Analysis of the societal drivers of human echinococcosis in China

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Research Article

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Abstract

Background: Echinococcosis is a parasitic zoonotic disease that threatens human health and economic development. In China, 370 counties are endemic for echinococcosis. Qinghai-Tibet Plateau displays the highest number of patients and people at risk. Therefore, analyzing the societal factors of susceptibility to the disease is critical for efficient prevention and control of echinococcosis.

Methods: The demographic characteristics and lifestyle of echinococcosis cases were clustered using K-means cluster analysis to determine the main factors of risk to echinococcosis.

Results: Middle-aged and young people as well as those with a low education level and herdsmen are at risk of contracting echinococcosis. Nomadism, domestic and feral dogs in the surrounding environment, but also drinking heavily polluted natural surface water are the main behavioral risk factors. The cystic echinococcosis (CE) and alveolar echinococcosis (AE) cluster analysis focused on females, middle-aged and young people, winter settlement and summer nomadism, and domestic and feral dogs in the surrounding environment. There were significant differences in lifestyle between Qinghai-Tibet Plateau cases and non-Qinghai Tibet-Plateau cases.

Conclusion: According to the distribution of cases and CE and AE, this study identified the factors of risk to echinococcosis in the Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau. Adapted control techniques appropriate for the various epidemic areas should be established to serve as a reference for echinococcosis prevention.

1. Introduction

Echinococcosis is a zoonotic parasitic disease caused by the larval stages of cestodes of *Echinococcus* found in humans or animals. China is one of the countries with the most serious epidemic of echinococcosis worldwide. There are two types of echinococcosis epidemics: cystic echinococcosis (CE) caused by the larvae of *Echinococcus granulosus* and alveolar echinococcosis (AE) caused by the larvae of *Echinococcus multilocularis* [1]. Echinococcosis is primarily found in pastoral or semi-agricultural-semi-pastoral areas in Western China, affecting 370 counties in provinces or autonomous regions such as Inner Mongolia, Yunnan, Tibet, Sichuan, Gansu, Qinghai, Ningxia, Xinjiang and Shaanxi [2]. China echinococcosis endemic areas are separated into Qinghai-Tibet Plateau endemic areas and non-Qinghai-Tibet Plateau endemic areas based on geography and landform. There are 148 endemic counties on the Qinghai Tibet-Plateau, including all 74 counties in Tibet, 30 counties in Qinghai Province, 32 counties in Sichuan Province, 9 counties in Gansu Province and 3 counties in Yunnan Province, while there are 222 endemic counties on the non-Qinghai-Tibet Plateau. The Qinghai-Tibet Plateau is the “hot spot” in terms of prevalence of human echinococcosis in China [2]. The epidemiological assessment of echinococcosis conducted from 2012 to 2016 reported the average detection rate of echinococcosis in the population of 1.28% in the Qinghai-Tibet Plateau and the non-Qinghai-Tibet Plateau with an average detection rate of 0.13% [3]. The detection rate in the Qinghai-Tibet Plateau is almost 10 times that in the non-Qinghai-Tibet

Plateau because of animal husbandry and specific economy, culture, and production lifestyles [4]. Echinococcosis not only endangers people's health and life but also stifles the healthy growth of agriculture and animal husbandry economies [5]. It is also one of the primary reasons why people in these epidemic areas "become poor and return to poverty" [6].

CE mostly damages and impairs the target organs of the liver, lungs, brain, spleen, kidneys, and heart *et al* [7]. CE's liver cysts grow slowly, and population screening showed that more than half of the liver cysts did not change in size for ten years. In addition, the early stages of CE and AE do not cause symptoms, and the lesions of CE and AE could remain asymptomatic for 10–15 years [8–9]. AE, often known as "worm cancer," is more dangerous than CE with a faster growth and a death rate of up to 90% within 10 years if untreated or improperly treated [10–11]. The cyst grows and ruptures as the disease advances, resulting in lethal anaphylactic shock. CE in China accounts for 40% of the disease burden worldwide, with as much as 398,000 disability-adjusted life years (DALYs) [12]. AE in China accounts for 90% of total cases and 91% of new cases worldwide [13].

In susceptible populations, echinococcosis can create major medical, social, and economic difficulties. The identification of susceptible populations is thus critical for prevention and control. Similarly, properly targeting health education to the most susceptible population will also help reducing or eliminating risk factors and improving the efficiency of echinococcosis prevention and control. It will also help optimizing the allocation of public health resources. Most communities in the Qinghai-Tibet Plateau are Tibetans, and their lifestyles and customs differ from those of non-Qinghai-Tibet Plateau communities. Correlations were found between gender, age, education, occupation, or other societal traits and echinococcosis. However, most studies focused on only one population feature, and the other population characteristics were insufficiently detailed. One study used clustering analysis to identify vulnerable populations but only according to human demographics in Tibet Autonomous Region [14]. Thus, this work was undertaken as a comparative analysis of echinococcosis cases from Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau integrating together gender, age, education, occupation and societal aspects.

2. Material And Methods

2.1 Source of data.

Demographic information (gender, age, education, occupation, etc.) of echinococcosis patients, but also societal information (lifestyle, drinking water source, promiscuity with domestic dogs, presence of feral dogs and slaughter methods) were collected from 2012 to 2016 in 370 endemic counties by cross-sectional cluster sampling. Cases are standardized by gender, age, education, occupation, and other factors based on diagnosed cases (Table 1). Drinking water sources was classified according to the degree of cleanliness as level 1 (tap water and well water), level 2 (river water and spring water), and level 3 (water accumulation, ditch water, ponding). Human echinococcosis cases were identified using China's approved "Diagnostic criteria for echinococcosis" (WS 257–2006), a standard in line with that of WHO [15].

2.2 Statistical analyses.

Analyses were conducted using the SPSS 21.0 software package (IBM, Armonk, USA). A chi-square test was used to compare the lifestyle composition of cases from Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau. Clustering analysis was used to group data objects as previously described [16]. The k-means algorithm was used to separate n objects into k clusters, each having a high similarity of data objects, whereas data objects inside the other clusters are less similar [17].

The procedure was the following [18]:

(1) Any k point was chosen as the initial cluster center.

(2) The distance between the remaining points and the cluster center was calculated based on the minimum distance, as follows:

$$dis(x_i, x_j) = \sqrt{\sum_{d=1}^{D} (x_{i,d}, x_{j,d})^2}$$

(3) A new cluster center was calculated for each cluster.

(4) Steps (2) and (3) were repeated until no new cluster centers could be created.

R 4.0.0 is used (R Development Core Team; R Foundation for Statistical Computing; Vienna, Austria) was used for k-means clustering.

Table 1
Variable Standard standards.

Variables	Attributes
Gender	M (male), F (female)
Age	1 (> 21 years old), 2 (21–65), 3 (< 65 years old).
Education	Pre (preschool), I (illiteracy), P (primary), J (junior), S (senior), C (college and above)
Occupation	H (herdsman), HFa (semi-farmer and semi-herdsman), F (farmer), S (student), Pub (official), W (housework), M (religious), O (other)
Mode of residence	1 (settled), 2 (nomadism), 3 (winter settlement and summer nomadism), 4 (other)
Water quality	1 (drinking water cleanliness level 1), 2 (drinking water cleanliness level 2), 3 (drinking water cleanliness level 3).
Dogs in the surrounding environment	Yes, No
Neighbors owns dogs	Yes, No

3. Results

3.1 General situation.

There were 4323 cases, including 1811 males and 2512 females with a sex ratio of 1: 1.39, accounting for 41.9% and 58.1% of cases, respectively. The youngest case was two-year old and the oldest was 95 with a median age of 42. The Qinghai-Tibet Plateau was the host of 3286 cases while 1037 cases were found in the non-Qinghai-Tibet Plateau area (Table 2). CE represented 3237 cases and AE was responsible for 1110 cases (Table 2). There were 65 cases of co-infections with CE and AE. In analysis CE cases comprised confirmed CE cases and co-infections with CE and AE. Similarly, AE cases included confirmed AE cases and co-infections with CE and AE.

3.2 Identification of common risk factors for both CE and AE.

The cluster analysis was performed on Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau cases, respectively. Each ring was built from the inside out based on proportion, gender, age, education, occupation (Fig. 1).

3.2.1 Cluster Analysis of populations at risk in the Qinghai-Tibet Plateau.

The range of k-clusters was defined as 2–7 [19–20]. After determining the best k value, the instances from Qinghai-Tibet Plateau were grouped using k = 4 as the optimal cluster number (Fig. 1a) The first cluster comprised 1672 cases, essentially composed female individuals of age class 2, i.e. 21–65 years old, and illiterate herders (Fig. 1a). The second cluster comprised 730 cases, the majority being female individuals under the age of 21 and with only primary school education (Fig. 1a). The third cluster was made of 675 individuals who were primarily females of the age class 2 (21–65 years old), having a primary school education and working with herders. The last cluster comprised 209 individuals, the majority being males of the age class 2 (21–65 years old) in low educational level (primary school) with religious profession.

3.2.2 Cluster analysis of populations at risk in the non-Qinghai-Tibet Plateau

Four clusters were also found in the non-Qinghai-Tibet Plateau (Fig. 1b). The first one was made of 353 cases, mostly women and farmers of age class 2 (21–65 years) with primary school education. The second cluster grouped 296 individuals, mostly male farmers of age class 2 with elementary and junior middle school education. The 286 individuals making the third cluster were mostly elderly females of class age 3 (over 65 years old), uneducated and farmers. The last cluster made of 102 cases comprised mostly male individuals of age class 2 (21–65 years old), educated in junior high and senior high school, and having diverse occupational activities.

3.3. Clustering according to lifestyle

3.3.1 Cluster analysis of CE cases

Four clusters were found (Fig. 2a). The first one comprised 1062 individuals mostly females of age class 2 (21–65), living in a winter settlement and summer nomadism mode, with dogs in the vicinity and feral dogs in surrounding areas. The second cluster grouped 506 cases, also mostly females of age class 2 (21–65), living in a permanent residence, without dogs in the vicinity but with feral dogs in surrounding areas. The third cluster gathered 982 individuals and corresponded to females of the age class 2, living in permanent settlements with dogs in the vicinity and feral dogs in the surrounding environment. The last cluster comprised 663 individuals, mostly females again but from the age class 3 (65 years old), also living in permanent settlements, with both domestic dogs in the vicinity and feral dogs in the surrounding environment.

3.3.2 Cluster analysis AE cases

Only three clusters were identified in the case of AE (Fig. 2b). The first cluster comprised 290 cases, mostly females of age class 1 (20 and under), living in permanent settlements with dogs in the vicinity and feral dogs in the surrounding environment. The second cluster grouped 608 individuals, also mostly females but of the age class 2 (21–65 years old) with a lifestyle of winter permanent residence and summer nomadism and with domestic dogs in the vicinity and feral dogs in the surrounding environment. The last cluster was made predominantly of males of age class 2 (21–65 years) in permanent settlements and with domestic dogs in the vicinity and feral dogs in the surrounding area.

3.4 Lifestyle and human echinococcosis

The lifestyle patterns of human echinococcosis cases of Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau were analyzed using the following parameters: living patterns (permanent or nomadic), drinking water sources, neighborhood domestic dogs situation, and presence of feral dogs in the environment.

3.4.1 Lifestyle clustering analysis of Qinghai-Tibet Plateau cases

Using k = 3 as the best clustering number to cluster CE cases in Qinghai Tibet Plateau (Fig. 3). There are 1152 cases in the first category, concentrated in groups whose living mode is winter residence and summer nomadism, drinking water cleanliness is level 2, and neighbors have dogs and feral dogs in the surrounding area. The settlement living mode, level 2 and 3 drinking water cleanliness, and domestic and feral dogs in the surrounding environment are factors in the 997 cases in the second category. There are 84 cases in the third category, mainly concentrated in groups where the living style is the settlement, drinking level 1 cleanliness, and neighbors have no domestic dogs and the surrounding environment has no feral dogs. For AE, there are 458 cases in the first category, concentrated in groups whose living mode is winter residence and summer nomadism, drinking water cleanliness is level 2, and neighbors have dogs and feral dogs are present in the surrounding area. The nomadism living mode, level 2 and 3 drinking water cleanliness, and domestic and feral dogs are present in the surrounding environment are factors in the 376 cases in the second category. There are 224 cases in the third category, concentrated in groups where the living style is: settlement, level 1-drinking water cleanliness, and neighbors have dogs and feral dogs in the surrounding environment.

3.4.2 Lifestyle clustering analysis of non-Qinghai-Tibet Plateau cases

The findings of clustering cases for CE in non-Qinghai-Tibet Plateau with k = 4 as the optimal clustering number is displayed in Fig. 4. In the first group, there are 510 cases, concentrated in the population with the settlement, level 1 cleanliness of drinking water, neighbors with dogs, and no feral dogs in the surrounding environment. In the second category, there are 406 cases, which are concentrated in groups with a settled living mode, level 1 cleanliness of drinking water, neighbors with dogs, and feral dogs in the surrounding environment. There are 88 cases of the third group, which is concentrated in groups with a settled living mode, level 3 cleanliness of drinking water, neighbors with dogs, and no feral dogs in the surrounding environment. For AE, in the first group there are 20 cases, concentrated in the population with the settlement, level 2 cleanliness of drinking water, neighbors with dogs, and feral dogs in the surrounding environment. In the second category, there are 13 cases, which are concentrated in groups with a settled living mode, level 3 cleanliness of drinking water, neighbors with dogs, and feral dogs in the surrounding environment. There are 13 cases of the third group, which is concentrated in groups with a settled living mode, level 1 cleanliness of drinking water, neighbors with dogs, and no feral dogs in the surrounding environment. Seven cases in the fourth category were primarily concentrated in the population whose lifestyle consisted of winter residence and summer nomadism. The purity of drinking water was secondary water, neighbors owned dogs, and there were feral dogs in the surrounding environment.

3.4.3. Comparison of behavior patterns in Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau cases

Summer nomadism and winter permanent settlements is more frequent in the Qinghai-Tibet plateau cases than in non-Qinghai-Tibet Plateau ones. The proportion of cleanliness levels 2 and 3 of drinking water source selection is higher in Qinghai-Tibet plateau cases than in the non-Qinghai-Tibet Plateau ones and for the latter, the proportion of cleanliness level 1 is higher. As indicated in Table 3, the presence of domestic dogs in the neighborhood and that of feral dogs in the surrounding environment is higher on the Qinghai Tibet Plateau than on the non-Qinghai-Tibet Plateau. In Qinghai-Tibet Plateau, the families of the1202 cases (36.6%) did not choose to slaughter livestock. A total of the families of 1101 (33.5%) of cases choosed to slaughter livestock at home. Only the families of 146 cases (4.4%) choosed to resort to slaughter in centralized facilities, while the families of 837 (25.5%) cases used sporadic random livestock slaughter. A total of the families of 276 non-Qinghai-Tibet Plateau cases(26.6%) had no experience of slaughtering livestock. As stated in Table 3, the families of 551 cases (53.1%) choosed to slaughter livestock at home, and the families of 133 (12.8%) cases are involved in intensive slaughter.

Table 2
Echinococcosis cases in non-Qinghai-Tibet Plateau.

	CE	AE	Co infection of CE and AE cases	Total
Qinghai-Tibet Plateau	2233	1058	41	3286
Non-Qinghai-Tibet Plateau	1004	53	24	1037
Total	3237	1110	65	4323

Table 3
Comparison of the lifestyle of cases in Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau cases.

	Cases in Qinghai-Tibet Plateau	**Non-Qinghai-Tibet Plateau cases**	2	***P***
Mode of living				
Settle	1478(45.0%)	981(94.6%)	797.72	P < 0.05
Nomadism	1328(40.4%)	34(3.3%)		
Winter settlement and summer residence	480(14.6%)	21(2.0%)		
Other	0(0.0%)	1(0.1%)		
Sources of drinking water				
Level 1 cleanliness	1123(34.2%)	783(75.5%)	565.55	P < 0.05
Level 2 cleanliness	1726(52.5%)	160(15.4%)		
Level 3 cleanliness	437(13.3%)	94(9.4%)		
The neighbor has a dog				
Yes	3189(97.0%)	922(88.9%)	111.93	P < 0.05
No	97(3.0%)	115(11.1%)		
Around the feral dogs				
Yes	2943(89.6%)	455(43.9%)	978.18	P < 0.05
No	343(21.4%)	582(56.1%)		
Slaughter mode				
Concentrated slaughter	146(4.4%)	133(12.8%)	309.60	P < 0.05
Family slaughter	1101(33.5%)	551(53.1%)		
Sporadic slaughter	837(25.5%)	77(7.4%)		
Not slaughtered	1202(36.6%)	276(26.6%)		

4. Discussion

The specific characteristic of the epidemic of echinococcosis in China is that dogs are the common infectious source for both CE and AE. CE and AE display common risk factors with 115 counties endemic for both diseases. The natural and geographical environment, climate, and customs of the Qinghai-Tibet Plateau is different from that of the non-Qinghai-Tibet Plateau and the transmission cycles of *E.*

granulosus and *E. multilocularis* are also different. Population characteristics and risk factors in the Qinghai-Tibet Plateau and in the non-Qinghai-Tibet Plateau regions are thus also different. Some risk factors are similar in both regions such as middle-aged populations, low-education, occupations as herdsman or farmers [14]. Within the Qinghai-Tibet Plateau some groups at risk of CE and AE are similar: middle-aged, low-educated women who spend most of their time at home [21]. They frequently feed dogs and livestock, collect cow dung for fuel, shear wool, and perform other household duties. Therefore, they are extremely susceptible to *E. granulosus* and *E. multilocularis* [21]. Age and low education level are risk factors for echinococcosis based on community studies conducted in Argentina [22]. According to an epidemiological survey conducted in Chile, poor socioeconomic status and lack of education have also been linked to CE in humans [23].

In both the Qinghai-Tibet Plateau and the non-Qinghai Plateau, the susceptibility factors of echinococcosis are centered on children. However, in the former, the most affected group is made of children at school (15%), whereas in the latter the majority of affected children are not at school, only a minority being pupils (6.94%). Because of pastoral lifestyle and conditions, children are expected to help with household duties from a young age. The process involves contact with cattle and the possibility of coming into direct or indirect contact with dogs, which is exacerbated by inadequate local sanitation and a lack of hygiene awareness among children. There is thus a considerable chance of contracting echinococcosis. Unlike schistosomiasis, malaria, and other parasitic infections, echinococcosis has a slow onset and a hidden course. Most patients have been infected as children and youngsters and are very vulnerable since the symptoms are unclear and difficult to detect and treat [24].

As a result, improving surveillance, prevention, and control of echinococcosis infection in children is critical. It is crucial to expand health education and raise public awareness of echinococcosis prevention and control in the long run. Religious practices, in particular when associated with poor education, might be an aggravating factor in the Qinghai-Tibet Plateau. People in this region are Buddhists and thus they praise and highly respect all life forms. Lamas in temples will often take in or feed abandoned stray dogs leading to a higher concentration of such dogs, who represent a major risk of infection near temples [20–21].

The source of drinking water is also a major risk factor [25]. *E. granulosus* eggs can only be inactivated after being stored at -80°C for at least seven days and they can survive for more than 200 days at 7°C and 50 days at 21°C [26]. *E. multilocularis* eggs can also survive in water at 4°C for 16 months [27]. Parasitic eggs are very resistant in the environment and can even withstand common disinfectants. Boiling is the most effective method of inactivating *Echinococcus* eggs [21]. Therefore, drinking water is the most common way to become infected with echinococcosis [28]. Springs, rivers, ponds and ditches, but also wells and even tap water can be polluted by *Echinococcus* eggs from dog feces. The traditional Tibetan lifestyle of many people in the Qinghai-Tibet Plateau is to be settled in the winter in permanent residences and to follow a nomadic life during summer. During this nomadic period, people and dogs share the same water supply, which is not boiled, tap or well water but surface water such as springs and rivers often of poor quality. *Echinococcus* eggs in dog feces are likely to pollute surface water. Indeed, nomadic herders often prefer pastures with natural water sources to set up tents, and livestock and dog excrements are randomly discharged in the surrounding environment, polluting the surrounding water sources [29]. Drinking or using contaminated surface water increases the risk of infection. Furthermore, herdsmen, traditionally collect cow dungs as fuel, which will be brought into tents for usage [30]. These customs also increase the risk of infection with echinococcosis. Of course, drinking clean water minimizes the risk of infection, and thus tap water is an echinococcosis protective factor [21, 31–32]. However, it is not compatible with the traditional semi-nomadic way of life.

Although most patients in the non-Qinghai-Tibet Plateau tend to drink water with a higher level of cleanliness, economic development in some places is lagging. Therefore, water storage is still a traditional lifestyle and thus water purity cannot be ensured. However, building water pipelines in CE and AE endemic areas is challenging because of geographical and climatic factors, particularly the Qinghai-Tibet Plateau. Depending on local economic and environmental conditions, appropriate actions should be taken to disinfect and treat local household water, strengthen water source management, install disinfection or filtration units in order to enable local populations to access safe domestic water, and limit the danger of *Echinococcus* egg exposure.

In the case of the Qinghai-Tibet Plateau, the vast number of both domestic and feral dogs around strongly increases the risk of contamination, in particular for children. Their health awareness is low, and they lack prevention expertise. As aggravating factors, geographical characteristics in endemic areas, adverse climatic conditions and economic factors make access to clean drinking water more problematic and thus, increase again the likelihood of infection in children. Most studies revealed the presence of both feral dogs and domestic dogs, particularly on the Qinghai-Tibet Plateau. However, feral dogs are less common in non-Tibetan societies, probably because of a different cultural background [33]. Canines are the ultimate hosts of *Echinococcocus*, and their feces contain eggs and contaminate the environment, water sources and animal hair [34]. A survey on domestic dogs in an epidemic area showed the presence of positive *Echinococcus* antigens 4.25% of dog feces [5]. Feral dogs are also prevalent in CE and AE endemic areas [35–36]. Dog management and control are critical measures in preventing and controlling echinococcosis as the zoonotic risk of CE and AE increases with the number of dogs and time dogs are maintained [21]. The Tibetan semi-nomadic way of life is unique and should be maintained. However, it should come along with efficient control measures on animal husbandry and dogs, otherwise echinococcosis will remain a severe human concern [30]. However, these control measures are difficult to implement.

The main source of income in the agricultural and pastoral areas is livestock raising, which uses dogs to look after and protect herds. Cattle and sheep are also intermediate hosts of *E. granulosus*. During domestic and sporadic slaughter, the internal organs of livestock will generally be fed to dogs along with the parasites they may contain [36]. In-house slaughter represents a risk of echinococcosis 4.67 times higher [38]. Centralized slaughter can successfully cut off this transmission pathway, reducing the risk of dog illness and thus safeguarding the health of residents. The first strategy for preventing and controlling echinococcosis is to decrease or destroy *Echinococcus* eggs, and the second is to reduce the probability of interaction with *Echinococcus* eggs [37]. Human proximity to definitive hosts (dogs) and animal intermediate hosts (livestock or small mammals) will increases the potential risk of echinococcosis (CE and AE) [30].

Non-Qinghai-Tibet Plateau is mainly dominated by CE prevalence. The lifestyle of local residents is different from that of residents on the Qinghai Tibet Plateau, being mainly settled. So they can get clean, tap drinking water. In this case, the main risk factor for CE is the presence of domestic and feral dogs feral. Because the geographical and natural environment is different from the Qinghai Tibet Plateau, the main risk factors of AE are dogs in the surrounding environment and drinking water with low cleanliness.

Canine deworming and health education, particularly for vulnerable communities, are essential to enhance their understanding of mechanisms of infection and change inadequate hygiene practices. However, this study does have some drawbacks. The collection of influencing factors is limited, such as for CE, the infection rate of livestock, and for AE, the infection rate of small rodents.

5. Conclusion

In this study, the k-means clustering analysis revealed that the populations susceptible to echinococcosis were mostly comprising middle-aged, poorly-educated semi-nomadic herdsmen. However, on Qinghai-Tibet Plateau a specific group of patients was present who were young pupils. This is a serious signal that a special attention must be paid to this group of people. We should increase their health education, raise their awareness of avoiding and controlling echinococcosis. Adapting some traditions and lifestyles might be important to reduce the risk of infection. Simultaneously, in light of risk factors such as feral dogs, dog breeding, polluted drinking water, and domestic animal slaughter practices, we should increase management measures, improve relevant health regulations, improve sanitation conditions and provide adequate technology for water purification, centralized slaughter, monitoring and deworming.

Abbreviations

AE: Alveolar echinococcosis; CE: Cystic echinococcosis; DALYs: Disability-adjusted life years

Declarations

Data Availability Statement

The original contributions presented in the study are included in the article material, further inquiries can be directed to the corresponding author.

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Authors' contributions

LYW and RF conceived and designed the study. LYW and WPW collected the data. MQ and XXC analysed the data. LYW and MQ wrote the manuscript. LYW, RF and LG reviewed and edited the manuscript. All the authors read and approved the fnal manuscript.

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Consent for publication

Not applicable.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics Statement

This survey was approved by the Ethics Review Committee of the National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention. All participants were informed about the content and purpose of the investigation before data collection. The consenters were required to sign the "informed consent form", and the minor children obtained the informed consent of their guardians.

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Figures

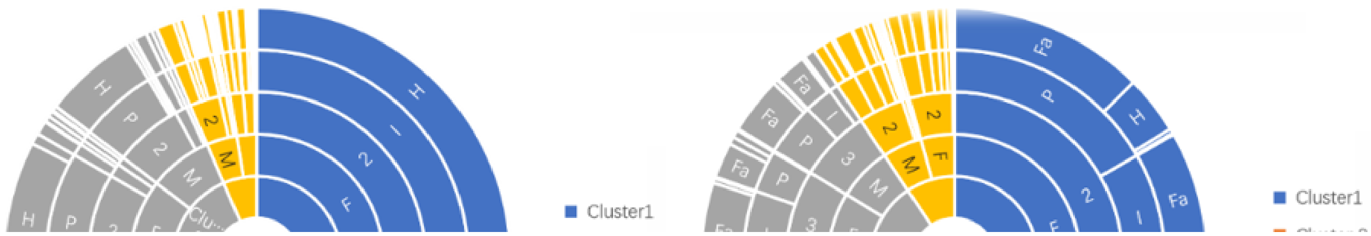

Figure 1

Cluster results of vulnerable populations in the Qinghai-Tibet Plateau and non-Qinghai-Tibet Plateau.

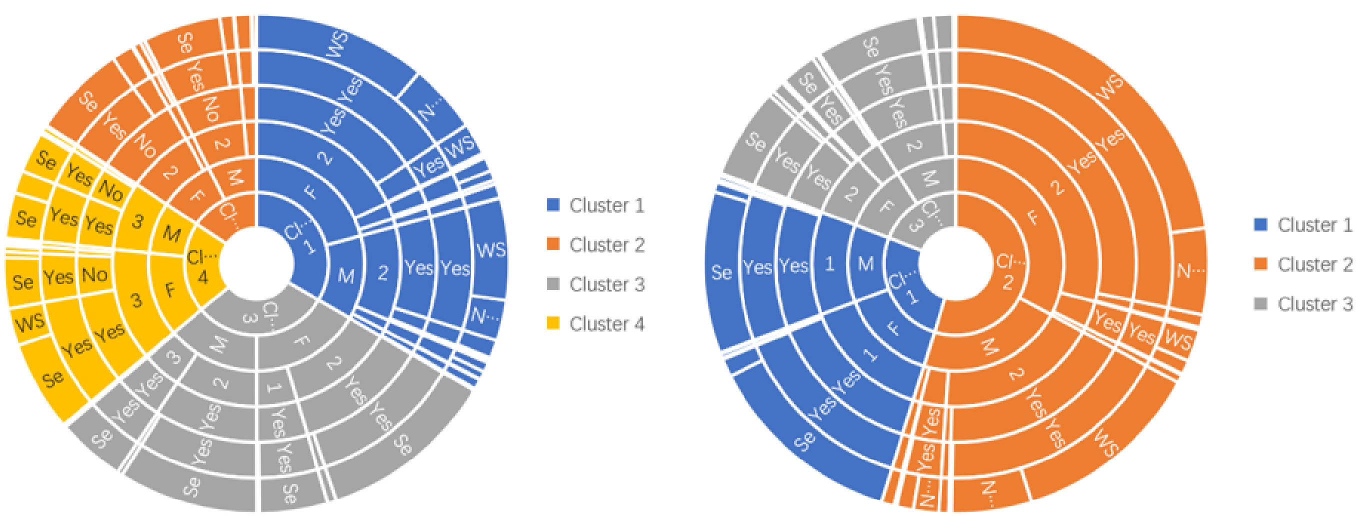

Figure 2

Clustering results for susceptible populations in CE and AE cases.

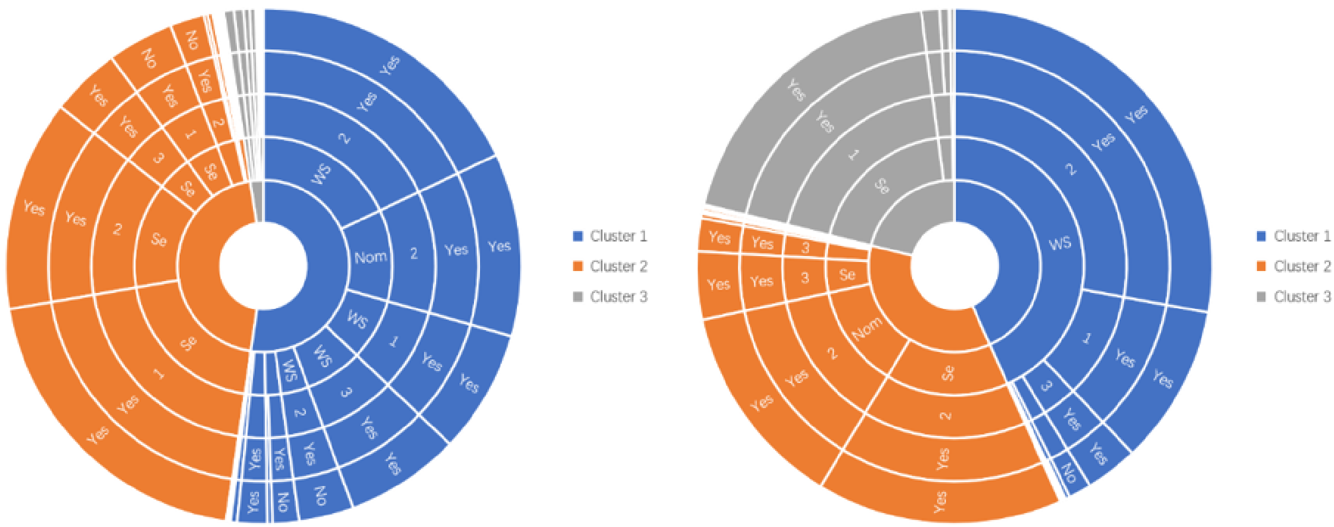

Figure 3

Results of lifestyle clustering in cases for CE and AE in Qinghai-Tibet Plateau.

Figure 4

Results of lifestyle clustering in cases for CE and AE in non-Qinghai-Tibet Plateau.

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