Analysis of Spatial Distribution Characteristics of Human Echinococcosis at the Township Level in Sichuan Province, China

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Research Article

Keywords: Sichuan province, Echinococcosis, Prevalence, Spatial autocorrelation

Posted Date: February 5th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-160062/v1>

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Abstract

Background

Echinococcosis is a global zoonotic parasitic disease caused by the larvae of *Echinococcus*, which affects both humans and animals. In China, this disease is highly endemic in Sichuan Province. In this study, we investigated the prevalence and spatial distribution characteristics of human echinococcosis at the township level in Sichuan province, so as to provide a reference for the development of precise prevention and control strategies in the future.

Methods

We explored the prevalence of echinococcosis using the B-ultrasonography diagnostic method in Sichuan province between 2016 and 2019, where patients and transmission conditions had been identified in the past. All data were inputted using Epi-Info software, while SPSS software was used for statistical analysis. We then employed ArcGIS software to draw the spatial distribution map and perform trend surface analysis. Finally, Geoda software was used to analyze spatial autocorrelation and draw Lisa clustering map.

Results

A total of 2 542 135 people from 649 towns in 35 counties of Sichuan province were screened for echinococcosis, of which 11 743 echinococcosis patients were detected. The prevalence of echinococcosis in humans was 0.462%, among which the occurrence of cystic echinococcosis [CE] was 0.221%, while that of alveolar echinococcosis [AE] was 0.244%. We also observed that the predominance of echinococcosis in humans decreased gradually from west to east and from north to south based on the results of the spatial distribution map and trend surface analysis. The Global Moran's I index was 0.77 ($Z = 32.07$, $P < 0.05$), which indicated that the prevalence of echinococcosis in humans was spatially clustered, exhibiting a significant spatial positive correlation. Further, the findings of local spatial autocorrelation analysis revealed that the "high-high" concentration areas were primarily located in some townships in the northwest of Sichuan province. On the other hand, the "low-low" concentration areas were predominantly located in some townships in the southeast of Sichuan province.

Conclusion

Our findings demonstrated that the prevalence of echinococcosis in humans of Sichuan province is following a downward trend, implying that the current prevention and control work has achieved some substantial outcomes. However, the prevalence in humans at the township level is widely distributed and differs greatly, with a clear clustering in space. Therefore in the future, precise prevention and control strategies should be formulated for clusters, particularly strengthening the "high-high" clusters at the township level.

Background

Echinococcosis (also known as hydatid disease) is a zoonotic parasitic disease caused by the larvae of *Echinococcus* spp.. Because of its specific manifestation and transmission mode in the hosts, it is defined to group C infectious diseases in China. It is a global public health problem due to the seriousness of the hazard [1–3]. Previous studies have established that four species of *Echinococcus* spp, namely, *echinococcus granulosus* (E.g), *echinococcus multilocularis* (E.m), *echinococcus oligarthrus* (E.o), and *echinococcus vogeli* (E.v), are responsible for echinococcosis in humans, of which E.g. and E.m are the most significant [4, 5]. The larvae of these four species of *Echinococcus* spp are subjected to three types of echinococcosis in humans, including cystic echinococcosis (CE), alveolar echinococcosis (AE), and polycystic echinococcosis (PE) [6]. Infected canines and felines such as dogs, wolves, foxes, and cats are important infection sources of echinococcosis. Intermediate hosts include even-toed ungulates and small mammals, while humans are involved as incidental hosts. This disease is primarily transmitted through the fecal-oral route. It has been identified that people living in echinococcosis-endemic areas are all susceptible to echinococcosis, and high-risk groups mainly include those involved in agricultural production, livestock slaughter, fur processing, and hunting. The life cycle of *Echinococcus* spp. must be completed by canine (feline) and cloven-hoofed animal hosts/small mammals, which involves three processes including egg, metacestode, and adult worm. This disease is clinically characterized by a range of symptoms, such as cyst pressure and irritation to affected organs, pain, fever, and allergic reactions [7]. Studies have shown that the mortality rate of AE exceeds 90% in patients who have been either untreated or undertreated for 10–15 years [8].

Echinococcosis infection is widespread worldwide, showing priority in agricultural and pastoral areas. It has been demonstrated that different *Echinococcus* spp. that cause different types of echinococcosis exhibits different global distributions, resulting in differences in the prevalence of different types of echinococcosis and regions. Currently, there are only two kinds of echinococcosis in China, namely, CE and AE, which are some of the highly prevalent types in other countries in the world. In comparison, the disease burden of AE in terms of Disability Adjusted of Life Years (DALY) in China accounted for 91%, while that of CE in the same country accounted for 40% of the world [9, 10]. Multiple recent reports have highlighted that echinococcosis is primarily dominant in pastoral areas and semi-agricultural and semi-pastoral areas of Inner Mongolia, Sichuan, Tibet, Gansu, Qinghai, Ningxia, Yunnan, Shaanxi, and Xinjiang in northwest China, especially in Sichuan, Tibet and Qinghai

in Qinghai-Tibet Plateau [11, 12]. Of these regions, Sichuan is one of the provinces with the most serious prevalence of echinococcosis in China, with a mixed epidemic area of CE and AE. According to a report by the national survey conducted in 2012 in Sichuan province, echinococcosis was prevalent in 35 counties in Sichuan, mainly predominant in the whole area of Ganzi (18 counties) and Aba prefectures (13 counties), in Muli and Yuexi counties of Liangshan prefecture, and also in Tianquan and Baoxing counties of Ya'an city. Subsequently, the estimated prevalence was 1.08% [13, 14].

Presently, although the occurrence of echinococcosis in Sichuan province is clear at the county level, it remains elusive at the township level that needs further inquiry. To fully understand the current status of the human echinococcosis prevalence at the township level in Sichuan Province, we herein performed echinococcosis screening for the whole population in Sichuan province from 2016 to 2019.

Recently, the spatial statistical analysis method has been widely applied in the field of epidemiologic study of echinococcosis, particularly in evaluating the difference of prevalence in different regions and identifying disease clustering [15, 16]. For instance, in 2009, Brundu et al. analyzed the spatial scan statistics of 1029 pastures where CE of bovine was found in Sardinia and Italy, revealing two clusters existed [17]. In another report, a spatial autocorrelation analysis of the prevalence of echinococcosis in 13 counties of Aba Prefecture in Sichuan province using the global Moran's I method by Qi YF demonstrated that the incidence of echinococcosis had a significant clustering distribution, whereas the global Getis'G result elucidated that there were clusters with a high prevalence of echinococcosis [18]. In addition, a study by Zhao Y et al. used spatial scan statistics and spatial autocorrelation analysis methods to assess the detection rate of echinococcosis in 18 counties of Ganzi Prefecture in Sichuan province, concluding that there was aggregation in the spatial distribution of echinococcosis [19].

In this work, we analyzed the spatial aggregation of human echinococcosis prevalence at the township level in Sichuan province using global and local spatial autocorrelation analysis methods. We hereby aim to identify the spatial aggregation areas of echinococcosis at the township level in Sichuan province, so as to determine the areas that need to strengthen the key prevention and control in the future. We also purposed to provide a baseline reference for the formulation of precise strategies and measures for the prevention and mitigation of echinococcosis.

Materials And Methods

Survey areas

A survey conducted from 2016 to 2019 was used to investigate the prevalence of human echinococcosis in areas where many echinococcosis cases were reported previously.. The scope of this study comprised of 325 townships under 18 counties in Ganzi Prefecture, 230 townships under 13 counties in Aba Prefecture, 70 townships under 2 counties in Liangshan Prefecture, and 24 townships under 2 counties in Ya'an City. Overall, 649 townships were covered to screen human echinococcosis (Fig. 1).

Survey contents and methods

Target population

All permanent residents (including those who had a continuous residence at the surveyed areas for more than 6 months) aged 2 years and above were screened for Echinococcosis.

Survey of prevalence

We investigated the prevalence of human echinococcosis based on the requirements of the Technical Plan for Echinococcosis Prevention and Control. We then performed a B-ultrasound examination of the abdomen using the portable ultrasonic diagnostic instrument. Patients were diagnosed following the Diagnostic Criteria for Echinococcosis (WS257-2006)[20], while serological tests were supplemented to suspected patients. In particular, the anti-echinococcosis antibody in the serum of suspected patients was detected with ELISA. The IgG Antibody Diagnostic Kit was purchased from Shenzhen Kangbaide Biotechnology Co., Ltd.

Trend surface analysis

We adopted trend surface analysis to establish whether the prevalence of echinococcosis at the township level exhibits a trend in Sichuan province, as well as to understand the trend direction and degree.

Spatial clustering analysis

In this study, the detection rate of human echinococcosis in Sichuan Province was analyzed by global autocorrelation and local control autocorrelation, in order to understand the aggregation degree and scope of echinococcosis.

Data processing and statistical analysis

In this study, all data (consisting of name, sex, age, lesion type, lesion size, and location) were inputted using Epi-info software version 7.2.4. We subsequently combined the data of 35 counties. The error and duplicate data were eliminated, whereby the error was corrected via the double-entry comparison method, and error corrections were made using the two-item comparison method, and finally a human echinococcosis screening database was created.

Statistical data analyses were executed using SPSS version 21.0 software. We also calculated the prevalence of human echinococcosis in each township.

Prevalence of human echinococcosis was calculated as per the following formula:

$$P = n/N \times 100\%$$

where P is the prevalence of the population in the surveyed area, n refers to the number of patients detected, and N denotes the number of examined people.

We further used the ArcGIS 10.2 software to map the spatial distribution map of the human echinococcosis prevalence at the township level and to analyze the trend surface, while GeoDa 1.6.7 software was employed to analyze the prevalence of human echinococcosis in townships for global and local spatial autocorrelations. Then, the spatial autocorrelation indexes were respectively adopted as Global Moran's I index and Anselin's Local Moran's I index, and the related results were displayed visually. A level of $P < 0.05$ was considered statistically significant.

Results

Basic information

In total, 649 townships from 35 endemic counties in 4 prefectures(cities) of Sichuan province were included to carry out this survey. A total of 2 758 525 people were examined, and 11 743 patients were detected. Notably, we found the distribution of patients in 426 townships, including 405 townships with CE patients, 167 townships with AE patients, and 146 townships with both kinds of echinococcosis patients (Table 1).

Table 1 Distribution of human echinococcosis at the township level in Sichuan Province

City	No. of townships surveyed	No. of CE epidemic townships	No. of AE epidemic townships	No. of total epidemic townships
Aba Prefecture	230	134	40	146
Ganzi Prefecture	325	255	125	262
Liangshan Prefecture	70	12	0	12
Ya'an City	24	4	2	6
Total	649	405	167	426

Geographical distribution

Here, we found that the prevalence of echinococcosis in Sichuan province was 0.462%. Noticeably, 5 out of the 35 endemic counties exhibited a predominance of more than 1%, namely, Shiqu (6.512%), Seda (3.056%), Baiyu (1.237%), Dege (1.180%), and Ganzi (1.171%) counties (Table 2).

Table 2 The prevalence of human echinococcosis of epidemic counties in Sichuan province

City	County	Total no. of townships	Pop. in endemic areas	No. exam'd	Total no. of patients	Total prevalence (%)	CE		AE	
							No. patients	Prevalence (%)	No. patients	Prevalence (%)
Aba Prefecture	Aba	21	84 299	75 150	109	0.145	83	0.110	26	0.035
	Heishui	17	63 700	57 226	46	0.080	39	0.068	7	0.012
	Hongyuan	11	47 186	45 751	90	0.197	83	0.181	7	0.015
	Jinchuan	23	86 657	79 499	95	0.119	91	0.114	4	0.005
	Jiuzhaigou	19	80 701	77 204	8	0.010	8	0.010	0	0.000
	Li	13	50 235	45 405	17	0.037	17	0.037	0	0.000
	Maerkang	14	55 459	50 378	160	0.318	160	0.318	0	0.000
	Mao	21	111 578	106 125	5	0.005	5	0.005	0	0.000
	Rangtang	12	44 525	39 564	207	0.523	3	0.008	204	0.516
	Ruoergai	19	80 931	71 028	380	0.535	380	0.535	0	0.000
	Songpan	26	70 087	65 888	2	0.003	2	0.003	0	0.000
	Wenchuan	13	100 093	96 302	2	0.002	2	0.002	0	0.000
	Xiaojin	21	82 243	76 227	30	0.039	25	0.033	5	0.007
Ganzi Prefecture	Batang	19	52 232	48 108	52	0.108	52	0.108	0	0.000
	Baiyu	17	59 118	55 382	685	1.237	423	0.764	264	0.477
	Danba	15	54 842	53 538	25	0.047	24	0.045	1	0.002
	Daofu	22	44 549	40 588	109	0.269	109	0.269	0	0.000
	Daocheng	14	35 393	28 206	16	0.057	15	0.053	1	0.004
	Derong	12	28 785	26 490	3	0.011	4	0.015	0	0.000
	Dege	26	90 523	81 810	965	1.180	698	0.853	269	0.329
	Ganzi	22	66 501	62 016	726	1.171	283	0.456	450	0.726
	Jiulong	18	53 471	52 770	13	0.025	13	0.025	0	0.000
	Kangding	21	117 695	112 059	68	0.061	42	0.037	27	0.024
	Litang	24	72 344	68 346	265	0.388	265	0.388	0	0.000
	Luhuo	16	39 890	39 768	108	0.272	103	0.259	5	0.013
	Luding	12	87 961	85 978	18	0.021	13	0.015	5	0.006
	Seda	17	56 777	51 403	1 571	3.056	739	1.438	840	1.634
	Shiqu	22	89 367	88 116	5 738	6.512	1 731	1.964	4 061	4.609
	Xiangcheng	12	29 839	26 936	9	0.033	9	0.033	0	0.000
	Xinlong	19	51 970	46 209	166	0.359	147	0.318	19	0.041
	Yajiang	17	42 034	38 577	30	0.078	30	0.078	0	0.000
Liangshan Prefecture	Muli	29	138 555	121 198	12	0.010	12	0.010	0	0.000
	Yuexi	41	378 425	349 851	7	0.002	7	0.002	0	0.000
Ya'an City	Baoxing	9	51 725	43 940	2	0.005	1	0.002	1	0.002

City	County	Total no. of townships	Pop. in endemic areas	No. exam'd	Total no. of patients	Total prevalence (%)	CE		AE	
							No. patients	Prevalence (%)	No. patients	Prevalence (%)
	Tianquan	15	158 835	135 099	4	0.003	3	0.002	1	0.001
Total		649	2 758 525	2 542 135	11 743	0.462	5 621	0.221	6 197	0.244

Based on the analysis at the township level, we observed that the top three overall prevalences were all under the jurisdiction of Shiqu county, they were Changsha Gongma (14.961%), Gemeng (12.065%), and Sexu (10.588%) townships. In particular, the top three occurrences of CE were Gayi (3.243%) and Changxu Gongma (3.21%) townships in Shiqu county, and Suoba (3.22%) township in Dege county. Conversely, the top three incidences of AE were Changsha-Gongma (12.986%), Gemeng (10.462%), and Mengyi (10.363%) townships in Shiqu county. The number of townships with human prevalence 0–0.1%, 0.1–1%, and 1% or above were 153, 209, and 64, respectively (Table 3).

Table 3 The prevalence of different types of echinococcosis in Sichuan province

Human prevalence(%)	No. of CE epidemic townships	No. of AE epidemic townships	No. of total epidemic townships
$P \geq 1$	47	36	64
$0.1 \leq P < 1$	197	71	209
$P < 0.1$	161	60	153
Total	405	167	426

Comparison with previous results

Overall, the survey results in 2016–2019 demonstrated that the prevalence of CE was 0.31%, while AE was 0.35%. In comparison, the prevalence of AE was significantly higher than that of CE ($\chi^2 = 28.166$, $P < 0.05$). On the other hand, the survey findings of 2012 showed that the predominance of CE was 0.88%, whereas that of AE was 0.27% [14]. In contrast, the prevalence of CE was significantly higher than that of AE ($\chi^2 = 372.204$, $P < 0.05$) (Fig. 2).

Description of spatial distribution characteristics

The spatial distribution map of Sichuan province displayed that the high prevalence of echinococcosis was primarily distributed in the west, northwest, and north, while the low prevalence was predominantly distributed in the south and east. The prevalence of echinococcosis in Sichuan province exhibited spatial clustering characteristics, indicating that areas with high or low prevalence tended to aggregate into pieces. However, the judgment of this aggregation was not statistically significant, and therefore we adopted spatial autocorrelation analysis and other methods for further inference (Fig. 3).

Trend surface analysis

To make a three-dimensional trend analysis chart, we used the trend analysis function of ArcGIS 10.1 software. The x- and y-axes represented longitude and latitude, respectively, while the z-axis denoted the human prevalence in townships. Additionally, the blue line represented the change of prevalence from south to north, whereas the green line indicated the change of prevalence from east to west. Remarkably, the findings illustrated that the prevalence of echinococcosis at the township level in Sichuan province followed a decreasing trend from north to south and from west to east, which agreed with the results based on regional distribution characteristics (Fig. 4).

Spatial clustering analysis

Global spatial autocorrelation analysis

The results of global spatial autocorrelation analysis of the prevalence of echinococcosis at the township level in Sichuan province indicated that there were positive spatial autocorrelation and aggregation distribution rather than random distribution (Table 4).

Table 4 Spatial autocorrelation global Moran's I analysis on the prevalence of echinococcosis

Rate type	Moran's	Z-value	P-value	Expected value	Standard deviation
Total prevalence	0.77	22.07	<0.01	-0.0 015	0.02
Prevalence of CE	0.70	29.67	<0.01	-0.0 015	0.02
Prevalence of AE	0.71	30.52	<0.01	-0.0 015	0.02

Local spatial autocorrelation analysis

In this subsection, the outcomes of local spatial autocorrelation analysis showed that the “high-high” gathering areas of overall prevalence were mainly located in the townships of Shiqu, Seda, Ganzi, Dege, and Baiyu counties, totaling 41. The “high-high” gathering areas of CE prevalence were dominantly located in townships of Shiqu, Seda, Ganzi, Dege, Baiyu, Rangtang, Xinlong, and Litang counties, totaling 48. The “high-high” gathering areas of AE prevalence were predominantly located in towns of Shiqu, Dege, Seda, Ganzi, and Rangtang counties, totaling 31.

The “low-low” gathering areas of the overall prevalence were primarily located in townships of Jiuzhaigou, Songpan, Heishui, Mao, Li, Wenchuan, Xiaojin, Baoxing, Tianquan, Kangding, Luding, Muli, Daocheng, Xiangcheng, and Yuexi county, totaling 193. The “low-low” gathering areas of the predominance of CE were largely located in townships of Jiuzhaigou, Songpan, Heishui, Mao, Li, Wenchuan, Xiaojin, Baoxing, Tianquan, Kangding, Luding, Muli, Daocheng, Xiangcheng, and Yuexi county, totaling 165. Finally, the “low-low” gathering areas of the occurrence of AE were generally in the townships of Jiuzhaigou, Songpan, and Kangding, totaling 4 (Fig. 5).

Discussion

Echinococcosis is a worldwide zoonotic parasitic disease that seriously endangers the health and life safety of people. It also affects social and economic development, brings heavy economic burdens to the families of patients, and is one of the major reasons that lead people in endemic areas of China to become poor and live in poverty due to illness [21]. To deeply understand the prevalence of human echinococcosis in Sichuan province, we herein performed a survey in 35 epidemic counties previously identified in 2012 from 2016 to 2019. We specifically investigated the epidemic areas and human echinococcosis at the township level in Sichuan province. Our results revealed that the echinococcosis patients were distributed in 426 townships, which were primarily located in the northwestern part of Sichuan province and concentrated in high mountain meadows, pastoral areas with a cold, arid climate and little rainfall, and semi-agricultural and semi-pastoral areas. A major reason for this is that *Echinococcus* eggs are well adapted for cold, dry, and rainless natural environments. In addition, there were abundant animal resources in these environments, which form a relatively suitable food chain for predation and prey, thus enabling *Echinococcus* spp. to form a complete life history, resulting in the prevalence of echinococcosis [22, 23]. We also found that CE and AE were prevalent in 405 and 167 townships, CE epidemic areas were more widespread compared with AE. This observation may be attributed to the fact that CE is mainly spread in the biological circulation chain composed of domestic dogs as the main definitive host and domestic animals as the main intermediate hosts, while AE is primarily spread in the biological circulation chain composed of foxes and dogs as the main definitive host and small mammals as the main intermediate hosts. In comparison, the distribution range of small mammals is smaller than that of domestic animals [24–27].

Among the 426 townships where patients were distributed, we noted that there were 64 townships with a human population prevalence of $\geq 1.00\%$, which were predominantly distributed in some townships of Shiqu, Seda, Ganzi, Dege, and Baiyu counties in the northwest part of Sichuan province. Similarly, the spatial distribution of human echinococcosis prevalence map elucidated that echinococcosis was largely spread in Sichuan province, particularly with a high prevalence in the northwest.

Trend surface analysis is a commonly used spatial statistical analysis method for evaluating the trend and gradual change of spatial geographical position on a regional scale. It often establishes a polynomial regression mathematical model and carries out interpolation analysis according to the observed values of observed variables and the polynomial regression results of their sampling locations, so as to obtain one-dimensional, two-dimensional, or three-dimensional continuous line segments, planes, or solid surfaces [28]. Based on the results of the trend analysis, we demonstrated that the predominance of human echinococcosis in Sichuan province followed a trend in both the east-west and north-south directions for most of the years, gradually decreasing from west to east and from north to south. These findings were concurred with the results of trend surface analysis of echinococcosis conducted by Qi Yanfeng in Aba Prefecture in 2013 and also with the spatial and temporal distribution characteristics of the new human echinococcosis prevalence in Sichuan province between 2007 and 2017 by He Wei et al. The true explanations why the areas with high prevalence were essentially distributed in the northwest of Sichuan may be as follows. First, the climatic conditions of high altitude and low temperature favored the *Echinococcus* eggs to survive for a long time to exacerbate the spread of echinococcosis. Second, the existence of a large number of intermediate hosts increased the spread of diseases, developed animal husbandry was brought a large number of intermediate hosts of CE, and grassland was also a favorable environment for the intermediate hosts of AE (small mammals). Previous findings have shown that most of the areas with high prevalence had developed animal husbandry. Third, close contact with dogs, feeding diseased organs to dogs, not washing hands before eating or preparing food, and lack of safe drinking water sources significantly increased the risk of infection [29–34].

According to the results of the 2012 national echinococcosis prevalence survey, the number of patients with CE in Sichuan province was distinctively higher than those with AE, while the findings of the 2016–2019 survey showed that AE patients accounted for 52.77% of the total number of patients. The major reasons for this discrepancy may be as follows. First, the infectious source of CE was primarily dogs, and since the implementation of the Echinococcosis Prevention and Control Project, Sichuan province had standardized the management and deworming

of dogs, and reduced the number of stray dogs, the infectious source had been effectively controlled, so the number of newly found patients had decreased. Second, the surgical operation difficulty of CE was less compared to that of AE, and more CE patients were effectively cured [35, 36]. Third, the experience and diagnostic techniques of ultrasonographers differ from one region to another, and there may be caused inaccurate diagnosis.

Numerous reports have concluded that the prevalence and transmission of echinococcosis are influenced by natural, biological, and social factors, and were also restricted by the imago in the definitive host segments and eggs in the external environment, larvae in intermediate hosts and stability of parasites, and had spatial autocorrelation [37–42]. According to the literature, spatial autocorrelation can accurately reflect the aggregation degree of an indicator in a spatial unit. For example, if an indicator shows the same distribution between its center and its surroundings in space, it is referred to as a spatial positive correlation, if an indicator is spatially opposite, it is called spatial negative correlation, and ultimately if an indicator is spatially random, it indicates that the spatial correlation is not significant. In addition, spatial autocorrelation is categorized into global and local spatial autocorrelations. Specifically, the global spatial autocorrelation analysis is used to explore the spatial aggregation of an indicator over the entire study area, using a single value to reflect the autocorrelation of the whole region. Subsequently, the common indicators of analysis included Global Moran's I index, Getis-Ord General G coefficient, and the Geary C coefficient. On the other hand, the local spatial autocorrelation analysis is used to investigate the degree of correlation between an indicator in each spatial unit and neighboring units. To test whether its spatial autocorrelation is significant for the whole survey area, thus indicating the spatial distribution pattern of the index with high and low and low, the common analysis indexes include local Moran's I index and local Getis-Ord G coefficient [43, 44]. Therefore, spatial autocorrelation analysis can be employed in medicine and related fields, which can improve the understanding of researchers of the spatial distribution law of disease prevalence, hence providing a reliable basis for formulating disease prevention and control strategies. Here, we employed spatial autocorrelation statistical analysis to explore the spatial distribution characteristics of echinococcosis at the township level in Sichuan province. Through the global autocorrelation analysis of the total prevalence of echinococcosis, and the prevalence of populations CE and AE, we found that the predominance of different types of echinococcosis exhibited a positive spatial correlation, with an aggregated distribution.

Moreover, the results of global spatial autocorrelation analysis showed that the prevalence of echinococcosis was clustered in space with a positive spatial correlation, that is, the prevalence of neighboring areas of the townships with high prevalence was also high, while that of neighboring areas of the townships with low prevalence was also low, which was spatially diffuse. On the other hand, in the local spatial autocorrelation analysis, the LISA aggregation map clearly showed the “high-high” and “low-low” clusters of human echinococcosis prevalence at the township level. Of note, the “high-high” clusters were dominantly distributed in most of the townships of Shiqu, Seda, Ganzi, Dege, and Baiyu counties near the northwest of Sichuan province. The areas with high prevalence might be associated with special natural environmental and socio-geographical factors influenced by the high altitude. Meanwhile, the unhealthy production lifestyle of local Tibetans might have a great similarity due to the close geographical location, thus forming a high-risk behavior of echinococcosis. Additionally, the “low-low” gathering areas were mostly located in some townships of Jiuzhaigou, Songpan, Heishui, Mao, Li, Wenchuan, Xiaojin, Baoxing, Tianquan, Kangding, Luding, Muli, Daocheng, Xiangcheng, and Yuexi county near the southeast in Sichuan province. These areas did not belong to the Qinghai-Tibet plateau, and their altitude was relatively low, and the natural conditions were superior to those of high prevalence areas, production and lifestyle were relatively healthy, thus these risks were relatively small. These findings suggest that we need to strengthen the comprehensive prevention and control of echinococcosis in “high-high” gathering areas, at the same time, we should actively explore the favorable factors for the low prevalence of echinococcosis in “low-low” gathering areas to provide a baseline reference for the prevention and control of echinococcosis in “high-high” gathering areas. In this regard, we thus recommend the following suggestions. First, based on previous screening results, “high-high” gathering areas should carry out herd screening in endemic villages, especially in remote agricultural and pastoral areas, nomadic and migratory groups; “low-low” congregation areas should strengthen screening in pastoral areas, temples, and other key areas. Second, “high-high” gathering townships should perform standardized management on dogs, bring dogs into legal management, establish a standardized management and control mechanism for dogs, manage household registration of domestic dogs, establish a regular deworming system for domestic dogs in combination with local conditions, establish the deworming day and conduct its regularly. Conversely, “low-low” gathering townships should prohibit the import of wild dogs and prevent the introduction of infection sources. Third, according to local conditions, “high-high” clustering townships should explore a centralized slaughter management mechanism for cattle and sheep. All endemic townships should strictly implement the quarantine system of cattle and sheep origin, take harmless treatment of diseased organs, immunize sheep in stock, ensure good immunization registration, and carry out small mammals in settlements and the surrounding 1 km radius in the epidemic areas of alveolar echinococcosis. Fourth, “high-high” gathering townships should actively organize and publicize echinococcosis prevention policies and knowledge, mobilize patients who meet the treatment conditions to carry out the treatment in medical institutions, make full use of various media to disseminate health knowledge, strengthen publicity and education to the masses in townships where echinococcosis was prevalent, guide key populations such as monks and nuns to support participation in echinococcosis prevention and control, and compile echinococcosis prevention and control materials parallel with local customs. Health education materials containing the core information of echinococcosis prevention and control are produced, farmers and herdsman are guided to develop good health habits, and the knowledge of echinococcosis prevention and control is included in the health education content of schools in epidemic areas. Students are

regularly guided to spread the knowledge of echinococcosis prevention and control to parents and society through “small hands pull big hands” activities. Finally, “low-low” gathering townships should strengthen the publicity of the knowledge of prevention and treatment of echinococcosis among the migrant population, in order to prevent infection from outside [45].

Conclusion

In summary, this study is the first to examine the echinococcosis prevalence and spatial distribution characteristics of the population in Sichuan province at the township level, to define the specific spatial distribution of the aggregated areas, and to propose the key prevention and control in the “high-high” aggregated areas in the future. However, despite these promising results, this study did not further analyze the specific reasons for the formation of spatial gathering areas in combination with the prevention and control measures implemented in the local gathering and non-gathering areas, as well as the biological, socio-geographical, and natural environmental factors. In this respect, this work has certain limitations, especially in formulating specific prevention and control measures. Therefore, we recommend that specific prevention and control work should be explored and studied in depth in the future.

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Figures

Figure 1

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

Figure 2

The comparison of the prevalence of CE and AE in 2012 and 2016-2019.

Figure 3

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

Figure 4

Trend analysis of echinococcosis in Sichuan province.

Figure 5

Local spatial autocorrelation Lisa clustering map of new prevalence of echinococcosis in the rural population of Sichuan province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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