

RESEARCH

Open Access



# High-risk spatiotemporal patterns of leprosy in the southeastern region of Yunnan province from 2010 to 2022: an analysis at the township level

Longchong Qiao<sup>1,2,3,4†</sup>, Chunyu Zhang<sup>5†</sup>, Mengyan Zhang<sup>1,2,3,4</sup>, Haiqin Jiang<sup>1,2,3,4</sup>, Ying Shi<sup>2,3</sup>, Wenyue Zhang<sup>2,3</sup>, Youming Mei<sup>2,3</sup>, You Li<sup>1\*</sup> and Hongsheng Wang<sup>1,2,3,4\*</sup>

## Abstract

**Background** Despite being preventable and curable, leprosy remains endemic in some undeveloped regions, including China. Wenshan Zhuang and Miao Autonomous Prefecture (Wenshan prefecture) currently bears the highest leprosy burden in China. In this ecological study, we aimed to analyze the epidemiological characteristics as well as identify and visualize the high-risk townships of Wenshan prefecture using the most updated leprosy data from 2010 to 2022.

**Methods** Geographical information system combined with spatial scan statistics was used for newly detected leprosy cases abstracted from the Leprosy Management Information System in China. Global Moran's *I* index was used to uncover the spatial pattern of leprosy at the township level. Spatial scan statistics, encompassing purely temporal, purely spatial, spatial variation in temporal trends, and space-time analysis, were implemented for detecting the risk clusters.

**Results** Between 2010 and 2022, Wenshan prefecture detected 532 new leprosy cases, comprising 352 (66.17%) males and 180 (33.83%) females. The aggregated time primarily occurred between October 2010 and March 2014. The distribution pattern of newly detected leprosy cases was spatially clustered. We identified four high-risk spatial clusters encompassing 54.51% of the new cases. Furthermore, spatial variation in temporal trends highlighted one cluster as a potential high-risk area. Finally, two space-time clusters were detected, and the most likely cluster was predominantly located in the central and northwest regions of Wenshan prefecture, spanning from January 2010 to September 2013.

**Conclusions** In this ecology study, we characterized the epidemiological features and temporal and spatial patterns of leprosy in Wenshan prefecture using the most recent leprosy data between 2010 and 2022. Our findings offer

<sup>†</sup>Longchong Qiao and Chunyu Zhang contributed equally to this work and should be considered as co-first authors.

\*Correspondence:

You Li  
you.li@njmu.edu.cn  
Hongsheng Wang  
whs33@vip.sina.com

Full list of author information is available at the end of the article



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

scientific insights into the epidemiological profiles and spatiotemporal dynamics of leprosy in Wenshan prefecture. Clinicians and policymakers should pay particular attention to the identified clusters for the prevention and control of leprosy.

**Keywords** Leprosy, Geographical information systems, Spatiotemporal analysis, Wenshan prefecture

## Background

Leprosy, also named Hansen's disease [1], is the second most serious human mycobacterial disease following tuberculosis [2]. Caused by *Mycobacterium leprae* (*M. leprae*), it is a curable chronic communicable disease that primarily damages patients' skin, peripheral nerves, and eyes [3]. Without prompt treatment, patients affected may become disabled and disfigured, which imposes a heavy burden on their lives and families, and triggers social discrimination [4].

Due to inadequate effective treatment strategies, leprosy had posed a persistent global challenge over the past year [5]. The introduction of multidrug therapy (MDT), which consists of rifampicin, clofazimine, and dapsone, has enabled a substantial reduction in the prevalence rate of leprosy [6, 7]. Most countries have successively met the elimination standard of 1 case per 10,000 population [8] proposed by the World Health Organization (WHO), nonetheless, there are approximately 200,000 new cases annually worldwide. The majority of these new cases are reported from some less developed regions such as India, Brazil, and Indonesia [9].

Leprosy was once also widely prevalent in China, affecting millions of people. However, the widespread use of MDT and national control efforts have considerably controlled the prevalence of leprosy. China then achieved the elimination standard at the national level and county level in 1981 and 2015, respectively. Despite these achievements, the transmission of leprosy has not been interrupted in China [10, 11], some remote southeastern areas of Yunnan Province, such as Wenshan Zhuang and Miao Autonomous Prefecture (Wenshan prefecture), still bear a heavy burden of leprosy [12, 13]. Between 2010 and 2022, nearly one-quarter of new leprosy cases reported in Yunnan Province were from Wenshan prefecture. This necessitates identifying the high-risk areas of leprosy in Wenshan prefecture to attain the goal of creating a leprosy-free world, as proposed by the WHO [14].

Recently, both spatial and temporal techniques have been widely utilized to detect high-risk areas of infectious diseases [15–18], including leprosy [19–21]. Nevertheless, existing leprosy-related studies were confined to a prefecture-level [19, 22] or county-level [13, 21] analysis, yielding only a broad overview of leprosy distribution. As the transmission of leprosy continues to decline, a more granular investigation could yield nuanced insights into the localized patterns of this disease, potentially leading to more precise resource allocation and enhanced

accuracy in disease mapping. Consequently, there is an imperative need for detailed cluster analysis of leprosy at a finer geographical scale, such as townships. To address this research gap, we embarked on a comprehensive spatiotemporal analysis of leprosy at the township level utilizing the latest leprosy data of Wenshan prefecture from 2010 to 2022. Our findings may facilitate an in-depth understanding of the geographic focal points requiring intervention in Wenshan prefecture. Additionally, these evidence-based insights will be invaluable for policymakers, enabling them to devise targeted strategies and measures for the prevention and control of leprosy [23].

## Methods

### Study design

This is a retrospective ecological study conducted in Wenshan Prefecture. Using the secondary data from January 1, 2010, to December 31, 2022, this study aims to identify high-risk townships of leprosy, improve the accuracy of disease mapping, and enhance the precision of resource allocation. Through spatial and temporal analyses, the study seeks to provide evidence-based insights to inform public health strategies and targeted interventions in the region.

### Study setting

Located in the southeast region of Yunnan Province, Wenshan prefecture (22°40'–24°48'N, 103°35'–106°12'E) is bordered by Guangxi Zhuang Autonomous Prefecture and Vietnam strategically. By the end of 2022, Wenshan prefecture covers an area of 31,456 km<sup>2</sup>, encompassing 7 counties, 1 city, 101 townships, and 3 streets. The population of Wenshan prefecture consists of 3.454 million permanent residents; more than half of the residents are ethnic minorities. Its gross domestic product is 140.539 billion yuan, ranking eighth in Yunnan province; the new case detection rate (NCDR) of leprosy ranks first in Yunnan province. All the information above was obtained from Wenshan Statistical Yearbook 2022.

### Inclusion and exclusion criteria

From January 1, 2010, to December 31, 2022, all newly detected leprosy cases in Wenshan prefecture, where patients had lived for more than six months (considered permanent residence) at the time of diagnosis, were included in our study ( $N=532$ ). Cases of relapse or those without permanent residence in Wenshan prefecture were explicitly excluded ( $N=35$ ).

### Data sources

In this ecological study, three files were aggregated at the township level to conduct spatiotemporal analysis, as described below.

### Case file

Data on new leprosy cases detected from January 2010 to December 2022 in Wenshan prefecture were acquired from the Leprosy Management Information System in China (LEPMIS), which stores extensive records, including clinical (disability status at diagnosis, WHO-type, etc.) and demographical information (sex, age at diagnosis, ethnicity, etc.), of patients diagnosed with leprosy. Based on LEPMIS, the case file primarily consisted of the number of new leprosy cases per township, by month and year over the 13 years. In addition, the demographic and clinical information of each patient, such as sex, age at diagnosis, WHO-type, and disability status at diagnosis, were included for epidemiological analysis, and the names of each patient were removed for confidential reasons. All new cases over the 13 years were clinically confirmed by the medical staff at the Wenshan Institute of Dermatology. The diagnosis criteria for new leprosy cases, which remained almost unchanged during the study, were primarily based on the clinical symptoms, bacterial culture results, and histopathological examination results [24].

### Population file

The permanent population of each township from 2010 to 2022 was obtained from the Wenshan Institute of Dermatology.

### Coordinate file

The Wenshan Institute of Dermatology provided the vector maps of 104 townships in Wenshan prefecture in the form of shapefiles. Additionally, the coordinates of each township in Wenshan prefecture were obtained from Google Maps (Google Inc., Mountain View, CA, US).

All these 3 files can be matched to the township level polygon maps according to the international administrative code of the residential address.

### Statistics analysis

#### Descriptive analysis

We firstly described the epidemiological profiles, including age at diagnosis, sex, annual NCDR, and the annual proportion of multibacillary (MB) cases and grade 2 disability cases (G2D), of all the newly detected leprosy cases.

The statistical indicators mentioned above can be calculated as follows:

$$\text{NCDR} = \frac{\text{Newly detected leprosy cases in a certain area and period}}{\text{Population in the selected area and period}}$$

$$\text{MB proportion} = \frac{\text{Newly detected MB cases in a certain area and period}}{\text{Newly detected leprosy cases in a certain area and period}}$$

$$\text{G2D proportion} = \frac{\text{Newly detected G2D cases in a certain area and period}}{\text{Newly detected leprosy cases in a certain area and period}}$$

### Spatial pattern analysis

Using data aggregated at the township level, we conducted a global spatial autocorrelation analysis of the NCDR of leprosy to investigate the spatial pattern of new leprosy cases among the 104 townships in Wenshan prefecture. Global Moran's  $I$  index, with a value ranging between  $-1$  and  $1$ , was utilized to qualify global spatial autocorrelation [25]. Moran's  $I > 0$  indicated a spatially clustered distribution of leprosy, whereas Moran's  $I < 0$  suggested a dispersion distribution. Moran's  $I = 0$  indicated random distribution [17]. The spatial weight matrix was constructed using the Queen method [21] before calculating the global Moran's  $I$  index. The Z-score test was adopted to assess the significance of Moran's  $I$ . When the Moran's  $I > 0$  and  $Z\text{-score} \geq 1.96$ , the distribution of leprosy can be deemed as spatially clustered.

### Spatiotemporal clustering analysis

Based on the discrete Poisson probability model, we conducted a retrospective spatiotemporal scan statistical analysis, which included purely temporal, purely spatial, spatial variation in temporal trends (SVTT), and space-time analysis, to detect the high-risk clusters of leprosy. These analyses can be conducted by gradually scanning a window across time or space, recording the number of observed and expected observations inside the window at each location, and reporting the clusters whose observed cases exceed the expected cases [26, 27]. The purely temporal and purely spatial statistics scan the window only in one dimension (time or space), whereas the space-time statistic scans the window both in temporal and space dimensions. To identify the clusters exhibiting distinct time trends, SVTT, an emerging technique, was also utilized [28, 29]. The temporal trend for each location and size was calculated. Internal time trends (ITT) refer to time trends within the scanning windows, whereas external time trends (ETT) refer to those outside the scanning windows. Two statistical indicators, namely relative risk (RR) and log-likelihood ratio (LLR), were reported in the spatiotemporal scan statistical analysis. RR was calculated for quantifying the risk of the identified cluster poses, whereas LLR was calculated for ranking the clusters [30]. The statistically significant cluster with the highest LLR was deemed as the most likely cluster, whereas those with areas not overlapping with the most likely cluster were deemed as the secondary cluster

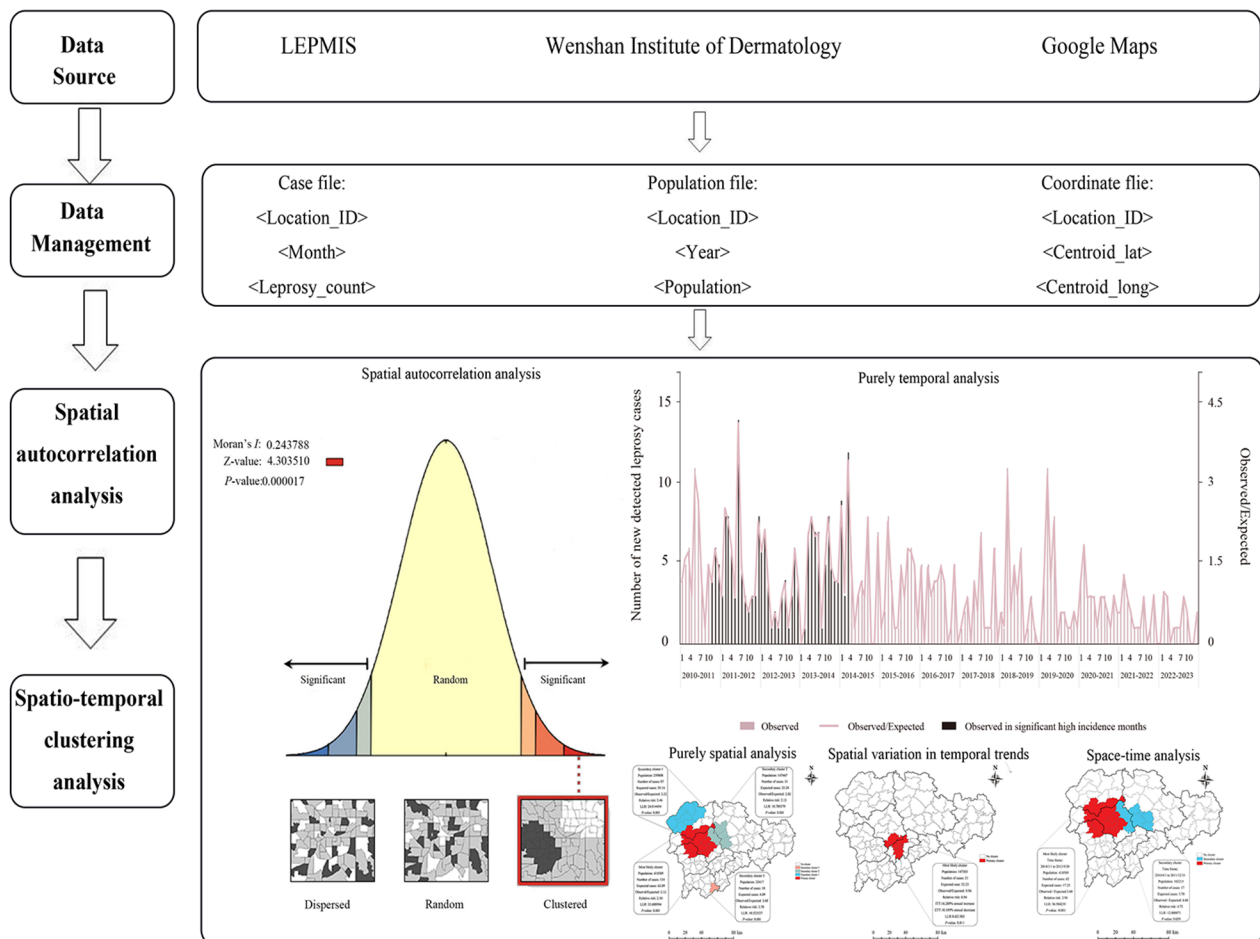
[31]. Previous studies have concluded that the size of the spatial and temporal scanning window can easily influence the results of spatiotemporal scan statistics [32–34]. Therefore, it is of great significance to choose an appropriate maximum cluster size. Consulting similar research methods [32, 33], we set 30% and 14% as the maximum temporal and spatial cluster sizes, respectively.

Figure 1 illustrates the broad study framework, including data sources, data management, global spatial autocorrelation analysis, and spatiotemporal analysis. Microsoft Excel 2019 (Microsoft Corp., Redmond, WA, USA) was utilized to clean and manage the original data. Data were analyzed using RStudio (R Foundation for Statistical Computing, Vienna, Austria), ArcGIS 10.8 (ESRI, Redlands, CA, USA), and SaTScan 10.1.2 (Boston, MA, USA). The results of the spatial analysis were visualized using ArcGIS. The *P*-values of global spatial autocorrelation and spatiotemporal clustering analysis were evaluated using 999 Monte Carlo simulations at a significance level of 0.05.

## Results

### Descriptive analysis

From 2010 to 2022, 532 new leprosy cases were detected in Wenshan prefecture (Table 1). The NCDR ranged from 1.79/100,000 in 2010 to 0.46/100,000 in 2022 (Table 1; Fig. 2a), presenting a significant decreasing trend ( $\chi^2=56.159$ ,  $P<0.001$ ). Concerning the clinical characteristics, approximately 15% of the newly detected cases (14.29%,  $n=76$ ) were classified as G2D cases. The annual proportion of G2D ranged from 19.05% in 2010 to 0 in 2022 (Table 1; Fig. 2b), thereby demonstrating a significant decreasing trend ( $\chi^2=10.796$ ,  $P=0.001$ ). MB cases remained the primary type of the newly detected cases within the study period, despite marginal fluctuation ( $\chi^2=0.237$ ,  $P=0.626$ ) (Table 1; Fig. 2c). Of the 532 cases, 352 were males and 180 were females, with a ratio of nearly 2:1 (Table 1; Fig. 2d). Most of patients were aged between 15 and 59 years old (85.15%,  $n=453$ ). Children under 15 years old accounted for 6.20% of the total cases (Table 1; Fig. 2d).



**Fig. 1** Framework of this study

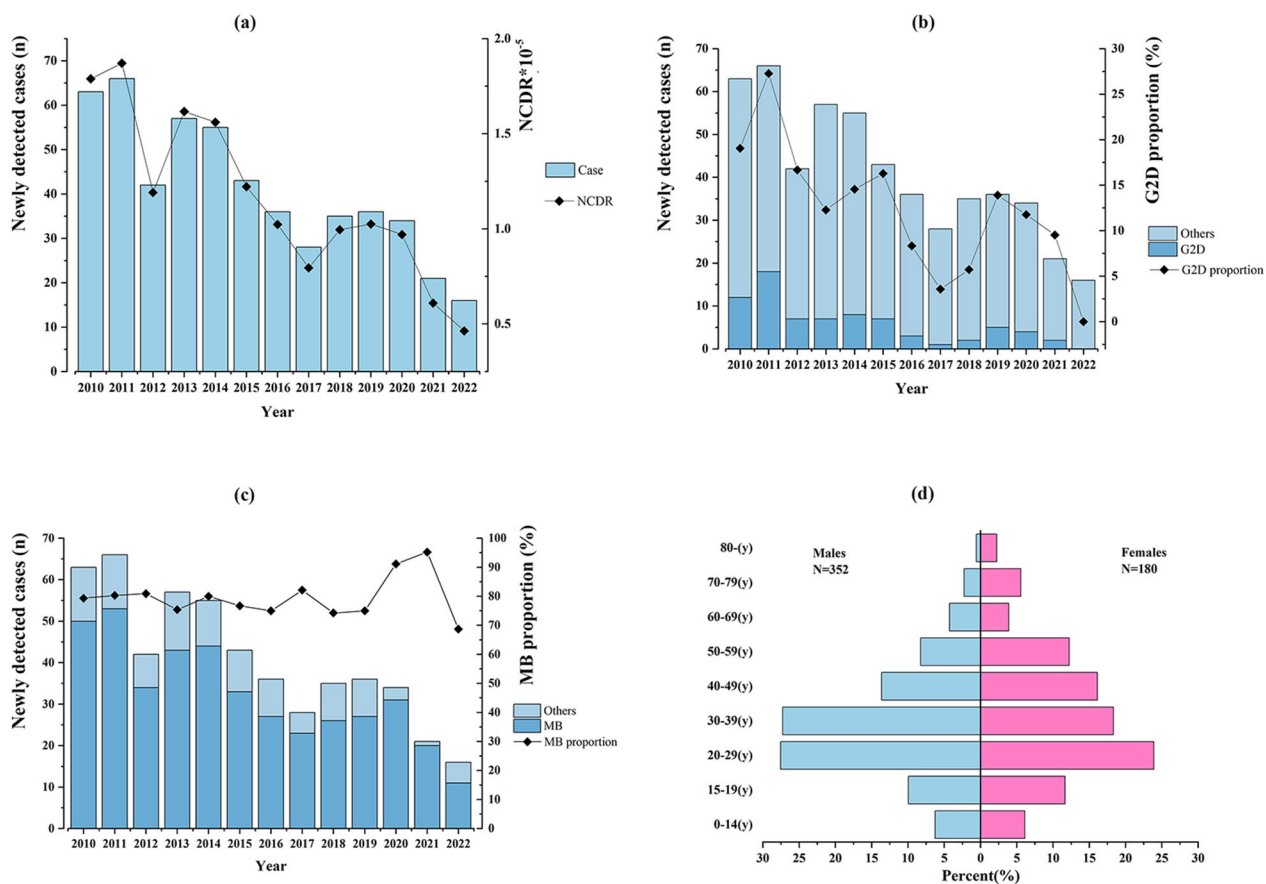
**Table 1** Epidemiological and demographical characteristics of newly detected leprosy cases in Wenshan prefecture, 2010–2022

Year	N (NCDR)	Disability (%)		WHO-type (%)		Age group (%)			Sex (%)	
		G2D	Others	MB	Others	0–14	15–59	60–	Male	Female
2010	63(1.79)	12(19.05)	51(80.95)	50(79.37)	13(20.63)	3(4.76)	55(87.30)	5(7.94)	42(66.67)	21(33.33)
2011	66(1.87)	18(27.27)	48(72.73)	53(80.30)	13(19.7)	3(4.55)	54(81.82)	9(13.63)	46(69.70)	20(30.30)
2012	42(1.19)	7(16.67)	35(83.33)	34(80.96)	8(19.04)	5(11.90)	36(85.71)	1(2.39)	30(71.43)	12(28.57)
2013	57(1.62)	7(12.28)	50(87.72)	43(75.44)	14(24.56)	5(8.77)	48(84.21)	4(7.02)	34(59.65)	23(40.35)
2014	55(1.56)	8(14.55)	47(85.45)	44(80.00)	11(20.00)	2(3.64)	51(92.73)	2(3.63)	36(65.45)	19(34.55)
2015	43(1.22)	7(16.28)	36(83.72)	33(76.74)	10(23.26)	6(13.95)	30(69.77)	7(16.28)	27(62.79)	16(37.21)
2016	36(1.02)	3(8.33)	33(91.67)	27(75.00)	9(25.00)	3(8.33)	28(77.78)	5(13.89)	25(69.44)	11(30.56)
2017	28(0.80)	1(3.57)	27(96.43)	23(82.14)	5(17.86)	1(3.57)	24(85.71)	3(10.72)	18(64.29)	10(35.71)
2018	35(0.99)	2(5.71)	33(94.29)	26(74.29)	9(25.71)	4(11.43)	30(85.71)	1(2.86)	21(60.00)	14(40.00)
2019	36(1.03)	5(13.89)	31(86.11)	27(75.00)	9(25.00)	0(0)	32(88.89)	4(11.11)	25(69.44)	11(30.56)
2020	34(0.97)	4(11.76)	30(88.24)	31(91.18)	3(8.82)	1(2.94)	29(85.29)	4(11.77)	25(73.53)	9(26.47)
2021	21(0.61)	2(9.52)	19(90.48)	20(95.24)	1(4.76)	0(0)	20(95.24)	1(4.76)	11(52.38)	10(47.62)
2022	16(0.46)	0(0)	16(100)	11(68.75)	5(31.25)	0(0)	16(100)	0(0)	12(75.00)	4(25.00)
Total	532(1.17*)	76(14.29)	456(85.71)	422(79.32)	110(20.68)	33(6.20)	453(85.15)	46(8.65)	352(66.17)	180(33.83)

N. Number of newly detected leprosy cases

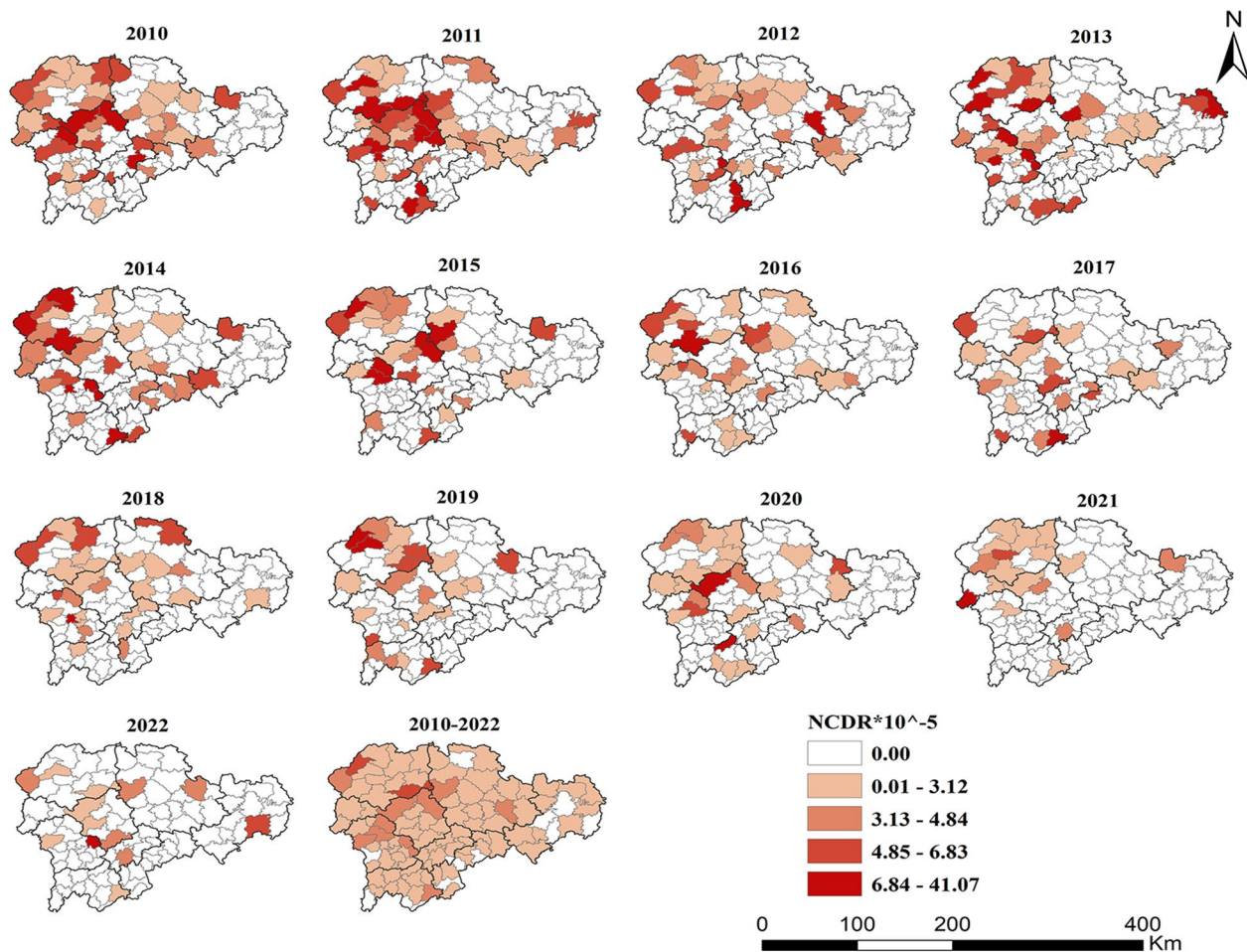
NCDR (1/100000 population)

\*: Average



**Fig. 2** Clinical and demographical profiles of leprosy cases in Wenshan prefecture from 2010 to 2022. **(a)** Temporal trend of newly detected leprosy cases. **(b)** Temporal trend and proportion of disability **(c)** Temporal trend and proportion of clinical type **(d)** Demographical characteristics of newly detected leprosy cases





**Fig. 3** The NCDRs of leprosy at the township level in Wenshan prefecture, from 2010 to 2022

**Table 2** Global spatial autocorrelation analysis of leprosy cases in Wenshan prefecture, 2010–2022

Year	Global moran'I	Z	P	Pattern
2010	0.106	2.0143	0.029	Clustered
2011	0.130	2.5275	0.01	Clustered
2012	-0.028	-0.3944	0.3964	Random
2013	-0.01	0.073	0.447	Random
2014	0.101	2.1693	0.036	Clustered
2015	0.148	3.1529	0.009	Clustered
2016	0.105	1.8901	0.0397	Clustered
2017	-0.0671	-0.9639	0.175	Random
2018	0.0057	0.2519	0.37503	Random
2019	0.197	3.4299	0.005	Clustered
2020	0.0803	1.5225	0.07504	Random
2021	0.102	1.995	0.039	Clustered
2022	-0.0194	-0.1417	0.493	Random
2010–2022	0.2736	4.6664	0.001	Clustered

**Spatial pattern analysis**

Figure 3 presented the spatial variation of NCDR of leprosy from 2010 to 2022 at the township level in Wenshan prefecture. The highest NCDRs of leprosy primarily

occurred in the townships of Yanshan and Qiubei counties, respectively, in the central and northwest regions of Wenshan prefecture. The NCDRs of leprosy were relatively low in south and east regions, such as Malipo, Xichou, and Funing counties. No cases were found in 13 townships between 2010 and 2022, which mainly concentrated on Funing and Malipo counties.

Results of global autocorrelation analysis of the average annual NCDR of leprosy from 2010 to 2022 in Wenshan prefecture demonstrated a positive spatial autocorrelation (Moran's  $I=0.2736$ ,  $P=0.001$ ). Similar results were also reported when conducting global autocorrelation analysis year by year, except for several years (Table 2). The results indicated the distribution of newly detected leprosy cases in Wenshan prefecture was spatially clustered at the township level in most years.

**Purely temporal cluster**

Purely temporal scanning analysis for high-rate leprosy clusters demonstrated that the aggregated time predominantly occurred between October 2010 and March 2014

(LLR=20.28,  $P=0.001$ ). During the aggregated time, 204 (38.35%) new leprosy cases were detected. Additionally, the risk of leprosy-related incidents during the aggregated time was 1.79 (RR=1.79) times higher than that in other periods from 2010 to 2022 (Fig. 4).

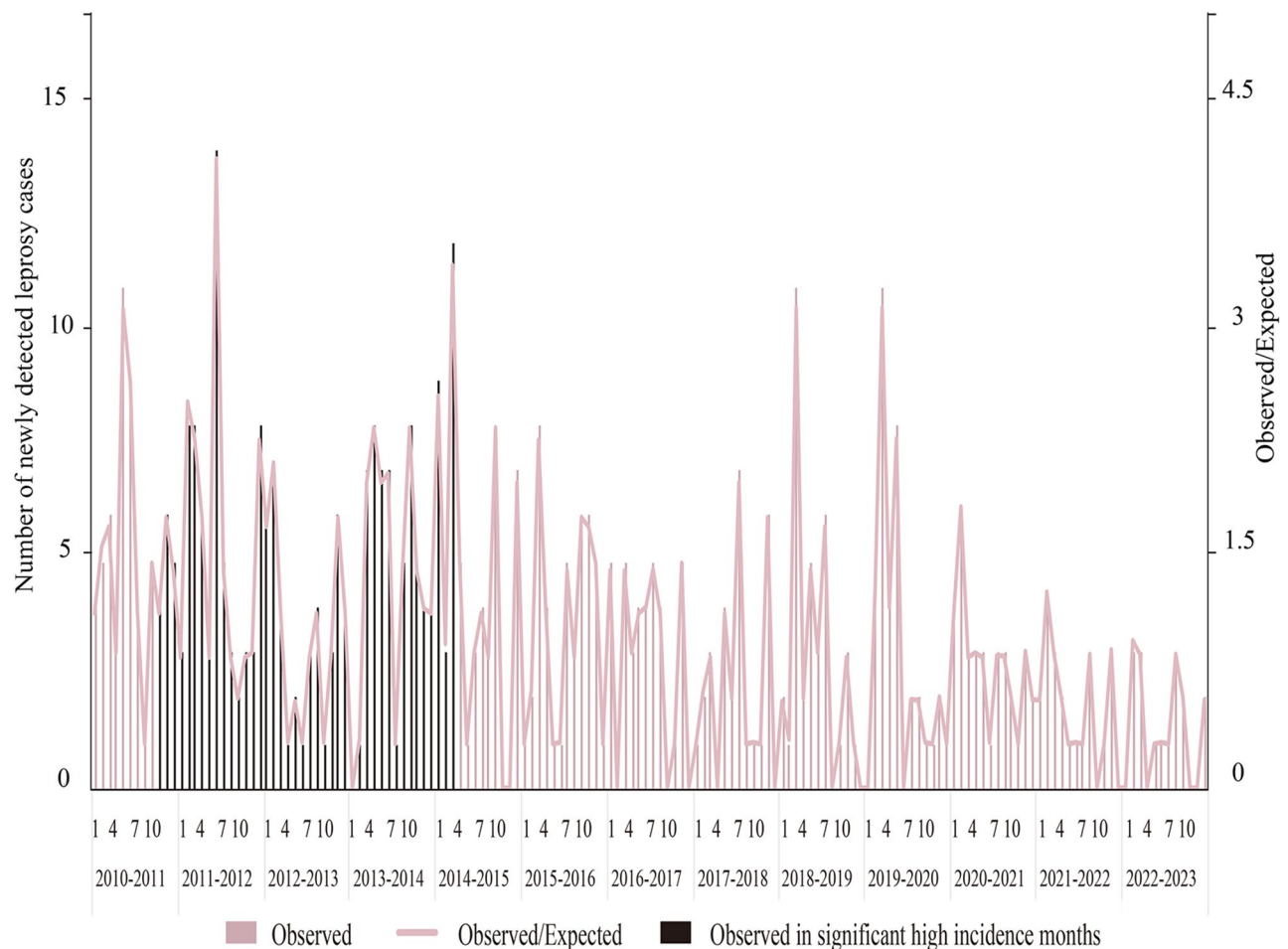
**Purely spatial clusters**

Purely spatial scanning analysis for high-rate leprosy clusters identified four high-risk clusters ( $P=0.001$ ) (Fig. 5; Table 3). These significant high-risk clusters consisted of 878,281 people, only accounting for 24.88% of the total population while over half of the newly detected leprosy cases (54.51%,  $n=290$ ) were included. The RR for these detected clusters ranged from 2.13 to 3.78 and consisted of 23 townships from 5 counties or cities. The most likely cluster (LLR=35.69,  $P=0.001$ ) was scattered from the northwest to the central areas of Wenshan prefecture, encompassing 11 townships scattered on the border of Wenshan, Yanshan, and Qiubei counties. The remaining 3 secondary high-risk clusters encompassed 12 townships from Qiubei, Yanshan, Guangnan, and Maguan

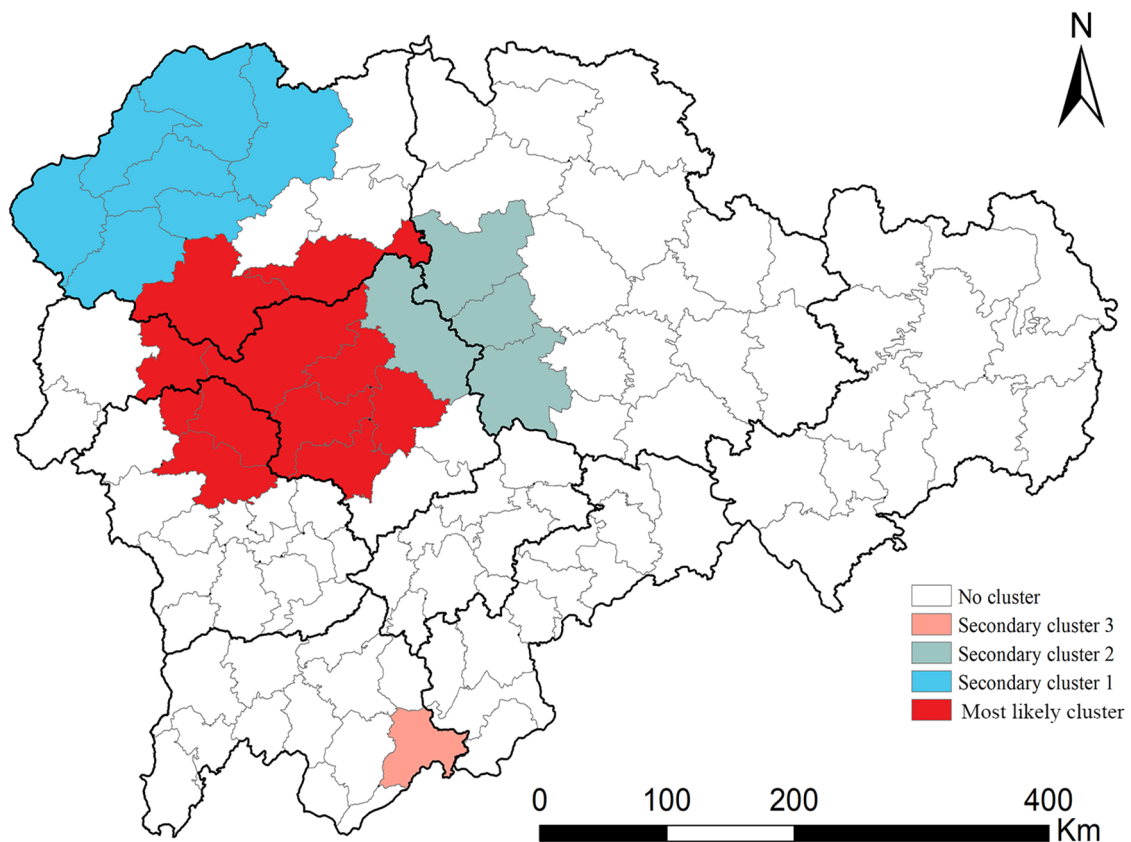
counties. They were primarily located in the northwest, central, and south regions of Wenshan prefecture. These four clusters encompassed nearly all townships of Qiubei and Yanshan counties while there were no townships from Funing, Malipo, and Xichou counties.

**Spatial variation in temporal trends**

The result of SVTT from 2010 to 2022 demonstrated a 9.282% average annual decrease in the NCDR of leprosy. Only one most likely cluster was identified from 2010 to 2022 (LLR=8.62,  $P=0.011$ ) (Fig. 6; Table 3). This cluster consisted of 147,503 (4.18%) people; only 21 (3.95%) cases were reported over the study period. The most likely cluster, with an RR of 0.94, comprised four townships in the central-southern regions of Wenshan prefecture, from Xichou and Yanshan counties. These townships in the cluster demonstrated an increasing annual average trend of 16.289% while those outside the cluster showed a decreasing annual average trend of 10.189%.



**Fig. 4** Purely temporal analysis of leprosy in Wenshan prefecture from 2010 to 2022



**Fig. 5** Purely spatial clusters of leprosy in Wenshan prefecture from 2010 to 2022

**Table 3** High-risk leprosy clusters detected by spatiotemporal analysis

Cluster	Time frame	Locations (N)	Observed	Expected	RR	LLR	P
<b>Purely spatial analysis</b>							
Most likely cluster	2010/1/1-2022/12/31	11	134	63.09	2.50	35.69	0.001
Secondary cluster 1	2010/1/1-2022/12/31	7	87	39.16	2.46	24.01	0.001
Secondary cluster 2	2010/1/1-2022/12/31	4	51	25.24	2.13	10.78	0.001
Secondary cluster 3	2010/1/1-2022/12/31	1	18	4.89	3.78	10.52	0.001
<b>Spatial variation in temporal trends</b>							
Most likely cluster	2010/1/1-2022/12/31	4	21	22.23	0.94	8.62	0.02
<b>Space-time clusters</b>							
Most likely cluster	2010/1/1-2013/9/30	11	62	17.25	3.94	36.58	0.001
Secondary cluster	2010/4/1-2011/12/31	6	17	3.70	4.72	12.80	0.029

**Space-time clusters**

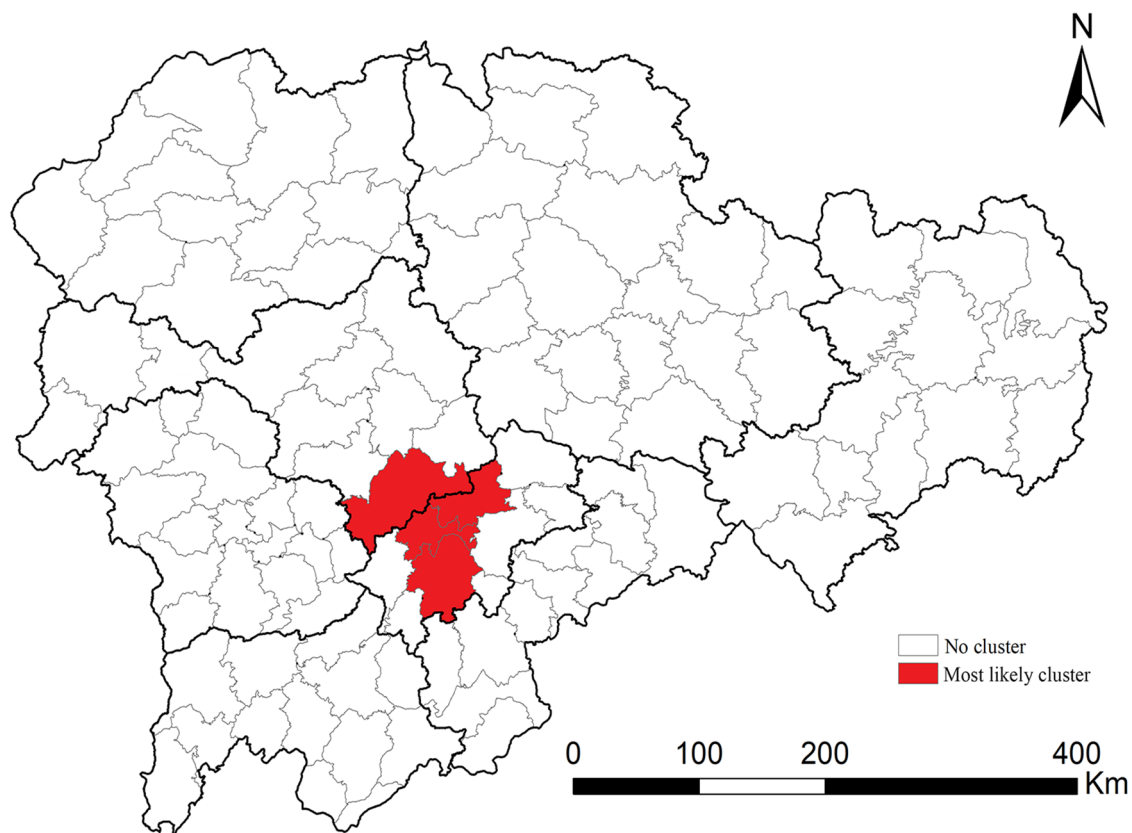
Two statistically significant space-time clusters were identified upon considering both time and space dimensions (Fig. 7; Table 3). The RR ranged from 3.94 to 4.72 and consisted of 17 townships across 4 cities or counties. These two clusters encompassed 601,804 (17.05%) people and 79 (14.85%) new leprosy cases within the cluster time. The most likely space-time cluster (LLR=36.58, P=0.001) consisted of 11 townships scattered across the borders of Wenshan city, Yanshan, and Qiubei counties. It was primarily located in the central and north-western regions of Wenshan prefecture, spanning from January

2010 to September 2013. The secondary space-time cluster (LLR=12.80, P=0.029) encompassed six townships scattered across the counties of Yanshan and Guangnan in the central region of Wenshan prefecture, spanning from April 2010 to December 2011. No statistically significant space-time clusters were observed after 2013.

**Discussion**

Using the most updated leprosy data from 2010 to 2022, we illustrated the clinical and demographic profile as well as the spatiotemporal dynamics of newly detected leprosy cases in Wenshan prefecture, Yunnan Province,





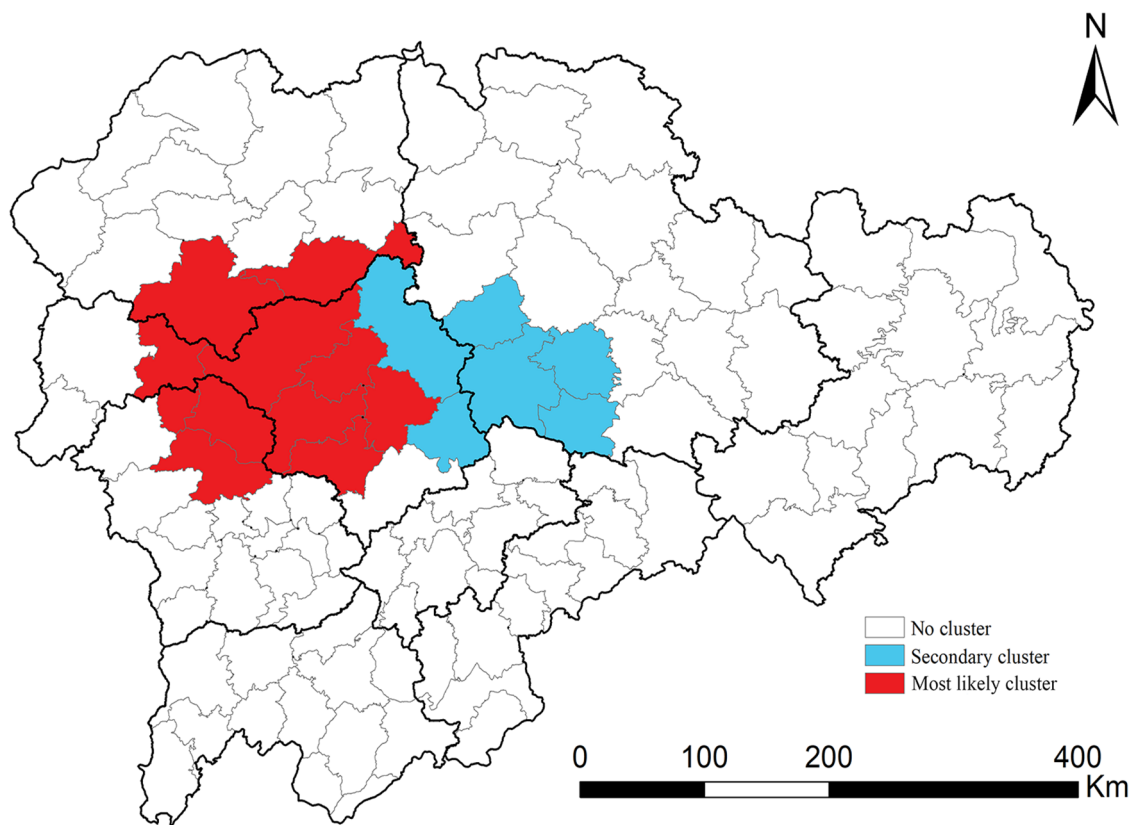
**Fig. 6** Spatial variation in temporal trends of leprosy cases in Wenshan prefecture from 2010 to 2022

China. The findings of our study not only contributed to a better understanding of the current situation of leprosy, but also highlighted priorities for follow-up work for Wenshan prefecture.

Similar to other areas [35–37], both the annual new cases and NCDR of leprosy in Wenshan prefecture demonstrated a significant decreasing trend from 2010 to 2022. Meanwhile, the number of townships affected with leprosy also decreased yearly. Factors, such as the widespread use of MDT, the establishment of leprosy-related policies, increased access to clean water and sanitation, and socioeconomic development, play a non-negligible role in this achievement [1, 12]. Clinically, approximately 15% of the newly detected cases were G2D cases, despite a declining trend in the annual proportion. This high proportion can be attributed to the late diagnosis of patients [38]. Furthermore, MB cases remain the primary type of leprosy. Previous study has demonstrated that the predominance of MB cases also indicates late diagnosis [39]. Therefore, to achieve the goal of eradicating leprosy, it is of great necessity to find patients with leprosy at an early stage. The monitoring system for early detection of leprosy's symptoms, which has proven effective in Zhejiang province [40], should also be implemented in Wenshan prefecture to help find patients with leprosy in a

more timely way. Meanwhile, the household contacts of patients with leprosy are more likely to develop leprosy than others [41], so contacts screening periodically may also facilitate early detection. Demographically, our present study found that men accounted for nearly 2/3 of all the newly detected leprosy cases, which was almost similar to those in South-East Ethiopia (64.5%) [42] and Nigeria (67.74%) [43]. This may be partly explained that men in Wenshan prefecture often work outside and thus are more likely to be exposed to *Mycobacterium lepre* infection than women. Furthermore, children under 15 years old accounted for 6.20% of the total cases, which is nearly two times higher than that in Togo [44]. Therefore, active leprosy transmission still persists in communities in Wenshan prefecture, although there were no childhood cases reported after 2020.

Other leprosy-related studies show that the distribution of leprosy presents a spatial heterogeneity at the county level [13, 21, 40]. Our study further demonstrated that the distribution of the newly detected leprosy cases was spatially clustered at the township level in Wenshan prefecture in most years. This clustered pattern may be attributed to the uneven distribution of leprosy-associated factors, such as medical resources, socioeconomic status, and social vulnerability [22]. Knowing the



**Fig. 7** Space-time clusters of leprosy cases in Wenshan prefecture from 2010 to 2022

spatial heterogeneity, we then conducted a spatiotemporal analysis to detect the high-risk areas, in which priority should be given while formulating policies and allocating resources.

Purely temporal analysis identified the aggregated time within the 13 years primarily occurred between October 2010 and March 2014, which indicated that the NCDR of leprosy after 2015 was significantly lower than that before 2015. This phenomenon was supposedly related to a chemoprophylaxis trial commencing in 2015 in southwest China [45]. In this trial, single-dose rifapentine or rifampicin was applied to the vast majority of household contacts of patients with leprosy in Wenshan prefecture. The high-risk population of leprosy was protected using effective interventions so the NCDR after 2015 was significantly lower than that before 2015.

Purely spatial analysis found four statistically significant high-risk clusters of leprosy from five counties or city in the central, northwest, and south regions of Wenshan prefecture. Previous study based on the county level reported that all the eight counties or cities of Wenshan prefecture bear a higher leprosy burden than that in other regions in Yunnan Province [13]. High leprosy frequencies have also been found in all 8 counties or cities of Wenshan prefecture [21]. Based on the township level,

our study further highlighted the high-risk townships of leprosy in Wenshan prefecture. These townships were primarily concentrated in Qiubei and Yanshan counties while townships in other counties reported few leprosy cases.

The results of SVTT demonstrated annual increase and decrease trends in the ITT and ETT, respectively. The detected cluster only consisted of four townships, suggesting an overall decrease in the leprosy NCDR in Wenshan prefecture from 2010 to 2022. Situated in the central-southern part of Wenshan prefecture, the cluster was not reported by spatial analysis alone. Considering the annual increase in the NCDR of leprosy in these four townships, they should be regarded as potential high-risk areas deserving more attention.

The space-time analysis identified two statistically significant clusters. Interestingly, the location of the most likely cluster was similar to that detected by the purely spatial analysis, which re-emphasized these townships sustaining the heaviest leprosy burden than other townships of Wenshan prefecture. More preventive measures, such as adequate financial, leprosy-related public health education and promotion campaigns, symptom surveillance periodically, contacts screening, and

chemoprophylaxis of contacts, should be conducted in these high-risk townships [46, 47].

Our study provided major implications for not only Wenshan prefecture but also other areas experiencing a heavy burden of leprosy. We analyzed township-level NCDR of leprosy using a spatiotemporal approach; this technique is applicable in various settings. To the best of our knowledge, this is the first study to identify high-risk areas for leprosy at the township-level, limited health care resources can be allocated more accurately and efficiently, potentially offering precise theoretical support for its eradication in Wenshan prefecture.

This study also has some limitations. First, the date of leprosy diagnosis rather than the date of symptom onset was used because of the long incubation period of leprosy [48]. Second, the underreporting and migration, especially in the context of the COVID-19 pandemic, may have resulted in an underestimation of the NCDR of leprosy [49]. Third, spatiotemporal scan statistics analysis has some limitations related to sensitivity despite we have made many efforts. Finally, the potential risk factors (some meteorological factors, living environment, and poverty, etc.) associated with leprosy were not assessed. Further studies can be conducted to reveal the relationship between these factors and leprosy.

## Conclusion

Leprosy is still an unneglected public health issue in Wenshan prefecture, especially for the areas located in the the central and north-western regions of Wenshan prefecture. In this ecological study, we explored the epidemiological characteristics and spatiotemporal patterns of leprosy in Wenshan prefecture over a 13-year period. Despite a declining trend in the NCDR of leprosy, the spatial distribution of newly detected leprosy cases exhibited significant spatial heterogeneity at the township level in most years. Spatiotemporal analysis suggested that the high-risk zones were primarily scattered in the counties of Yanshan, Qiubei, and Wenshan, particularly in the border townships of these three counties. Our findings will supposedly inform policymakers while designing intervention measures and allocating health resources more reasonably.

## Abbreviations

Wenshan prefecture	Wenshan Zhuang and Miao Autonomous Prefecture
MDT	Multidrug therapy
M. leprae	Mycobacterium leprae
WHO	World Health Organization
NCDR	New case detection rate
LEPMIS	Leprosy Management Information System in China
MB	Multibacillary cases
G2D	Grade 2 disability cases
SVTT	Spatial variation in temporal trends
ITT	Internal time trends; ETT: External time trends; RR: relative risk
LLR	Log-likelihood ratio

## Acknowledgements

We thank all the workers in the Wenshan Institute of Dermatology for providing the data and their excellent work has contributed to the effective control of leprosy in Wenshan prefecture. We thank Bullet Edits Limited for the linguistic editing and proofreading of the manuscript.

## Author contributions

H.W. and Y.L. conceived and designed the study. W.Z., H.J. and Y.S. participated in the acquisition of data. L.Q. and C.Z. analyzed the data. M.Z. and Y. M. gave advice on methodology. C.Z. and L.Q. drafted the manuscript. H.W. and Y.L. revised the manuscript. All authors read and approved the final manuscript.

## Funding

This work was supported by grants from the National Natural Science Foundation of China (Grant 81972950, 82173431, 82103748), Jiangsu Provincial Medical Key Laboratory, Jiangsu Province Capability Improvement Project through Science, Technology and Education (ZDXYS202204), the Nanjing Incubation Program for National Clinical Research Center (2019060001), Chinese Academy of Medical Sciences Innovation Fund for Medical Science (2022-I2M-C&T-B-094).

## Data availability

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

## Declarations

### Ethics approval and consent to participate

Ethical approval for the data has been obtained from the Ethics Committee in the Institute of Dermatology, Chinese Academy of Medical Sciences & Peking Union Medical College (2022-KY-041). Informed written consent was obtained from each participant, who were ensured that data would remain confidential and used for research purposes only. All methods were carried out in accordance with the Chinese Statistical Law to ensure that participants' personal information was kept confidential. All experimental protocols were approved by the institutional review board of Institute of Dermatology, Chinese Academy of Medical Sciences & Peking Union Medical College, Nanjing, China.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

### Author details

<sup>1</sup>Department of Epidemiology, Center for Global Health, School of Public Health, Nanjing Medical University, 101 Longmian Avenue, Nanjing, Jiangsu 211166, China

<sup>2</sup>Institute of Dermatology, Chinese Academy of Medical Sciences & Peking Union Medical College, Nanjing, Jiangsu, China

<sup>3</sup>National Centre for Leprosy Control, China CDC, Nanjing, Jiangsu, China

<sup>4</sup>Jiangsu Key Laboratory of Molecular Biology for Skin Diseases and STIs, Nanjing, Jiangsu, China

<sup>5</sup>Department of Leprosy Control, Wenshan Institute of Dermatology, Wenshan, Yunnan, China

Received: 25 June 2024 / Accepted: 24 September 2024

Published online: 04 October 2024

## References

1. Deps P, Cruz A. Why we should stop using the word leprosy. *Lancet Infect Dis*. 2020;20:e75–8.
2. Lockwood DN, Saunderson PR. Nerve damage in leprosy: a continuing challenge to scientists, clinicians and service providers. *Int Health*. 2012;4:77–85.
3. Maymone MBC, Laughter M, Venkatesh S, Dacso MM, Rao PN, Stryjewska BM, et al. Leprosy: clinical aspects and diagnostic techniques. *J Am Acad Dermatol*. 2020;83:1–14.

4. Rodrigues LC, Lockwood D. Leprosy now: epidemiology, progress, challenges, and research gaps. *Lancet Infect Dis*. 2011;11:464–70.
5. Aubry A, Sammarco Rosa P, Chauffour A, Fletcher ML, Cambau E, Avanzi C. Drug resistance in leprosy: an update following 70 years of chemotherapy. *Infect Dis Now*. 2022;52:243–51.
6. Yang J, Kong J, Li B, Ji Z, Liu A, Chen J, et al. Seventy years of evidence on the efficacy and safety of drugs for treating leprosy: a network meta-analysis. *J Infect*. 2023;86:338–51.
7. Smith CS, Aerts A, Saunderson P, Kawuma J, Kita E, Virmond M. Multidrug therapy for leprosy: a game changer on the path to elimination. *Lancet Infect Dis*. 2017;17:e293–7.
8. Rinaldi A. The global campaign to eliminate leprosy. *PLoS Med*. 2005;2:e341.
9. World Health Organization. Weekly Epidemiological Record. 15 September 2023;98(37):409–430. <https://iris.who.int/handle/10665/372812>
10. Chokkakula S, Chen Z, Wang L, Jiang H, Chen Y, Shi Y, et al. Molecular surveillance of antimicrobial resistance and transmission pattern of *Mycobacterium leprae* in Chinese Leprosy patients. *Emerg Microbes Infect*. 2019;8:1479–89.
11. Le W, Haiqin J, Danfeng H, Ying S, Wenyue Z, Jun Y, et al. Monitoring and detection of leprosy patients in Southwest China: a retrospective study, 2010–2014. *Sci Rep*. 2018;8:11407.
12. Shui TJ, Long H, Xiong L, Zhang XH, He J, Chen X. Towards the elimination of leprosy in Yunnan, China: a time-series analysis of surveillance data. *PLoS Negl Trop Dis*. 2021;15:e0009201.
13. Chen X, Shui TJ. The state of the leprosy epidemic in Yunnan, China 2011–2020: a spatial and spatiotemporal analysis, highlighting areas for intervention. *PLoS Negl Trop Dis*. 2021;15:e0009783.
14. World Health Organization. Towards zero leprosy (Hansen's disease) strategy 2021–2030. World Health Organization. 2021. <https://iris.who.int/handle/10665/340774>
15. Zhou Y, Luo D, Liu K, Chen B, Chen S, Pan J, et al. Trend of the tuberculous pleurisy notification rate in Eastern China during 2017–2021: Spatiotemporal Analysis. *JMIR Public Health Surveill*. 2023;9:e49859.
16. Landier J, Rebaudet S, Piarroux R, Gaudart J. Spatiotemporal analysis of malaria for new sustainable control strategies. *BMC Med*. 2018;16:226.
17. Castro RR, Santos RSC, Sousa GJB, Pinheiro YT, Martins R, Pereira MLD, et al. Spatial dynamics of the COVID-19 pandemic in Brazil. *Epidemiol Infect*. 2021;149:e60.
18. Tan H, Liang L, Yin X, Li C, Liu F, Wu C. Spatiotemporal analysis of pertussis in Hunan Province, China, 2009–2019. *BMJ Open*. 2022;12:e055581.
19. Ortuno-Gutierrez N, Mzembaba A, Ramboarina S, Andriamira R, Baco A, Braet S, et al. Exploring clustering of leprosy in the Comoros and Madagascar: a geospatial analysis. *Int J Infect Dis*. 2021;108:96–101.
20. Machado LMG, Dos Santos ES, Cavalheiro A, Steinmann P, Ignotti E. Spatio-temporal analysis of leprosy risks in a municipality in the state of Mato Grosso-Brazilian Amazon: results from the leprosy post-exposure prophylaxis program in Brazil. *Infect Dis Poverty*. 2022;11:21.
21. Zhang M, Qiao L, Sun P, Jiang H, Shi Y, Zhang W, et al. Spatiotemporal pattern of leprosy in southwest China from 2010 to 2020: an ecological study. *BMC Public Health*. 2024;24:465.
22. Bulstra CA, Blok DJ, Alam K, Butlin CR, Roy JC, Bowers B, et al. Geospatial epidemiology of leprosy in northwest Bangladesh: a 20-year retrospective observational study. *Infect Dis Poverty*. 2021;10:36.
23. Rosychuk RJ. Identifying geographic areas with high disease rates: when do confidence intervals for rates and a disease cluster detection method agree? *Int J Health Geogr*. 2006;5:46.
24. Alemu Belachew W, Naafs B. Position statement: LEPROSY: diagnosis, treatment and follow-up. *J Eur Acad Dermatol Venereol*. 2019;33:1205–13.
25. Zhou C, Li T, Du J, Yin D, Li X, Li S. Toward Tuberculosis elimination by understanding epidemiologic characteristics and risk factors in Hainan Province, China. *Infect Dis Poverty*. 2024;13:20.
26. Toan doTT, Hu W, Quang Thai P, Hoat LN, Wright P, Martens P. Hot spot detection and spatio-temporal dispersion of dengue fever in Hanoi, Vietnam. *Glob Health Action*. 2013;6:18632.
27. Kulldorff M, Athas WF, Feurer EJ, Miller BA, Key CR. Evaluating cluster alarms: a space-time scan statistic and brain cancer in Los Alamos, New Mexico. *Am J Public Health*. 1998;88:1377–80.
28. Moraga P, Kulldorff M. Detection of spatial variations in temporal trends with a quadratic function. *Stat Methods Med Res*. 2016;25:1422–37.
29. Ramasamy J, Janarthanan K. A study on spatial variations in temporal trends of Dengue Incidences in Tamil Nadu, India. *Int J Sci Technol Res*. 2019;8:788–92.
30. Firouraghi N, Bergquist R, Fatima M, Mohammadi A, Hamer DH, Shirzadi MR, et al. High-risk spatiotemporal patterns of cutaneous leishmaniasis: a nationwide study in Iran from 2011 to 2020. *Infect Dis Poverty*. 2023;12:49.
31. Bruce AT, Berra TZ, Dos Santos FL, Alves YM, Souza LLL, Ramos ACV, et al. Temporal trends in areas at risk for concomitant tuberculosis in a hyper-endemic municipality in the Amazon region of Brazil. *Infect Dis Poverty*. 2020;9:111.
32. Rao H, Shi X, Zhang X. Using the Kulldorff's scan statistical analysis to detect spatio-temporal clusters of tuberculosis in Qinghai Province, China, 2009–2016. *BMC Infect Dis*. 2017;17:578.
33. He WC, Ju K, Gao YM, Zhang P, Zhang YX, Jiang Y, et al. Spatial inequality, characteristics of internal migration, and pulmonary tuberculosis in China, 2011–2017: a spatial analysis. *Infect Dis Poverty*. 2020;9:159.
34. Tango T, Takahashi K. A flexibly shaped spatial scan statistic for detecting clusters. *Int J Health Geogr*. 2005;4:11.
35. Yotsu RR, Miyamoto Y, Mori S, Ato M, Sugawara-Mikami M, Yamaguchi S, et al. Hansen's disease (leprosy) in Japan, 1947–2020: an epidemiologic study during the declining phase to elimination. *Int J Infect Dis*. 2022;125:265–74.
36. Li X, Jin G, Yang J, Li Y, Wei P, Zhang L. Epidemiological characteristics of leprosy during the period 2005–2020: a retrospective study based on the Chinese surveillance system. *Front Public Health*. 2022;10:991828.
37. Rodrigues RN, Leano HAM, Bueno IC, Araujo K, Lana FCF. High-risk areas of leprosy in Brazil between 2001–2015. *Rev Bras Enferm*. 2020;73:e20180583.
38. Abdela SG, Diro E, Zewdu FT, Berhe FT, Yeshaneh WE, Tamirat KS, et al. Delayed diagnosis and ongoing transmission of leprosy in the post-elimination era in Boru Meda hospital, Ethiopia. *J Infect Dev Ctries*. 2020;14:510–5.
39. Chu T, Liu D, Huai P, Chen X, Han S, Chen S, et al. Comprehensive measures succeeded in improving early detection of leprosy cases in post-elimination era: experience from Shandong province, China. *PLoS Negl Trop Dis*. 2020;14:e0007891.
40. Wu L, Shen Y, Yao Q, Sang X, Fei L, Kong W, et al. Temporal-spatial distribution characteristics of leprosy: a new challenge for leprosy prevention and control in Zhejiang, China. *PLoS Negl Trop Dis*. 2021;15:e0008956.
41. Teixeira CSS, Pescarini JM, Alves FJO, Nery JS, Sanchez MN, Teles C, et al. Incidence of and factors associated with Leprosy among Household contacts of patients with Leprosy in Brazil. *JAMA Dermatol*. 2020;156:640–8.
42. Zhu G, Xiao J, Liu T, Zhang B, Hao Y, Ma W. Spatiotemporal analysis of the dengue outbreak in Guangdong Province, China. *BMC Infect Dis*. 2019;19:493.
43. Peters ES, Eshiet AL. Male-female (sex) differences in leprosy patients in south eastern Nigeria: females present late for diagnosis and treatment and have higher rates of deformity. *Lepr Rev*. 2002;73:262–7.
44. Bakoubayi AW, Haliba F, Zida-Compaore WIC, Bando PP, Konu YR, Adoli LK, et al. Any resurgence of leprosy cases in the Togo's post-elimination period? Trend analysis of reported leprosy cases from 2010 to 2022. *BMC Infect Dis*. 2024;24:588.
45. Wang L, Wang H, Yan L, Yu M, Yang J, Li J, et al. Single-dose Rifapentine in Household contacts of patients with Leprosy. *N Engl J Med*. 2023;388:1843–52.
46. Liu J. Sustainable development of leprosy elimination by 2030 in China. *Lancet Reg Health West Pac*. 2024;44:101044.
47. Qiu Y, Qin H, Ying M, Xu K, Ren J. WeChat-based health education to improve health knowledge in three major infectious diseases among residents: a multicentre case-controlled protocol. *BMJ Open*. 2020;10:e037046.
48. Palit A, Kar H. Prevention of transmission of leprosy: the current scenario. *Indian J Dermatol Venereol Leprol*. 2020;86:115–23.
49. da Paz WS, Souza MDR, Tavares DDS, de Jesus AR, Dos Santos AD, do Carmo RF, et al. Impact of the COVID-19 pandemic on the diagnosis of leprosy in Brazil: an ecological and population-based study. *Lancet Reg Health Am*. 2022;9:100181.

## Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.