Geographic distribution and prevalence of human echinococcosis at the township level in the Tibet Autonomous Region

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Abstract

Background: Echinococcosis, a zoonotic parasitic disease, is caused by larval stages of cestodes in the Echinococcus genus. Echinococcosis is highly prevalent in ten provinces/autonomous regions of western and northern China. In 2016, an epidemiological survey of Tibet Autonomous Region (TAR) revealed that the prevalence of human echinococcosis was 1.66%, which was much higher than the average prevalence in China (0.24%). Therefore, to improve on the current prevention and control measures, it is important to understand the prevalence and spatial distribution characteristics of human echinococcosis at the township level in TAR.

Methods: Data for echinococcosis cases in 2018 were obtained from the annual report system of echinococcosis of Tibet Center for Disease Control and Prevention. Diagnosis had been performed via B-ultrasonography. The epidemic status of echinococcosis in all townships in TAR was classified according to the relevant standards of population prevalence indices as defined in the national technical plan for echinococcosis control. Spatial scan statistics were performed to establish the geographical townships that were most at risk of echinococcosis.

Results: In 2018, a total of 16,009 echinococcosis cases, whose prevalence was 0.53%, were recorded in 74 endemic counties in TAR. Based on the order of the epidemic degree, all the 692 townships were classified from high to low degrees. Among them, 127 townships had prevalence rates ≥ 1%. The high prevalence of human echinococcosis in TAR, which is associated with a wide geographic distribution, is a medical concern. Approximately 94.65% of the villages and towns reported echinococcosis cases. According to spatial distribution analysis, the prevalence of human echinococcosis was found to be clustered, with the specific clustering areas being identified. The cystic echinococcosis primary cluster covered 88 townships, while that of alveolar echinococcosis's covered 38 townships.

Conclusions: This study shows spatial distributions of echinococcosis with different epidemic degrees in 692 townships of TAR and high-risk clustering areas at the township level. Our findings indicate that strengthening the echinococcosis prevention and control strategies in TAR should directed at townships with a high prevalence and high-risk clustering areas.

Keywords: Human echinococcosis, Prevalence, Geographic distribution, Tibet Autonomous Region, China
**Background**

Echinococcosis, which is commonly known as hydatidosis, is a zoonotic parasitic disease caused by the larvae of *Echinococcus*. Globally, this disease is highly prevalent in pastoral areas of many countries [1]. In endemic areas of China, the number of patients with echinococcosis was estimated to be 166,098 in 2016 [2]. There are two major types of echinococcosis: cystic echinococcosis (CE) which is caused by the larvae of *E. granulosus* and alveolar echinococcosis (AE) which is caused by the larvae of *E. multilocularis* [3].

Echinococcosis is a long-course disease that mainly affects the liver, but also, the lungs and spleen [4, 5]. As the disease progresses, the infected organs deteriorate, causing organ dysfunction and eventually, death [4]. AE, also known as "parasitic cancer", is the most lethal parasitic zoonosis with a 10-year mortality rate of more than 90% if untreated [4, 6]. Echinococcosis is a major public health concern with a substantive economic burden [3, 7, 8].

A national echinococcosis survey in China, conducted between 2012 and 2016, showed that 31 provincial-level administrative divisions (PLADs) had reported cases of echinococcosis. Within these PLADs, 370 counties reported local endemic human echinococcosis cases. These cases were mainly detected in the pastoral, semi-agricultural and semi-pastoral areas of TAR, Sichuan, Qinghai, Xinjiang, Gansu, Ningxia, Inner Mongolia, Yunnan and Shaanxi [2]. In addition, echinococcosis is closely associated with poverty among farmers and herdsmen [9]. In 2016, the prevalence of echinococcosis in TAR was 1.66%, with the estimated number of cases being 49,935 [2]. The average infection rates for intermediate hosts (cattle and sheep) as well as dogs were 13.21% and 7.30%, respectively [2]. These infections are highly associated with the prevalence of human echinococcosis [10].

In China, and globally, TAR is the region with the highest prevalence of echinococcosis [2]. In 2016, a sampling survey revealed that all the 74 counties under TAR jurisdiction were epidemic. All 692 townships in the 74 counties in 6 prefecture-level cities (Lhasa City, Changdu city, Shannan city, Shigatse city, Naqu city, Linzhi city) and one prefecture (Ali Prefecture) have been recognized as endemic areas for echinococcosis [2]. Given the severe epidemic situation, and the serious public health challenges associated with echinococcosis, a general census of human echinococcosis was performed in 2017. This census, which revealed an echinococcosis rate of 90.34%, was aimed at informing on suitable strategies for early detection and diagnosis. All echinococcosis patients were identified and, with their informed consents, treated with albendazole. Some of the patients were recommended for surgical treatment. In 2018, comprehensive measures for echinococcosis prevention and control were implemented.
in the 74 epidemic counties. However, implementation of these measures was challenging due to the complex natural environment, harsh climatic conditions, inadequate infrastructure, poor agricultural and animal husbandry practices, lagging social and economic development, delayed prevention and disease control strategies, difficult living and working conditions, outdated medical and health facilities as well as equipment, lack of vehicles suitable for the complex road conditions, sparsely populated areas, large service radius, and lack of professional as well as technical personnel [8, 10–13]. Since the launch of the National Echinococcosis Prevention and Control Project in 2008, the county level is the relevant level for defining the epidemic risk and allocation of health resources [14]. However, variations in epidemic degrees among townships within the same county have been found to significantly differ, with different epidemic characteristics. Therefore, scaling down the epidemic region from the county level to the township level is required to appropriately allocate health resources and improve the efficiencies of prevention and control measures. The risk of echinococcosis transmission has been comprehensively assessed. However, data for AE and CE elucidate on disease dynamics and on its relative distributions depending on the pathogen. CE and AE exhibit different transmission cycles and epidemic characteristics, and require different prevention and control measures. Therefore, careful analysis of relative distributions of CE and AE is necessary for designing relevant control measures that are suitable to local conditions, classify guidance, and improve efficiency.

Elucidation of the prevalence of echinococcosis at the township level in TAR is very important for prevention and control. In this study, we investigated the prevalence of the two main species of medical interest (AE and CE) in all 692 townships in TAR. Our findings will inform the development of suitable prevention and control measures and help in rational allocation of health resources.

Methods

Data source

Demographic data for each of the 692 townships of 74 endemic counties of TAR were obtained from the population survey released by the National Bureau of Statistics in 2018. Clinically diagnosed and confirmed cases of human echinococcosis were obtained from the annual report system of echinococcosis of the Tibet Center for Disease Control and Prevention. Most of the patients were diagnosed by echinococcosis census completed by the local health departments in their villages. Since echinococcosis has a long incubation period, the TAR census of echinococcosis was performed among people aged two and over in 692 townships. This census was complete by the end of 2018. Human echinococcosis cases were diagnosed by B-ultrasonography following the official “Diagnostic criteria for echinococcosis” of China (WS 257–2006), which is in line with that of World Health Organization [15]. Based on this strategy, the diagnostic criteria for CE by ultrasonography includes: a) Unilocular anechoic lesions that are round or oval with clearly visible cyst walls (laminated layers) and snowflake-like inclusions or floating laminated membranes; b) Multivesicular or multiseptate cysts with wheel-like appearances; and c) Unilocular cysts with daughter cysts and honeycomb appearances. The diagnostic criteria for AE include: the presence of lesions that are characterized by heterogenous hypodense masses, often associated with necrotic cavities, irregular lesion contours and lack of well-defined walls [15]. Serological tests were performed for patients exhibiting space occupying lesions and live or work in epidemic areas or for those reporting contact histories with domestic or wild animals and their fur. These tests were performed by enzyme-linked immunosorbent assay (ELISA) (Zhuhai Hai Tai Biopharmaceutical Co., Ltd. Zuhui, China). Suspected cases were confirmed by positive serological tests [15]. After obtaining their informed consents, the identified patients were treated with albendazole and recommended for surgical treatment [15]. Data were analyzed at the township level.

Classification of prevalence

Based on official “Diagnostic criteria for echinococcosis” of China (WS 257–2006), echinococcosis cases were classified into CE, AE, and co-infections with CE and AE [15]. The prevalence of CE was determined by including the confirmed cases of CE as well as the co-infections of CE with AE in the calculations. Similarly, the prevalence of AE was obtained by including the confirmed cases of AE as well as co-infections of CE with AE in the calculation. Classification of the prevalence of human echinococcosis was based on classification standards for endemic counties as reported in the 2019 edition of technical guidelines for echinococcosis control in China [16]. Due to differences in transmission cycles, preventive strategies, control measures, clinical manifestations, as well as treatment regimens, the characteristics of CE and AE were independently described and analyzed. Each case was classified based on epidemic status, from the highest to the lowest, to provide a qualitative understanding of the epidemic status of echinococcosis in given townships. The 2019 edition of technical guidelines for echinococcosis control in China recommend that evaluation of echinococcosis control and elimination measures should be based at the township level [16]. Since the current epidemic areas of echinococcosis in China were only considered at the county level and no classification standards for township level are available, we classified the epidemic status of echinococcosis
in all townships in TAR following the relevant standards of population prevalence index in the national technical plan for echinococcosis control (2019 Edition). The classification criteria were: Class I epidemic townships: prevalence rate ≥ 1%; Class II epidemic townships: prevalence rate ≥ 0.1% and < 1%; Class III epidemic townships: prevalence rate ≥ 0 and < 0.1%; Class IV epidemic townships: townships with appropriate transmission circulation conditions and a prevalence rate equal to 0 [16]. Statistical analyses were performed using the SPSS 21.0 software package (IBM, Armonk, USA). The ArcGIS 10.1 program (ESRI, Redlands, USA) was used for geographic mapping and prevalence analysis.

Spatial scan clustering
SaTScan V9.5 (Management Information Services, Maryland, USA) was used for retrospective spatial scan analysis. The spatial clustering scanning analysis was based on echinococcosis cases and exposed population in the 692 townships by the end of 2018. The discrete Poisson probability model was applied using a circular window for high-rate clusters. Areas of high incidence were scanned using a moving circular window, dynamically varying in size. The maximum sizes of spatial and temporal windows were defined as 25% of the total population of the entire area. Likelihood ratio tests and Monte Carlo randomization tests were used to determine the significance of spatiotemporal clusters. Finally, the window with the maximum Log-likelihood ratio (LLR) value was defined as the primary cluster while other clusters with statistically significant LLRs were defined as secondary clusters and minor secondary clusters. The radius of minor secondary clusters was less than 50 km. Relative risk (RR) and P-value for each cluster were obtained by Monte Carlo randomization tests. W randomization data sets were generated by Monte Carlo randomization tests. The maximum LLR were calculated in the same way as the observed data and were sorted from large to small. If the maximum LLR of the real data set is ranked R, then P=R/(W+1). The higher the ranking, the smaller the P-value, indicating that the probability for random aggregation is smaller. Scan results were visualized using the Arcgis10.1 software (ESRI, Redlands, USA).

Results
Prevalence of human echinococcosis
From a total of 3,002,828 people, there were 16,009 (0.53%) echinococcosis-positive patients. In 2018, the total population of Tibet was 3,324,078 with the census rate of echinococcosis being 90.34% [17]. Among them, there were 14,398 (44.45%) CE cases, 942 (2.87%) AE cases and 137 (0.46%) co-infections of CE and AE. The proportions of male and female cases were 35.4% and 64.6%, respectively. The youngest in age was 2 years old, while the oldest was 93 years with a median age of 46 years. Due to a lack of detailed classification records and failure to classify them as cystic or alveolar echinococcosis, a total of 532 cases (3.32%) were unclassified (Table 1).

The prevalence of human echinococcosis at the township level ranged from 0 to 7.78% in TAR. The three highest townships with the highest prevalence rates were Axiu township in Baqeen County of Naqu Prefecture-level city with 216/2775 (7.78%) cases, Buta township in Deengqeen County with 130/3260 (3.99%) cases, and Meiyu township in Zogang county of Changdu Prefecture-level city with 201/5152 (3.90%) cases. All cases were distributed in 655 townships. However, there were no cases of echinococcosis in 37 townships (Fig. 1, Table 2).

The overall prevalence rate of CE was 0.48%, and all cases were distributed in 655 townships of 74 counties. The three townships with the highest prevalence of CE were Axiu township in Baqeen County of Naqu Prefecture-level city with 171/2775 (6.16%) cases, Meiyu township in Zogang County of Changdu Prefecture-level city with 201/5152 (3.90%) cases, and Baixiong township in Nierong County of Naqu Prefecture-level city with 144/4325 (3.33%) cases (Fig. 2, Table 3). The overall prevalence of AE was 0.04%, with the 1079 recorded cases being found to be distributed in 143 townships from 32 counties. The three townships with the highest prevalence for AE were Axiu township with 46/2775 (1.66%) cases, Baqeen township with 35/2300 (1.52%) cases, both of which are in Baqeen County of Naqu Prefecture-level city, and Buta township in Deengqeen County with 34/3260 (1.04%) cases (Fig. 3, Table 4).

Classification of the prevalence of human echinococcosis in China
The epidemic levels of 692 townships in TAR were: 127 (18.35%) were Class I epidemic townships; 446 (64.45%) were Class II epidemic townships; 82 (11.85%) were Class III epidemic townships; while 37 (5.35%) were Class IV epidemic townships (Fig. 1, Table 2). The classifications of CE and AE were further analyzed based on similar classification criteria. Among the 692 townships in TAR, 655 (95.55%) had CE cases with 116 (16.76%) of them being Class I epidemic townships, 445 (64.31%) being Class II epidemic townships, 94 (13.58%) being Class III epidemic townships and 37 (5.35%) being Class IV epidemic townships (Fig. 2, Table 3). With respect to AE, 143 (20.7%) out of 692 townships had AE cases with 3 (0.43%) of them being Class I epidemic townships, 53 (7.66%) being Class II epidemic townships, 87 (12.57%) being Class III epidemic townships.
### Table 1  Epidemic status of human echinococcosis in Tibet Autonomous Region, 2018

| Prefecture/Prefecture-level (municipal level) city | Number of endemic counties | Population of endemic areas | All cases Total cases | CE | AE | Co-infection of CE and AE cases | Unclassified cases | Prevalence rate (1/10,000) of CE | Prevalence rate of AE (1/10,000) | Prevalence rate of Co-infection of CE and AE cases (1/10,000) |
|--------------------------------------------------|----------------------------|-----------------------------|----------------------|----|----|-------------------------------|-------------------|---------------------------------|------------------------|---------------------------------|
| Lhasa                                            | 8                         | 477,334                     | 958                  | 932| 3  | 22                            |                   | 20.07                          | 19.55                  | 0.08                            |
| Changdu                                          | 11                        | 723,005                     | 2856                 | 2266| 12 | 54                            | 224                | 39.50                          | 32.09                  | 5.06                            |
| Shannan                                          | 12                        | 306,813                     | 1295                 | 1259| 1  | 7                             | 28                 | 42.21                          | 41.26                  | 0.26                            |
| Shigatse                                         | 18                        | 772,334                     | 3147                 | 3025| 10 | 12                            | 90                 | 40.75                          | 39.32                  | 0.28                            |
| Naqu                                             | 11                        | 478,172                     | 6019                 | 5273| 603| 44                            | 99                 | 125.88                         | 111.19                 | 13.53                           |
| Ali                                              | 7                         | 103,155                     | 1075                 | 986 | 3  | 17                            | 69                 | 104.21                         | 97.23                  | 1.94                            |
| Linzhi                                           | 7                         | 141,995                     | 659                  | 647 | 10 | 2                             | 0                  | 46.41                          | 45.71                  | 0.85                            |
| Total                                            | 74                        | 3,002,828                   | 16,009               | 14,398| 942| 137                           | 532                | 53.31                          | 48.40                  | 3.59                            |

*AE Alveolar echinococcosis, CE Cystic echinococcosis*
Spatial distribution and identification of clusters of human echinococcosis

The analysis of CE revealed one primary cluster and seven secondary clusters. The primary cluster was centered at 36°10' North and 89°39' East with a radius of 632.91 km, covering 88 townships in 12 counties. It was dominated by the Naqu Prefecture-level city, with 82 townships in all the 10 epidemic counties (Nagqum, Brum, Nyainrong, Amdo, Xainza, Sog, Bangoin, Baqeen, Nyima, and Shuanghu), followed by Damxung in Lhasa city and Geerzee in the Ali Prefecture. This cluster had 356,976 exposed persons, with a risk of infection 3.35 times higher than in other areas \((P < 0.01)\). It is the key area in TAR for the prevention and control of CE. The extent and risk status of secondary clusters are shown in Fig. 4 and Table 5. A relatively important secondary cluster area was centered at 30°11' North and 92°86' East with a radius of 103.61 km, covering 27 towns from 7...
counties, including Maizhokunggar in Lhasa city, Sangri and Gyaca of Shannan Prefecture-level city, Nagqu and Jiali in Naqu Prefecture-level city, as well as Nyingchi and Gongbo’gyamda in Linzhi Prefecture-level city. The RR value of this cluster was 1.77 ($P<0.01$). Another important secondary cluster area was centered at 28°75' North and 84°83' East with a radius of 151.51 km, covering 25 towns from 6 counties. The RR value of this cluster was 1.71 ($P<0.01$). The remaining secondary clusters were relatively small, involving only a few townships.

Spatial clustering scans of AE revealed the presence of one primary cluster and two secondary clusters (Fig. 5 and Tables 6 and 7). The primary cluster was centered at 32°49' North and 94°54' East, with Gongri township in Baqeen county being the center. The radius of this cluster was 157.23 km, covering 38 townships in 6 counties, including Deengqeen and Banbar in Changdu Prefecture-level city, as well as Biru, Nyainrong, Sog, and Baqeen in Naqu Prefecture-level city. The RR value of this cluster area was as high as 21.04 times that of the surrounding area ($P<0.01$).

One secondary cluster was centered at 31°56' North and 89°52' East, with Mendang Township in Bangoin County being at the center. This cluster had a radius...
of 158.35 km, covering 22 townships in 4 counties in the Naqu Prefecture-level city, including 10 townships in Bangoin County, 7 townships in Xainza County, 1 township in Suanghu County and 1 in Amdo County. The RR value of this cluster area was 8.02. The risk of AE transmission in this aggregation area was significantly higher than that of the surrounding area.

With Niangpu Township in Gongbo’ g Yamda county as the center, the other secondary cluster was centered at 30°34’ North and 93°04’ East. It had a radius of 93.93 km, covering 20 townships in 4 counties, including 8 townships in Gongbo’ g Yamda county, 10 townships in Jiali county, 1 township in MaizhoKunggar county and 1 in Banbar county. The RR value of this cluster area was 2.58 (P < 0.01).

**Discussion**

Both primary clusters for CE and AE, which had the largest number of Class I epidemic townships, covered the townships in Naqu prefecture-level city. These townships are located in the northern Tibet Plateau, whose average altitude is more than 4500 m and is a major pastoral area of Tibet. The Naqu Prefecture-level city of TAR has the highest prevalence of both AE and CE. As a pastoral area, there are many dogs, livestock, and wild animals. Particularly, the high prevalence of AE is associated with
the high abundance of stray dogs [18, 19]. These factors form the transmission cycles of CE and AE. Moreover, local residents have poor health habits and living conditions, including unclean domestic water due to poor natural environments and backward economic development. Local medical conditions are also limited. In most parts of TAR, like in the Naqu Prefecture-level city, local residents depend on pastoral work for living, with same traditional production and life styles, poor medical and health resources as well as shallow health awareness, which predisposes them to echinococcosis. Besides, knowledge on disease and appropriate prevention methods is generally low [2, 20].

Our findings show that compared to CE, the prevalence of AE in TAR is relatively low, and its distribution is relatively limited, in tandem with findings from other studies [2]. The transmission cycle of AE involves sylvatic cycles, with foxes and dogs as definitive hosts and small rodents as intermediate hosts. The distribution of small rodents is less than that of livestock. However, given the heavy disease burden on AE patients, the 56 AE epidemic class I and class II townships and the three AE cluster areas should be prioritized. In addition to strengthening the control of infection at source levels and health education measures, it is important to increase the surveillance of small rodents and lagomorphs (alternative intermediate hosts of \textit{E. multilocularis}), strictly control the number of stray dogs, and strengthen the screening of AE patients in these townships [24]. In China, the primary definitive host for both \textit{E. granulosus} and \textit{E. multilocularis} is dog [21, 22]. Therefore, monitoring the number of dogs and regular deworming of infected dogs is an important prevention and control approach [23]. In class I and II epidemic townships, each dog must be dewormed monthly, consistent with the required prevention and control measures. In addition, health education and people awareness should be intensified. In townships with insufficient health workers, rural cadres and volunteers should be actively recruited and trained to promote the implementation of this measure. In class III townships, the deworming frequency can be rationally reduced according to the actual situation. Deworming of dogs during the slaughtering season of intermediate hosts, such as yaks and sheep, as well as the strengthening of health education, awareness and slaughter management procedures must be implemented. Moreover, the intensification of health education and awareness for residents, as well as echinococcosis monitoring should be performed in class IV epidemic townships.

The relevant departments of epidemic counties in which these towns belong should pay more attention to the epidemic towns in the gathering areas, and strengthen the monitoring of echinococcosis and patient screening. If the epidemic areas involve the junction areas of multiple epidemic counties, the relevant epidemic counties should cooperate and implement the relevant prevention and control strategies. The spatial distribution of AE is more limited, with only three aggregation areas, however, the epidemic risk is relatively high, especially in the primary cluster area, suggesting that these aggregation areas require strengthening of prevention and control measures. The populations should be actively mobilized
Table 5  Spatial clustering analysis of human cystic echinococcosis in Tibet Autonomous Region, 2018

| Cluster          | Center point       | Scope | Number of towns | Radius(km) | Exposed population | Number of cases | RR  | LLR     | P-value |
|------------------|--------------------|-------|-----------------|------------|--------------------|-----------------|-----|---------|---------|
|                  | Latitude           | Longitude | Center town      | Number of towns |                   |                 |     |         |         |
| Primary cluster  | 36.099499 N        | 89.386002 E | Sewu town of Amdo county | 88          | 632.91             | 356,976         | 4494 | 1716  | 3.35    | 1,876.79 | < 0.01 |
| Secondary cluster1 | 30.110399 N   | 92.856300 E | Jinda town of Gongbo'gyamda county | 27          | 103.61             | 98,424          | 815  | 473    | 1.77    | 105.65   | < 0.01 |
| Secondary cluster2 | 28.750000 N  | 84.828003 E | Gongdang town of Gyirong county | 25          | 151.51             | 53,153          | 431  | 255    | 1.71    | 51.00    | < 0.01 |
| Minor secondary cluster1 | 28.343500 N | 89.611000 E | Samada town of Kangmar county | 9           | 48.71              | 18,832          | 219  | 91     | 2.44    | 65.61    | < 0.01 |
| Minor secondary cluster2 | 30.401300 N | 98.491096 E | Ltauo town of Konjo county | 7           | 37.23              | 22,215          | 233  | 107    | 2.20    | 56.17    | < 0.01 |
| Minor secondary cluster3 | 28.755199 N | 91.116699 E | Gongbuxue town of Nagarzee county | 3           | 30.80              | 16,538          | 371  | 79     | 4.76    | 283.07   | < 0.01 |
| Minor secondary cluster4 | 29.071199 N | 90.505997 E | Kalong town of Nagarzee county | 4           | 20.62              | 8,920           | 98   | 43     | 2.29    | 26.01    | < 0.01 |
| Minor secondary cluster5 | 28.648899 N | 97.541801 E | Zhiwagen town of Zayuu county | 2           | 47.02              | 6,316           | 73   | 30     | 2.41    | 21.48    | < 0.01 |
| Minor secondary cluster6 | 31.132999 N | 98.431099 E | Niangxi town of Jomda county | 2           | 21.23              | 10,820          | 104  | 58     | 1.80    | 14.96    | < 0.05 |

LLR: Log-likelihood ratio, RR: Relative risk
to participate in echinococcosis prevention and control strategies. Implementation of prevention and control approaches that are well adapted to the local reality and with high economic effects should be prioritized to significantly reduce disease burden and efficiently control echinococcosis epidemics. There were 532 unclassified cases in 93 townships, and in some townships it was true for all cases. This might seriously affect the management and prevention of echinococcosis; therefore, this issue should be addressed as a priority. B-mode ultrasound technicians should be trained at the township level. Quality control and supervision of the integrity of patient records and materials should also be improved. Based on our findings, when allocating health resources, the relevant administrative departments should focus on townships with a high prevalence and primary cluster areas.

This study is associated with some limitations. First, as a chronic infectious parasitic disease, echinococcosis is characterized by occult onsets and long incubation periods. Therefore, although the spatial distribution of prevalence can reflect the disease burden and historical risk of echinococcosis in different areas, it cannot sensitively reflect the current infection risks. Second, populations were screened for hydatid lesions using portable B-mode ultrasonography, therefore, only abdominal lesions of CE and AE could be detected, whereas lesions in the lungs, brain, and other organs outside the abdomen could not be detected. Furthermore, most patients were identified by screening or clinical examination, but a part of the infected population was not identified. Some patients were leaked during detections, thus, the prevalence determined in the survey may be underestimated. Finally, for the 532 (3.3%) confirmed patients, there were no clear classifications (CE or AE) and neither were there clear B-mode ultrasound images, which may lead to failures in identification and treatment. This may affect the analysis, follow-up and treatment of patients.

Conclusions
This study shows spatial distributions of echinococcosis with different epidemic degrees in 692 townships of TAR and high-risk cluster areas at the township level. There have been advances in the prevention and control of echinococcosis in TAR. Our findings provide a scientific reference for the relevant administrative departments in TAR to appropriately adjust the prevention and control strategies according to the different epidemic characteristics and epidemic degrees. Therefore, we suggest the formulation of different prevention and control strategies to efficiently prevent and control echinococcosis in TAR.
Table 6  Spatial clustering analysis of human alveolar echinococcosis in Tibet Autonomous Region, 2018

| Cluster               | Center point | Scope center town                      | Radius(km) | Exposed population | Number of cases | Number of expected cases | RR    | LLR   | P-value |
|-----------------------|--------------|----------------------------------------|------------|--------------------|----------------|-------------------------|-------|-------|---------|
| Primary cluster       | 32.494598 N  | Gongri town of Baget county            | 38         | 157.23             | 194,212        | 557                     | 61    | 21.04 | < 0.01  |
| Secondary cluster 1   | 31.559900 N  | Mendang town of Bangoin county          | 22         | 158.35             | 70,604         | 152                     | 22    | 8.02  | < 0.01  |
| Secondary cluster 2   | 30.342400 N  | Nangpu town of Gongbo'gyamda county     | 20         | 93.93              | 69,309         | 54                      | 22    | 2.58  | < 0.01  |

LLR Log-likelihood ratio, RR Relative risk
Abbreviations
AE: Alveolar echinococcosis; CE: Cystic echinococcosis; TAR: Tibet Autonomous Region; LLR: Log-likelihood ratio; RR: Relative risk.

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Authors’ contributions
LW designed the study, contributed to data collection, screening, verification, analysis, charting and writing. GQ and HP were involved in data collection, MQ and ZL were involved in data analysis and charting. RF and LG participated in spatial analysis, review and supervised the study. RF and LG revised the manuscript. All authors read and approved the final manuscript.

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Table 7 The correspondence table between the names of 74 counties involved in this paper and the names of Chinese Pinyin

| Prefecture/Prefecture-level city (municipal level) | County name involved in the article | County name in Chinese pinyin | Prefecture/Prefecture-level city (municipal level) | County name involved in the article | County name in Chinese pinyin |
|---------------------------------------------------|-----------------------------------|-------------------------------|---------------------------------------------------|-----------------------------------|-------------------------------|
| Lhasa                                             | Chenquian                         | Chengguan                    | Ngamring                                          | Angren                            |
| Lhunzhu                                           | Linzhi                            |                              | Xaitongmoin                                       | Xietongmen                        |
| Damxung                                           | Dangqiong                         |                              | Bainang                                           | Bailang                           |
| Nyeemo                                            | Nimu                              |                              | Rinbung                                           | Renbu                             |
| Quoxiu                                            | Qushui                            |                              | Kangmar                                           | Kangma                            |
| Doilungdeeqeen                                     | Duilong Deqing                    | Dinggyee                     | Zhongba                                           | Zhongba                           |
| Dagee                                             | Dazi                              |                               |                                                    |                                   |
| Maizhokunggar                                      | Mozhu Gongka                      | Yadong(CHomo)                | Yadong                                            |                                   |
| Changdu                                            | Karuo                             | Gyorong                      | Jilong                                            |                                   |
| Jomda                                             | Jiangda                           | Nyalamu                      | Nielamu                                           |                                   |
| Konjio                                            | Gongshe                           | Saga                         | Saga                                              |                                   |
| Rivoqee                                           | Leiwuqi                           | Gamba                        | Bangba                                            |                                   |
| Deengqeen                                         | Dingqin                           | 1.3 Naqu                     | Naqu County                                       |                                   |
| Chagyab                                           | Chaya                             | Jiali (Lhari)                | Jiali                                             |                                   |
| Baxoi                                             | Basu                              | Biru                         | Biru                                              |                                   |
| Zogang                                            | Zogong                            | Nyainrong                    | Nierong                                           |                                   |
| Mangkam                                           | Mangkang                           | Amdo                         | Anduo                                             |                                   |
| Lhorong                                           | Luolong                           | Xizha                        | Shenza                                            |                                   |
| Banbar                                            | Bianba                           |                                 | Sog                                              | Suoxian                           |
| Shannan                                            | Needong                           | Bangoin                      | Bange                                             |                                   |
| Canang                                             | Zanang                            | Baqueen                      | Baqing                                            |                                   |
| Gonggar                                            | Gongga                            | Nyima                        | Nima                                              |                                   |
| Sangri                                            | Sangri                            | Shuanghu                     | Shuanghu                                          |                                   |
| Qonggai                                           | Qiongjie                          | Burang                       | Pulan                                             |                                   |
| Quosum                                            | Quosong                           | Zanda                        | Zhada                                             |                                   |
| Comai                                             | Cuomei                            | Gar                          | Gaer                                              |                                   |
| Lhoshag                                           | Luozha                           |                                 | Ruto                                              |                                   |
| Gyaca                                             | Jiacha                            | Gee'gyai                     | Geji                                              |                                   |
| Lhunzuee                                          | Longji                            | Geerze                       | Gaize                                             |                                   |
| Cona                                              | Cuona                             | Coqueen                      | Cuoqin                                            |                                   |
| Nagarzees                                          | Langkazi                          |                                 | Nyingchi                                          | Linzhi County                     |
| Shigatse                                           | Xigazee                           | Songphuizi                   | Gongbo'gyamdha                                    | Gongbu Jiangda                    |
| Namling                                            | Nammulin                          | Mainling                     | Milin                                             |                                   |
| Gyangzee                                          | Jiangzi                           | Metog                        | Motuo                                             |                                   |
| Tingri                                            | Dingri                            | Bom(Bowo)                    | Bom                                               |                                   |
| Ságya                                             | Saja                              | Zayuu                        | Chayu                                             |                                   |
| Lhazee                                            | Lazi                              | Nang                         | Langxian                                          |                                   |
Data Availability
All data analyzed in the present study are included in the article material. Any inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate
This survey was approved by the Ethical Review Committee of the National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention (No. 20160810). The performed activities were all within the scope of the national project for echinococcosis control. All participants were informed of the content and purpose of the investigation and examination, potential complications, consequences as well as benefits before examination. Those who agreed to participate were required to sign written informed consent forms. All participants were given feedback. All echinococcosis diagnosed patients provided written agreements to participate and were provided with free drug treatment or subsidized surgical costs.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests to declare.

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