity, distinct spatiotemporal clustering patterns, and potential climatic and environmental risk factors for leptospirosis in Anhui Province during 2004–2023. These findings provide critical information regarding target regions, high-risk populations, and climatic and environmental factors to inform early warning systems and enhance prevention and control strategies for leptospirosis.

Leptospirosis is a globally neglected zoonotic disease, predominantly prevalent in Southeast Asia, Oceania, and Central and South America (*1*). Caused by pathogenic *Leptospira*, the disease accounts for approximately one million human cases and 60,000 deaths annually worldwide (*1*–*2*). Humans acquire infection through direct or indirect exposure to urine from reservoir animals, including pigs, dogs, and rodents (*2*). Since its classification as a notifiable infectious disease in China in 1955, leptospirosis has caused numerous outbreaks throughout history, primarily affecting central and southern regions including Anhui, Sichuan, Jiangxi, and Hunan provinces (*3*). Despite a significant decrease in overall incidence in recent years, small-scale outbreaks and sporadic cases continue to occur frequently across China (*4*). As a historically significant epidemic region, leptospirosis was first documented in Anhui Province in 1962. Severe outbreaks occurred in the Huaihe River Basin between 1970–1972 following heavy rainfall and flooding, with incidence peaking at 255.91 per 100,000 population in 1971, accounting for 30% of national cases (*3*). The disease exhibited distinct geographical shifts, predominantly affecting southern mountainous areas between 1960–1980 before transitioning to the northern Basin between 1980–2000. Jingde County emerged as a significant high-risk region, reporting the highest morbidity of 175.50 per 100,000 population in 1990 (*5*). Huaiyuan County represents another persistent hotspot, having reported peak morbidity of 56.73 per 100,000 population in 1972. Recent outbreaks in Huaiyuan, with 40 and 27 cases reported in 2016 and 2021 respectively, underscore that this region remains a significant leptospirosis hotspot in Anhui [data obtained from the China Information System for Diseases Control and Prevention (CISDCP)]. These epidemiological patterns indicate that leptospirosis continues to pose a serious yet neglected public health challenge warranting further investigation to identify high-risk regions and temporal clusters in Anhui Province.

To date, few comprehensive long-term studies have focused on demographic and spatiotemporal clustering analysis of leptospirosis in Anhui Province. To identify epidemiological characteristics and potential spatiotemporal hotspots, we conducted descriptive and geographical analyses spanning 2004–2023. Previous research has demonstrated that extreme weather events (e.g., heavy rainfall, flooding, and hurricanes), climatic factors (e.g., humidity and temperature), and environmental variables (e.g., land cover variations, presence of water bodies) may significantly influence leptospirosis transmission dynamics (*1*–*2*). To explore potential risk factors and their short-term effects on disease incidence, we performed correlation analyses between local climatic and environmental factors and leptospirosis cases in two high-risk counties — Huaiyuan and Jingde. The detailed characterization of epidemiological patterns, spatiotemporal hotspots, and identification of high-risk populations, climatic and environmental factors provides a scientific foundation for developing targeted prevention and control strategies for leptospirosis.

METHODS

Surveillance data of leptospirosis from January 2004 to December 2023 in Anhui Province, including both clinically diagnosed and laboratory-confirmed cases based on the Diagnostic Criteria for Leptospirosis (WS 2902008), were obtained from the CISDCP. The data included comprehensive demographic information such as age, gender, occupation, residential address, and date of illness onset for all leptospirosis patients. Demographic data for Anhui Province were obtained from the National Bureau of Statistics of China.

A descriptive analysis of county-level surveillance data was conducted to characterize the epidemiological features of leptospirosis. Spatiotemporal scanning analyses were performed using SaTScan (version 9.6, Information Management Services, Maryland, USA) based on spatial dynamic window scanning methodology. Relative risk (RR) and log-likelihood ratio (LLR) were calculated to quantify the elevated risk within scanning windows compared to areas outside these windows. The scanning window with the highest LLR value was designated as the primary cluster, while other windows with statistically significant LLRs were classified as secondary clusters. To investigate potential risk factors and their short-term effects on leptospirosis incidence, Spearman correlation analysis was conducted between local precipitation, temperature, normalized difference vegetation index (NDVI) and reported leptospirosis cases in two high-risk counties (Huaiyuan and Jingde) from 2004 to 2023 using SPSS (version 22.0, IBM Corp., Armonk, NY, USA). Monthly climatic data were obtained from the National Tibetan Plateau Data Center (https://data.tpdc.ac.cn/). Monthly NDVI data were sourced from the National Aeronautics and Space Administration (https://www.nasa.gov/). All statistical analyses were performed using SPSS, and circular heatmaps were generated using chiplot (https://www.chiplot.online/). Results were considered statistically significant when P values were less than 0.05.

RESULTS

Epidemiological Characteristics of Human Leptospirosis in Anhui

From 2004 to 2023, a total of 458 cases from 45 counties were reported in Anhui, with an annual average incidence rate of 0.037 per 100,000 population (Figure 1). Overall, leptospirosis incidence remained low throughout the study period, with notable spikes occurring in 2007, 2008, 2010, 2016, and 2021. Annual incidence rates fluctuated between 0.01 and 0.09 per 100,000 population.

Leptospirosis cases were documented across all age groups, with the highest prevalence observed among adults aged 40–59 years (n=222, 48.47%). Farmers constituted the predominant occupational category (n=405, 88.43%), followed by students (n=15, 3.28%). The male-to-female ratio was 2.14∶1. Leptospirosis cases were reported in every month except February, with August and September (n=349, 76.20%) representing the primary peak season annually, demonstrating distinct single-peak seasonal characteristics (Figure 2).

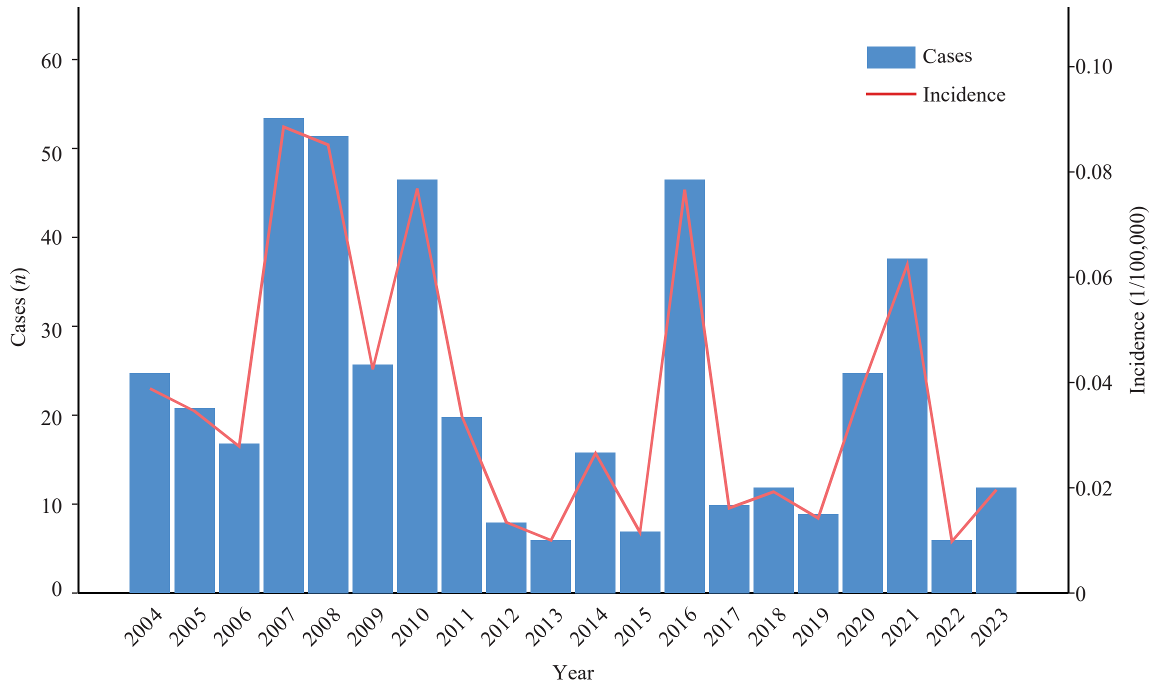

FIGURE 1. Annual distribution of leptospirosis cases in Anhui Province, China, 2004–2023.

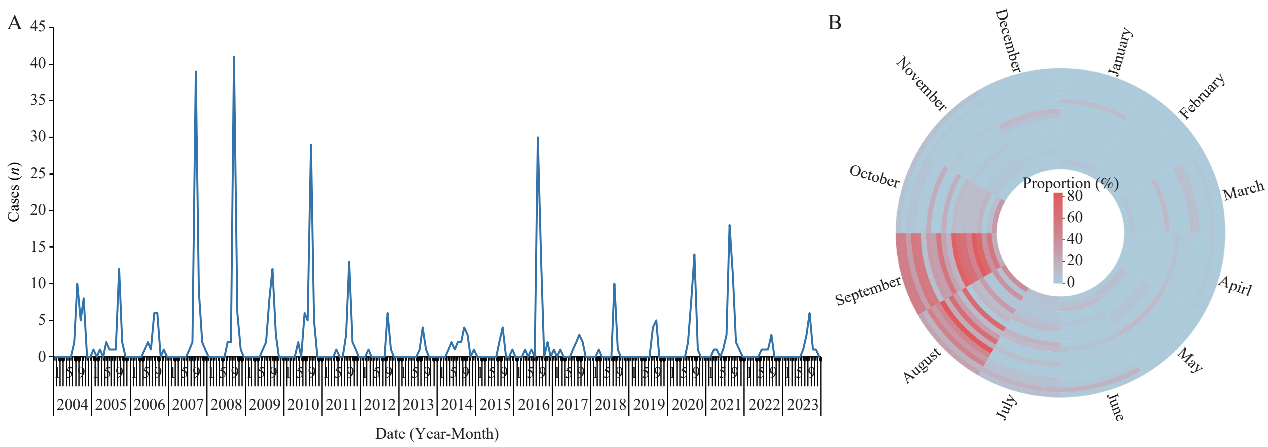

FIGURE 2. The monthly reported cases of leptospirosis in Anhui Province, China, 2004–2023，(A) Monthly distribution of leptospirosis cases each year; (B) Circular heatmap of the proportion of monthly leptospirosis cases each year.
Note: The order of the circles from the inside to the outside is represented 2004–2023.

Spatiotemporal Analysis of Human Leptospirosis in Anhui

Significant spatial heterogeneity was observed in the distribution of leptospirosis cases across counties in Anhui Province between 2004–2023, with Huaiyuan and Jingde emerging as the two highest-risk counties based on cumulative case numbers over the 20-year period (Supplementary Table S1, available at https://weekly.chinacdc.cn/). Multiple small-scale outbreaks occurred throughout this timeframe. Jingde County reported the highest incidence rates of 14.49, 8.98, and 15.26 per 100,000 population, accounting for 38.89%, 25.00%, and 46.81% of all Anhui cases in 2007, 2008, and 2010, respectively. Huaiyuan County subsequently emerged as a major hotspot, with incidence rates of 4.12 and 2.89 per 100,000 population, representing 85.11% and 72.97% of total provincial cases in 2016 and 2021, respectively. Spatiotemporal scan analysis revealed non-random distribution of leptospirosis across geographical areas and time periods, identifying one most likely cluster and one secondary cluster (Table 1). The most likely cluster was concentrated in the southern mountainous

TABLE 1. The results of spatiotemporal scan analysis of leptospirosis in Anhui Province, China, 2004–2023.

Cluster types	Year	Counties
Most likely cluster	2004–2012	Qimen, Yixian, Huangshan, Jingde, Jixi, Xiuning, Tunxi, Huizhou, Shexian.
Secondary cluster	2016–2021	Huaiyuan

areas, encompassing 9 adjacent counties (Qimen, Yixian, Huangshan, Jingde, Jixi, Xiuning, Tunxi, Huizhou, and Shexian) from 2004–2012 (LLR=737.62, RR=88.06, $P<0.001$). The secondary cluster was localized to Huaiyuan in the northern Huaihe River Basin from 2016–2021 (LLR=330.76, RR=65.60, $P<0.001$).

The Correlations Between Climatic, Environmental Factors and Leptospirosis in Huaiyuan and Jingde Counties

Based on the results of Spearman correlation analysis in Huaiyuan and Jingde, significantly positive correlations were observed between the numbers of reported case and average temperature, maximum temperature, and minimum temperature at lag periods of 0–3 and 6 months ($P<0.05$) (Table 2). Positive correlations were identified between leptospirosis and NDVI at lag periods of 0–1, 4, and 5 months in Huaiyuan, and at lag periods of 0–3, 5, and 6 months in Jingde, respectively ($P<0.05$) (Table 2). Similarly, positive correlations were observed between leptospirosis and rainfall at lag periods of 0–3 and 6 months in Huaiyuan, and at lag periods of 1–4 months in Jingde ($P<0.05$) (Table 2).

DISCUSSION

In this study, we analyzed the epidemiological characteristics and spatiotemporal patterns of leptospirosis in Anhui Province from 2004 to 2023, and explored potential climatic and environmental factors influencing disease transmission in high-risk regions. Throughout the 20-year study period, leptospirosis maintained a generally low incidence with significant spatial heterogeneity. Our findings suggest that temperature, rainfall, and NDVI may play substantial roles in driving increased leptospirosis incidence in Huaiyuan and Jingde Counties. This represents the first comprehensive analysis based on an extensive surveillance dataset to elucidate the predominant spatiotemporal patterns, identify key high-risk regions, and determine potential risk factors for leptospirosis in Anhui Province.

The significantly higher incidence among males compared to females in Anhui aligns with previous epidemiological studies (*3*–*4*). Middle-aged adults (40–59 years), males, and farmers — who constitute the primary local workforce — face elevated exposure risk to Leptospira-contaminated environments through activities such as rice harvesting, livestock management, fishing, and swimming (*4*,*6*). These findings underscore the necessity for enhanced health education targeting these vulnerable populations, particularly in rural communities. Our analysis revealed a distinct single-peak seasonal pattern of leptospirosis transmission, consistent with previous studies in Anhui (*7*). This peak coincides with the agricultural harvesting season and periods of high rainfall, further supporting the relationship between environmental conditions and disease transmission.

In this study, significant spatial heterogeneity was revealed. The high-incidence regions were predominantly concentrated in the southern mountainous areas and the northern Huaihe River Basin. Anhui, as a significant epidemic region, is traversed by both the Yangtze and Huaihe Rivers. The abundant rainfall, moist subtropical climate, and diverse host animal populations provide favorable environmental conditions for leptospirosis transmission. Notably, nine adjacent counties in the southern mountainous areas of Anhui formed the most likely high-risk cluster during 2004–2012, but the hotspots subsequently shifted to Huaiyuan in the northern Huaihe River Basin during 2016–2021. Rodents constituted the primary reservoir hosts in both high-risk regions of Huaiyuan and Jingde. The increased leptospirosis morbidity in Huaiyuan may be attributed to higher rodent densities and carrier rates, altered rodent species composition, and expanded rice cultivation areas (*8*–*10*). Three critical risk factors — rodent density exceeding 15%, rodent carrier rate exceeding 15%, and antibody levels against leptospirosis in the local population below 15% — precipitated the 2016 leptospirosis outbreak in Huaiyuan (*7*). Mechanized harvesting practices may have concurrently reduced human contact with contaminated environments in recent years (*4*). Consequently, more targeted control efforts are needed in these high-risk areas through enhanced epidemiological surveillance, promotion of protective

TABLE 2. Correlation coefficients between climatic, environmental factors and the numbers of reported cases in Huaiyuan and Jingde counties, Anhui Province, China, 2004–2023.

Characteristics	Lag (months)						
	0	1	2	3	4	5	6
Huaiyuan							
Average temperature (℃)	0.340**	0.439**	0.374**	0.223**	0.056	−0.096	−0.266**
Rainfall (mm)	0.279**	0.389**	0.339**	0.182**	0.038	−0.05	−0.147*
NDVI	0.377**	0.342**	0.116	0.108	0.208**	0.155*	−0.029
Maximum temperature (℃)	0.336**	0.437**	0.375**	0.224**	0.056	−0.094	−0.269**
Minimum temperature (℃)	0.340**	0.441**	0.375**	0.229**	0.065	−0.096	−0.264**
Jingde							
Average temperature (℃)	0.232**	0.410**	0.431**	0.293**	0.122	−0.063	−0.236**
Rainfall (mm)	−0.027	0.190**	0.272**	0.343**	0.234**	0.113	0.018
NDVI	0.248**	0.394**	0.398**	0.246**	0.048	−0.178**	−0.178**
Maximum temperature (℃)	0.243**	0.411**	0.430**	0.284**	0.123	−0.054	−0.230**
Minimum temperature (℃)	0.220**	0.409**	0.435**	0.304**	0.120	−0.072	−0.239**

Abbreviation: NDVI=normalized difference vegetation index.
* P<0.050
** P<0.001.

equipment (rubber boots and gloves), and implementation of leptospirosis immunization when warranted.

Significant associations between leptospirosis, and climatic and environmental risk factors — including average humidity, precipitation, temperature, and difference water index — have been documented in previous research, though the reported lag effects vary considerably from weeks to months or even years (*1*,*11*). Our results demonstrate that the numbers of reported cases were significantly associated with temperature, rainfall, and NDVI in the two high-risk counties of Huaiyuan and Jingde. The strongest positive correlations were observed between leptospirosis and concurrent NDVI, with local temperature and rainfall showing strongest associations at a one-month lag in Huaiyuan. Compared to July measurements in 2015 and 2020, Huaiyuan experienced substantial rainfall increases of 47.06% and 19.83% in 2016 and 2021, respectively. The lagged effects of local precipitation likely constituted the primary risk factor for subsequent leptospirosis outbreaks in Huaiyuan, consistent with findings from Lezhi, China (*12*). Humid and warm conditions favor *Leptospira* survival, increase animal reservoir abundance, and facilitate environmental transmission of the pathogen. NDVI correlates with vegetation cover, livestock grazing patterns, animal reservoir abundance, and agricultural activities. Therefore, systematic monitoring and early-warning systems, coupled with locally-tailored intervention measures, are essential to reduce the burden of leptospiral infection in Huaiyuan.

In summary, our findings revealed significant spatial heterogeneity and distinct spatiotemporal clustering of leptospirosis in Anhui Province from 2004 to 2023. These results provide important insights for characterizing high-risk areas and strengthening ongoing surveillance and control efforts. However, this study has several limitations. Potential socioeconomic factors, host animal density, and *Leptospira*-carrying rates that may influence leptospirosis transmission were not included in the analysis. Additional risk factors should be explored in future investigations.

Conflicts of interest: No conflicts of interest.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. The regions with top five highest numbers of annual reported cases in Anhui Province, China, 2004–2023.

Year	1	2	3	4	5
2004	Xiuning	Jingde, Shexian	Huangshan	Yixian, Qimen	Jixi
2005	Jingde	Shexian	Xiuning	Mingguang	Huangshan, Fengyang
2006	Jingde	Shexian	Xiuning, Mingguang, Huangshan, Qimen, Huizhou, Wuhe		
2007	Jingde	Shexian	Yixian	Qimen	Xiuning
2008	Jingde	Shexian	Yixian, Qimen	Huangshan	Xiuning
2009	Shexian	Jingde	Huaiyuan	Xiuning, Huizhou	Yixian, Qingyang
2010	Jingde	Xiuning, Huangshan	Shexian	Huaiyuan	Qimen, Dangtu, Huaining, Yizhou
2011	Jingde, Huangshan	Yixian	Xiuning	Huaiyuan, Mingguang, Lixin, Yingdong	
2012	Jingde	Yixian	Huaiyuan		
2013	Shexian	Jingde, Xiuning, Tianchang, Huaiyuan			
2014	Jingde	Xiuning, Huangshan	Shexian, Yixian, Yongqiao, Tunxi, Daguan		
2015	Jingde	Xiuning, Huaiyuan, Tianchang, Tongcheng, Jixi			
2016	Huaiyuan	Huangshan,Taihe	Xiuning, Yixian, Nanqiao		
2017	Huaiyuan	Jingde, Shexian	Yixian, Sixian, Congyang		
2018	Huaiyuan	Guichi			
2019	Huaiyuan	Jingde			
2020	Huaiyuan	Jingde, Sixian, Yingshang, Yeji, Jinghu, Yingzhou			
2021	Huaiyuan	Yian, Fengtai	Sixian, Lixin, Wuhe, Xiejiaji, Tianjiaan, Shucheng, Nanling		
2022	Qingyang	Huaiyuan, Yixian, Guangde, Yingquan			
2023	Guichi	Qingyang, Huaiyuan, Sixian, Yingshang, Xiuning, Tongcheng, Dongzhi, Lingbi, Linquan			