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Past, present and future epidemiology of echinococcosis in China based on nationwide surveillance data 2004–2022

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SUMMARY

Objectives: We evaluated the epidemiological characteristics of echinococcosis, a global public health threat, in China to inform global control efforts.
Methods: Descriptive, statistical, cluster, spatial, and trend analyses were used to evaluate the epidemiology at national, provincial, and county levels based on 2004–2022 nationwide surveillance data from China.
Results: Between 2004 and 2022, China recorded 72,676 cystic echinococcosis (CE) cases, 11,465 alveolar echinococcosis (AE) cases, and 5703 others, with an average annual cases per million (ANpM) of 3.45. Females had a higher incidence (ANpM = 3.87) than males (3.05), with most cases (41.15%) in the 30–49 age group, mainly among herders (38.76%) and farmers (37.82%). Seven provinces (Xizang, Qinghai, Xinjiang, Ningxia, Gansu, Sichuan, and Inner Mongolia) accounted for 98.12% of cases, with the Tibetan Plateau showing the highest rates (ANpMs = 155.51 for CE, 46.95 for AE). Surgery and case fatality rates were 39.45% and 5.23% in key surveillance regions (KSRs). Prevalence among residents (0.20%), livestock (1.33%), rodents

Abbreviations: AE, alveolar echinococcosis; ANpM, average annual cases per million; BS-PSRs, buffer areas in passive surveillance regions; CDCs, Centers for Disease Control and Prevention; CE, cystic echinococcosis; China CDC, Chinese Center for Disease Control and Prevention; IE, indistinguishable echinococcosis; KSRs, key surveillance regions; ME, mixed infections of cystic and alveolar echinococcosis; NEESP, National Echinococcosis Epidemiological Survey Project; NHIS, National Health Information System; NPES, National Projects for Echinococcosis Surveillance; OT-KSRs, other key surveillance regions; OT-PSRs, other passive surveillance regions; PSRs, passive surveillance regions; Pop 6, 6th national population censuses; Pop 7, 7th national population censuses; TP-KSRs, the Tibetan Plateau in key surveillance regions; WHO, World Health Organization

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(1.30%), and dogs (1.26%) declined with increased control funding in KSRs. Between 2023 and 2030, there will be an estimated 20,096 new cases and 45,323 cases requiring treatment.
Conclusion: The prevalence of echinococcosis has been alleviated in China, but significant control challenges remain, requiring sustained and targeted control measures.

Introduction

Echinococcosis is a globally distributed and potentially fatal infectious disease caused by *Echinococcus* species larvae.[1] An estimated 2–3 million people are infected, resulting in approximately 19,300 deaths annually, with a global disease burden of 871,000 disability-adjusted life years and economic losses exceeding $3 billion.[2] As a slowly developing parasitic disease, the time between infection and symptom onset ranges from several months to over 10 years, making it impractical to trace the infection source at the time of illness onset.[3] Therefore, long-term surveillance data are essential.

Echinococcosis exhibits complex transmission cycles that depend on the food chains involving hundreds of species of carnivores (definitive hosts) and herbivores (intermediate hosts).[4] Its spread is influenced by the interactions of host activities between human settlements and wilderness areas,[5] complicating the understanding of the transmission pathways and risk factors.[6] Given these considerations, integrating global and regional resources for long-term, comprehensive analyses are crucial for further understanding of echinococcosis epidemiology.

Europe is currently the region with the most comprehensive and frequent research on echinococcosis.[7] This is due to the alignment of resources, funding, and researchers in high-income regions, and the establishment of unified and complete notifiable disease reporting and surveillance systems. These systems effectively integrate the results of various projects, support historical data review, and aid the development of echinococcosis control programs. However, more diverse and extensive data to evaluate the global impact of the echinococcosis epidemic and refine control strategies are still needed.[8] Despite facing more serious epidemic stresses, most developing/low-income countries lack complete, comprehensive, and real data, limiting the foundation for such research.[9] Therefore, it is necessary to gather data on echinococcosis from different nations and regions worldwide and use real-world data to determine the epidemiological characteristics and translate them into effective control measures.

In China, significant progress in controlling parasitic infectious diseases has been achieved over the past two decades, driven by rapid economic growth and increasing living standards. The government has made notable efforts, such as successfully eliminating filariasis in 2007 and malaria in 2021, with plans to eliminate schistosomiasis by 2030.[10] Similarly, echinococcosis prevention and control programs have been prioritized.[11] The first cystic echinococcosis (CE) cases were recorded in Shandong in 1908, and alveolar echinococcosis (AE) was first reported in Xinjiang in 1956.[12] By 1949, only about 40 human echinococcosis cases had been recorded in China, but this number exceeded 10,000 by 1986, prompting the inclusion of echinococcosis control in national health plans. In 1989, echinococcosis was included in the management of notifiable infectious diseases in China, and since 2005, the central government has directly funded the detection, treatment, prevention, and surveillance initiatives.[11] Under the framework of the United Nations' 2030 Agenda for Sustainable Development and the WHO Road Map for Neglected Tropical Diseases 2021–2030,[13,14] the Chinese government has explicitly stated the goal of controlling echinococcosis nationwide by 2030 under the Healthy China initiative.[15] These efforts have improved the accuracy, scope, and availability of dynamic data on echinococcosis, advancing research, medical technology, and control strategies in China while contributing to the global understanding of echinococcosis epidemiology.

This study used historical data from the National Health Information System (NHIS) and annual reports of the National Projects for Echinococcosis Surveillance (NPES) of the Chinese Center for Disease Control and Prevention (China CDC). We evaluated prevalence and transmission trends, aiming to guide future prevention and control efforts in China, as well as to provide valuable reference data for global echinococcosis research.

Methods

Data curation

Between 2012 and 2016, the National Echinococcosis Epidemiological Survey Project (NEESP) was conducted across the Chinese Mainland. According to the results, 370 of 2583 county-level districts were designated as key surveillance regions (KSRs), characterized by clear transmission cycles involving humans, livestock/small mammals, and domestic/wild canines. In these regions, a dual surveillance scheme was implemented, combining passive hospital-based detection and active surveillance with community screening by the Centers for Disease Control and Prevention (CDCs), alongside host surveillance for livestock, rodents, and dogs. Other districts were designated as passive surveillance regions (PSRs) (see p.2 of the supplementary appendix for details). All human cases discovered in both KSRs and PSRs were reported to the NHIS, established in 2003 and officially launched in April 2004, with an infectious disease reporting network covering more than 95% of medical and health institutions (> 8000 public hospitals, 3386 CDCs, and approximately 168,000 health institutions) nationwide. Strict quality checks for case reports are carried out step-by-step by CDCs at county, city and provincial levels. The summary of data online is finally reviewed and confirmed by the China CDC to ensure standardization, completeness, and accuracy. In KSRs, CDCs also conduct annual disease surveys to monitor the progression of cases (including information on patients' state, treatment, and quality of life, etc.) and the prevalence among residents, intermediate hosts (livestock and rodents), and definitive hosts (mainly dogs) based on NEPS. These detailed data are progressively reviewed by local CDCs at all levels and reported to the China CDC, culminating in a national annual surveillance report for echinococcosis. The new cases identified in NEPS each year are also reported to the NHIS, but some data from Xizang (Tibet) Autonomous Region and Yunnan Province have not been registered. We have already addressed and corrected these vacancies in the present study. Cases are classified into four echinococcosis types: CE, AE, mixed CE/AE infections (ME), and indistinguishable echinococcosis (IE), where differentiation between AE and CE was not possible.

Statistical analyses

At the national level, we accessed NHIS data to extract the number of cases reported nationwide, with a follow-up completed on December 31, 2022. Descriptive and comparative analyses were conducted using SPSS software (v. 26; IBM Corp., Armonk, NY, USA) to elucidate echinococcosis incidence among age- and

Table 1
Sex and age characteristics of echinococcosis prevalence in the Chinese Mainland for 2004–2022 (n = 89,844).

Age	Prevalence											
	Male				Female				Total		χ^2 tests	
	Accumulated number of cases (proportion)	Pop 6	Pop 7	Annual average number of cases / million people [95% CI]	Accumulated number of cases (proportion)	Pop 6	Pop 7	Annual average number of cases / million people [95% CI]	Accumulated number of cases (proportion)	Annual average number of cases / million people [95% CI]	χ^2	*P*
0–9	1262 (3.10%)	79,527,231	88,986,789	0.79 [0.74–0.83]	1154 (2.35%)	66,886,928	79,141,155	0.83 [0.78–0.88]	2416 (2.69%)	0.81 [0.78–0.84]	1.74	0.19
10–19	2732 (6.72%)	92,172,107	84,660,133	1.63 [1.57–1.69]	2667 (5.42%)	82,625,469	73,280,001	1.80 [1.73–1.87]	5399 (6.01%)	1.71 [1.66–1.75]	14.02	0.0002
20–29	5109 (12.56%)	114,845,611	87,838,265	2.65 [2.58–2.73]	6308 (12.83%)	113,580,759	78,950,742	3.45 [3.36–3.53]	11,417 (12.71%)	3.04 [2.99–3.10]	195.19	< 0.0001
30–39	8153 (20.05%)	109,912,926	114,803,845	3.82 [3.74–3.90]	9867 (20.06%)	105,251,236	108,354,277	4.86 [4.77–4.96]	18,020 (20.06%)	4.33 [4.26–4.39]	261.70	< 0.0001
40–49	8521 (20.96%)	117,385,096	105,824,380	4.02 [3.93–4.10]	10,424 (21.19%)	112,963,421	101,355,837	5.12 [5.02–5.22]	18,945 (21.09%)	4.56 [4.49–4.62]	276.45	< 0.0001
50–59	6864 (16.88%)	81,446,172	111,921,496	3.74 [3.65–3.82]	8128 (16.53%)	78,619,473	110,643,586	4.52 [4.42–4.62]	14,992 (16.69%)	4.12 [4.06–4.19]	135.44	< 0.0001
60–69	4977 (12.24%)	50,582,897	73,209,048	4.23 [4.11–4.35]	6558 (13.33%)	49,197,667	74,179,450	5.60 [5.46–5.73]	11,535 (12.84%)	4.91 [4.82–5.00]	222.05	< 0.0001
70–79	2558 (6.29%)	27,682,312	38,915,166	4.04 [3.89–4.20]	3339 (6.79%)	29,142,218	41,913,719	4.95 [4.78–5.11]	5897 (6.56%)	4.51 [4.39–4.62]	59.10	< 0.0001
80–	486 (1.20%)	8,774,752	15,257,272	2.13 [1.94–2.32]	737 (1.50%)	12,214,594	20,543,563	2.37 [2.20–2.54]	1223 (1.36%)	2.27 [2.14–2.39]	3.33	0.07
Total	40,662	682,329,104	721,416,394	3.05 [3.02–3.08]	49,182	650,481,765	688,362,330	3.87 [3.83–3.90]	89,844	3.45 [3.43–3.47]	1262.07	< 0.0001

Pop 6: population from the results of the 6th national population census in 2010; Pop 7: population from the results of the 7th national population census in 2010; Annual average number of cases / million people = The number of cases / [(The population of the corresponding age group based on the results of the 6th national population census in 2010 + The population of the corresponding age group based on the results of the 7th national population census in 2010) / 2] × 1,000,000 / 19.

sex-based data matrices. The incidence rate, expressed as the average annual number of cases per million people (ANpM), was calculated using the average population data from the 6th (Pop 6) and the 7th (Pop 7) national population censuses conducted in the years 2010 and 2020, respectively (Supplementary Appendix, p. 3). Populations and cases were grouped by 10-year age intervals, with those aged ≥ 80 years being categorized into a single group. Chi-squared (χ^2) tests (with a significance threshold of $p < 0.05$) and Bonferroni-adjusted post-hoc tests were used to assess statistical differences. Data from the NPES were also analyzed for the years 2004–2022, including annual central government funding for echinococcosis control and prevention, annual prevalence rates in humans, livestock, rodents, and dogs, and potential correlations between funding and host infection rates, assessed through Pearson's correlation coefficient (Pearson's *r*).

At the provincial level, the incidence rates (ANpM) of CE, AE, ME, and IE were calculated for each province. Occupations were classified into 28 categories based on NHIS codes (O01–O28, Supplementary Appendix, p. 4). The proportions of cases in each occupation were clustered to evaluate the association of echinococcosis prevalence across provinces using the Hiplot Pro platform (https://hiplot.com.cn/). To better illustrate the data gradient, provincial administrative regions in the Chinese Mainland were divided into four traditional production zones: husbandry areas, semi-agricultural, and semi-husbandry areas, northern agricultural areas, and southern agricultural areas. We calculated the annual echinococcosis incidence per million people for 31 provincial administrative regions in the Chinese Mainland during 2005–2015 and 2016–2022 periods using population data from Pop 6 and Pop 7, respectively. Data were input into a time series model based on an exponential smoothing method to predict the prevalence over the next eight years (up to 2030). The root mean square error and the mean absolute percentage error were used to evaluate the goodness of fit and prediction accuracy of the simulation results, respectively, to identify the best models. The models were run using the SPSS software.

At the county level, ANpMs of CE and AE cases from 2004 to 2022 were analyzed. Spatial distribution was tested using the global spatial autocorrelation of the Moran's *I* statistic in ArcGIS (v10.8; Esri, Redlands, CA, USA), and cluster analysis was performed for ANpMs using the local spatial autocorrelation of the Getis-Ord (G_i^*) statistic to identify the hotspots of echinococcosis. Based on the test results, all county-level administrative regions were classified into four categories to describe the incidence, including the KSRs on the Tibetan Plateau (TP-KSRs), other KSRs (OT-KSRs), buffer zones of PSRs (BS-PSRs), and other PSRs (OT-PSRs) (see Supplementary appendix, p. 5).

Results

Incidence from NHIS at the national level

From 2004 to 2022, a total of 89,844 human cases of echinococcosis were reported in the Chinese Mainland, with an ANpM of 3.45 (95% confidence interval [CI]: 3.43–3.47). The male-to-female ratio was 1.00:1.21. The ANpM among female residents (3.87) was higher than that among males (3.05), with a statistically significant difference in the incidence (χ^2 = 1262.07, $P < 0.0001$; Table 1). This difference was especially pronounced in the six age groups within 10–79 years. The median age of echinococcosis cases was 44 years, with an interquartile range of 25 (Supplementary Appendix, p. 6). The highest number of cases (36,965, 41.15%) was observed among individuals aged 30–49 years. However, the highest prevalence was observed in the 60–69 age group, with an ANpM of 4.91 (95% CI: 4.82–5.00).

Table 2
Annual funding support, resident incidence and host surveillance prevalence of echinococcosis in key surveillance regions in China from 2004 to 2022.

Year	The central government disbursements funds directly		Annual surveillance data from NPES*													
			Echinococcosis of humans					CE of livestock			AE of rodents			*Echinococcus* infection of dogs		
	Amount (million USD)[6]	Trend (%)[5]	Prevalence (%)	CI 95%	Trend (%)[5]	No. of patients with surgery	No. of deaths	Prevalence (%)	CI 95%	Trend (%)[5]	Prevalence (%)	CI 95%	Trend (%)[5]	Prevalence (%)	CI 95%	Trend (%)[5]
2004[1]	-	-	3.80 (1067 / 28,100)	3.57–4.02		318	0	-	-	-	-	-	-	-	-	-
2005[2]	0.25	-	3.84 (837 / 21,769)	3.59–4.10	1.26 ↑	375	0	-	-	-	-	-	-	-	-	-
2006	0.92	273.93 ↑	1.68 (846 / 50,254)	1.57–1.80	-56.22 ↓	393	16	-	-	-	-	-	-	-	-	-
2007[3]	3.61	291.23 ↑	1.48 (5804 / 391,288)	1.45–1.52	-11.89 ↓	422	43	-	-	-	-	-	-	-	-	-
2008	10.20	182.75 ↑	1.43 (7533 / 528,200)	1.39–1.46	-3.85 ↓	683	120	-	-	-	-	-	-	-	-	-
2009	10.90	6.87 ↑	0.80 (6703/ 834,444)	0.78–0.82	-43.67 ↓	928	68	-	-	-	-	-	-	-	-	-
2010	17.20	57.75 ↑	0.41 (3725 / 89,9800)	0.40–0.43	-48.46 ↓	959	203	-	-	-	-	-	-	-	-	-
2011	17.84	3.74 ↑	0.23 (3554/ 1 521,495)	0.23–0.24	-43.58 ↓	1 401	47	-	-	-	-	-	-	-	-	-
2012	16.62	-6.83 ↓	0.20 (3392 / 1,665,763)	0.20–0.21	-12.82 ↓	1 403	66	-	-	-	-	-	-	-	-	-
2013	18.78	12.96 ↑	0.17 (3194 / 1,837,819)	0.17–0.18	-14.65 ↓	2 111	792	2.22 (1914 / 86,098)	2.12–2.32	-	-	-	-	3.27 (6418 / 196,413)	3.19–3.35	-
2014	18.71	-0.36 ↓	0.17 (3594 / 2,129,547)	0.16–0.17	-2.89 ↓	2 379	143	1.38 (2148 / 155,252)	1.33–1.44	37.76 ↓	-	-	-	2.52 (7429 / 294,793)	2.46–2.58	-22.88 ↓
2015	23.18	23.91 ↑	0.13 (2927 / 2,268,708)	0.12–0.13	-23.55 ↓	1 730	135	1.29 (1307 / 101,420)	1.22–1.36	-6.86 ↓	-	-	-	1.38 (3855 / 278,846)	1.34–1.43	-45.14 ↓
2016[4]	24.44	5.45 ↑	0.10 (5196 / 5,093,845)	0.10–0.10	-20.94 ↓	2 385	269	1.90 (4286 / 225,917)	1.84–1.95	47.21 ↑	8.04 (730 / 9,084)	7.48–8.60	-	1.83 (5532 / 301,528)	1.79–1.88	32.71 ↑
2017[4]	29.16	19.30 ↑	0.31 (21,481 / 7,013,705)	0.30–0.31	200.25 ↑	4 441	137	2.08 (883 / 42,363)	1.95–2.22	9.87 ↑	2.00 (297 / 14,846)	1.78–2.23	-75.11 ↓	3.21 (433 / 13,473)	2.92–3.51	75.17 ↑
2018	35.14	20.49 ↑	0.11 (3835 / 3,467,846)	0.11–0.11	-63.89 ↓	6 668	488	2.12 (888 / 41,853)	1.98–2.26	1.79 ↑	1.44 (320 / 22,292)	1.28–1.59	-28.24 ↓	2.35 (331 / 14,112)	2.10–2.60	-27.02 ↓
2019	38.14	8.56 ↑	0.09 (2932 / 3,176,714)	0.09–0.10	-16.54 ↓	3 071	786	1.27 (1489 / 117,395)	1.20–1.33	-40.22 ↓	0.74 (427 / 57,373)	0.67–0.81	-48.15 ↓	0.77 (586 / 75,857)	0.71–0.83	-67.06 ↓
2020	40.82	7.02 ↑	0.06 (1900 / 3,186,479)	0.06–0.06	-35.40 ↓	2 564	649	0.86 (1213 / 140,419)	0.82–0.91	-31.89 ↓	1.09 (688 / 63,192)	1.01–1.17	46.29 ↑	0.56 (1722 / 305,206)	0.54–0.59	-26.96 ↓
2021	46.51	13.93 ↑	0.04 (1346 / 3,249,616)	0.04–0.04	-30.53 ↓	1 792	359	0.63 (1408 / 222,844)	0.60–0.66	-26.86 ↓	1.07 (599 / 56,124)	0.98–1.15	-1.97 ↓	0.47 (2614 / 555,688)	0.45–0.49	-16.63 ↓
2022	41.76	-10.21 ↓	0.04 (1270 / 3,576,121)	0.03–0.04	-14.26 ↓	1 418	374	0.88 (1038 / 117,303)	0.83–0.94	40.05 ↑	0.92 (403/ 43,705)	0.83–1.01	-13.60 ↓	0.44 (1756 / 394,851)	0.42–0.47	-5.46 ↓
Total	394.17		0.20 (81,136 / 40,941,513)	0.20–0.20		35 441	4 695	1.33 (16,574 / 1,250,864)	1.30–1.35		1.30 (3464 / 266,616)	1.26–1.34		1.26 (30,676 / 2,430,767)	1.25–1.28	

*National Projects for Echinococcosis Surveillance (NPES). [1] The NHIS was officially launched on April 1, 2004, to receive echinococcosis case reports from health facilities nationwide. [2] Since 2005, the central government included echinococcosis into the national major infectious disease management system and began to allocate special funds for echinococcosis control and surveillance, free drug treatment for patients. Before this, funding was provided by various provincial governments, national science foundations, and international health projects. [3] Since 2007, the central government has increased funding for free surgical treatment of patients. [4] Since 2017 (some provinces started in 2016), according to the results of the National Echinococcosis Epidemiological Survey Project (NEESP) conducted during 2012–2016, the surveillance areas have been refined from highly endemic provinces to highly endemic counties. [5] Trend = (the statistical results for the current year - the statistical results for the previous year) / the statistical results for the previous year × 100%; [6] The Chinese yuan was converted into US dollars using the exchange rates published annually by the State Administration of Foreign Exchange (https://www.safe.gov.cn/safe/2020/1218/17833.html).

Prevalence in KSRs based on NEPS at the national level

Since 2005, the Chinese central government has allocated special funds for the treatment, surveillance, and prevention of echinococcosis in KSRs, with funding generally increasing annually, notwithstanding exchange rate fluctuations (Table 2). By the end of 2022, the central government had allocated a total of $394.17 million. Additionally, since 2007, provincial governments in KSRs have also invested nearly $200 million in additional funding for free treatment of echinococcosis, bringing the total expenditure on echinococcosis control in China close to $600 million. With this financial support, the vast majority of patients received free medical treatment, and 35,441 patients underwent free surgical procedures, representing a surgery rate of 39.45%. Mortality and case fatality rates in KSRs were recorded at 4.05 per million people per year and 5.23%, respectively. The prevalence of echinococcosis among residents in KSRs decreased by 98.95% from 3.80% in 2004 to 0.04% in 2022 and had a significant negative correlation with annual funding amounts (Pearson's $r = -0.72$, $P = 0.001$). In livestock, CE prevalence decreased from 2.22% in 2013 to 0.88% in 2022 (Pearson's $r = -0.65$, $P = 0.04$). Similarly, AE prevalence in rodents decreased from 8.04% in 2016 to 0.92% in 2022 (Pearson's $r = -0.78$, $P = 0.04$), and the

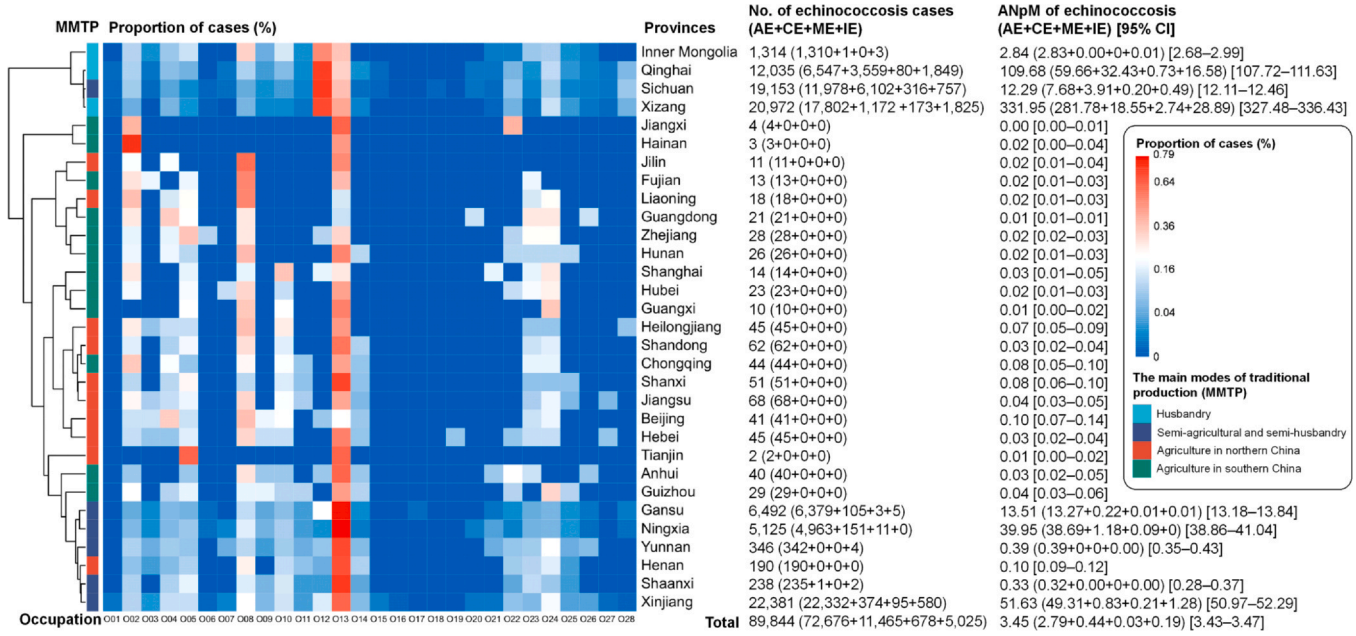

Fig. 1. Heat map of the occupational distribution of total echinococcosis cases at the provincial level in 31 administrative regions of the Chinese Mainland from 2004 to 2022 (n = 89,844). Proportion of cases (%) = the number of echinococcosis cases in this occupation at the provincial level / total number of cases at the provincial level × 100%; The proportion of cases was hierarchically clustered using Ward.D2 method; ANpM: annual average number of echinococcosis cases per million people = No. of echinococcosis cases / [(The population of the corresponding provinces based on the results of the 6th national population census in 2010+The population of the corresponding provinces based on the results of the 7th national population census in 2020) / 2] × 1,000,000 / 19.

positive rate of *Echinococcus* in dogs fell from 3.27% in 2013 to 0.44% in 2022 (Pearson's r = −0.77, P = 0.01).

Past incidence at the provincial level

By the end of 2022, among the 31 provincial administrative regions of the Chinese Mainland, 72,676 CE, 11,465 AE, 678 ME, and 5025 IE cases were reported (Fig. 1). Seven western provinces or autonomous regions, namely Xizang (281.78), Qinghai (59.66), Xinjiang (49.31), Ningxia (38.69), Gansu (13.27), Sichuan (7.68), and Inner Mongolia (2.83), had ANpMs for CE higher than the national average (2.79). The cumulative number of cases reached 71,311, accounting for 98.12% of the national case count (72,676) over 19 years. Five provincial administrative regions, namely Qinghai (32.43), Xizang (18.55), Sichuan (3.91), Ningxia (1.18), and Xinjiang (0.83), had ANpMs for AE higher than the national average (0.44), with 11,358 cumulative cases accounting for 99.07% of the 11,465 total cases in China.

Among the 28 NHIS-classified occupations, the groups with the highest case numbers were herders (38.76%, 34,821 / 89,844) and farmers (37.82%, 33,975 / 89,844). The occupational distribution of patients based on these two major traditional modes of production showed distinct clustering characteristics. The highest ANpM was observed in regions dominated by husbandry (53.96, 95% CI: 53.39–54.53), followed by semi-agricultural and semi-husbandry areas at (12.92, 95% CI: 12.81–13.03). Northern agricultural areas had significantly lower ANpMs (0.05, 0.05–0.06), as did southern agricultural areas (0.02, 0.02–0.03).

Future incidence at the provincial level

By the end of 2022, a total of 15,554, 8169, 255, and 1249 unresolved cases of CE, AE, ME, and IE, respectively, were reported, accounting for 21.40%, 71.25%, 37.61%, and 24.86% of the accumulated cases from 2004–2022, respectively. Predictions based on the time series model for the future incidence of echinococcosis indicate an annual decline in new cases across China from 2023 to 2030. The total number of new cases during this period is estimated at approximately 20,096, comprising about 16,256 CE, 2564 AE, and 152 ME cases. For 2023–2030, the average annual incidence is predicted to be 1.78 cases per million people (total population based on Pop 7), representing a 48.41% decrease, compared with the ANpM of 3.45 in 2004–2022. By 2030, China is projected to record an additional 1858 cases, with an incidence rate of 1.32 cases per million people (counted based on Pop 7), representing a 28.63% decrease from the 2603 cases and 1.85 incidence rate in 2022 (Supplementary Appendix, pp. 7–9). Notably, most of the provincial administrative regions covered by the KSRs (Xizang, Qinghai, Sichuan, Xinjiang, Gansu, and Ningxia) are expected to show a steady downward trend in incidence, while other provinces will primarily show a slow upward trend (Fig. 2).

Distribution of echinococcosis at the county level

Significant global spatial autocorrelations were observed in ANpMs for CE (Moran's I = 0.077, P < 0.0001) and AE (0.041, P < 0.0001). Specifically, CE, with its high adaptability, is distributed widely across almost all regions of China. High-intensity distribution areas are concentrated on the Tibetan Plateau (including most of Xizang, southern Qinghai, and western Sichuan), followed by northern Xinjiang, the Hexi/Gansu Corridor (a narrow plain located between the Tibetan Plateau and the Mongolian Plateau in central Gansu Province). AE, a potentially fatal disease, is mainly distributed in the western China, with the highest distribution intensity in eastern Tibetan Plateau, especially at the junction of Sichuan, Qinghai, and Xizang (Fig. 3).

Echinococcosis incidence at the county level

From 2004 to 2022, among the 2853 county-level administrative regions of the Chinese Mainland, 1187 counties reported CE cases. Of these, 183 counties exhibited a CE ANpM > 50 (a CE hyperendemic area as defined by the WHO), with 118 counties (64.48%) located on the Tibetan Plateau. AE cases were reported in 205 counties, of

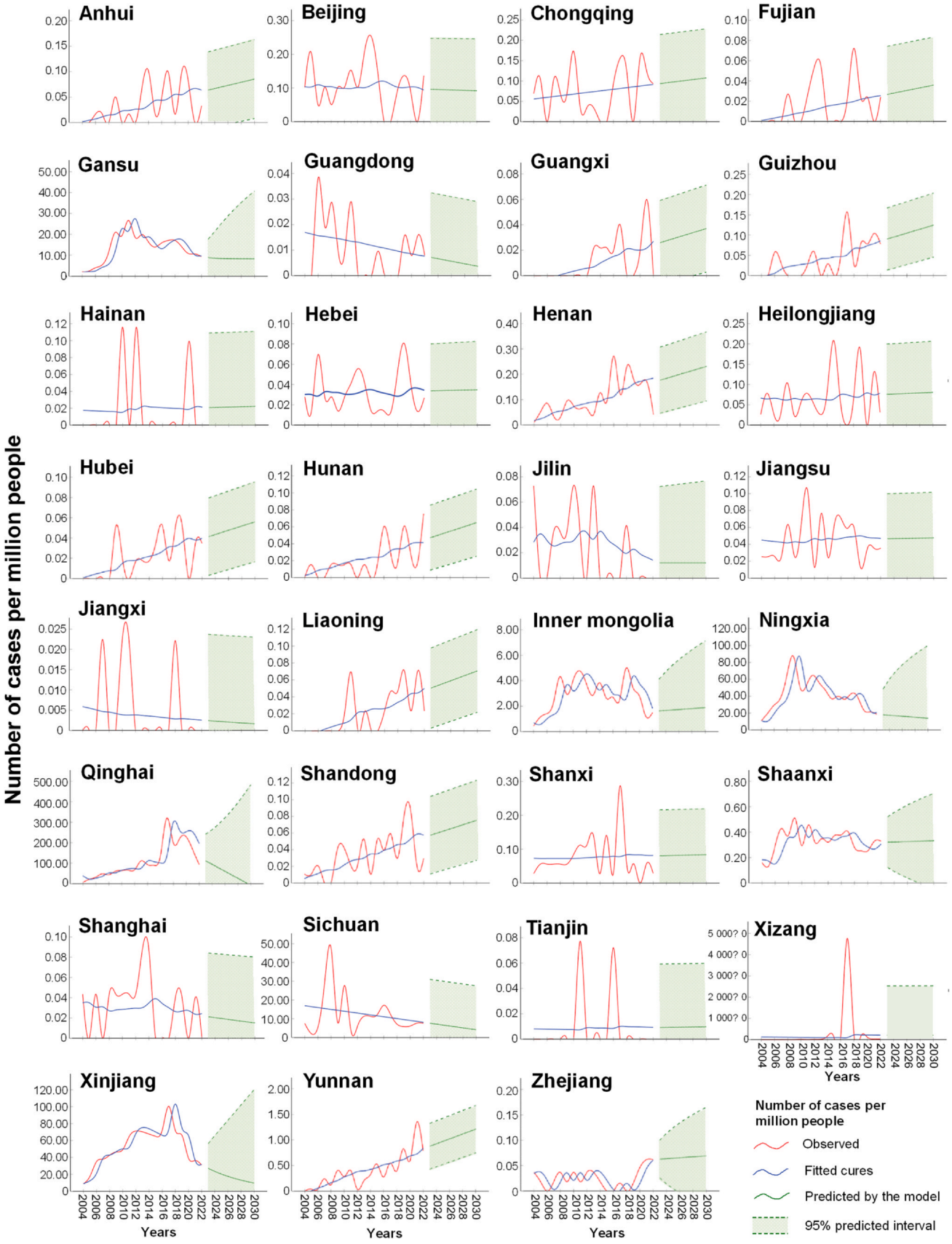

Fig. 2. Time-trend analysis of the incidence (the number of cases per million people) of human echinococcosis at the provincial level (observed cases for 2004 to 2022 and predicted cases for 2023–2030).

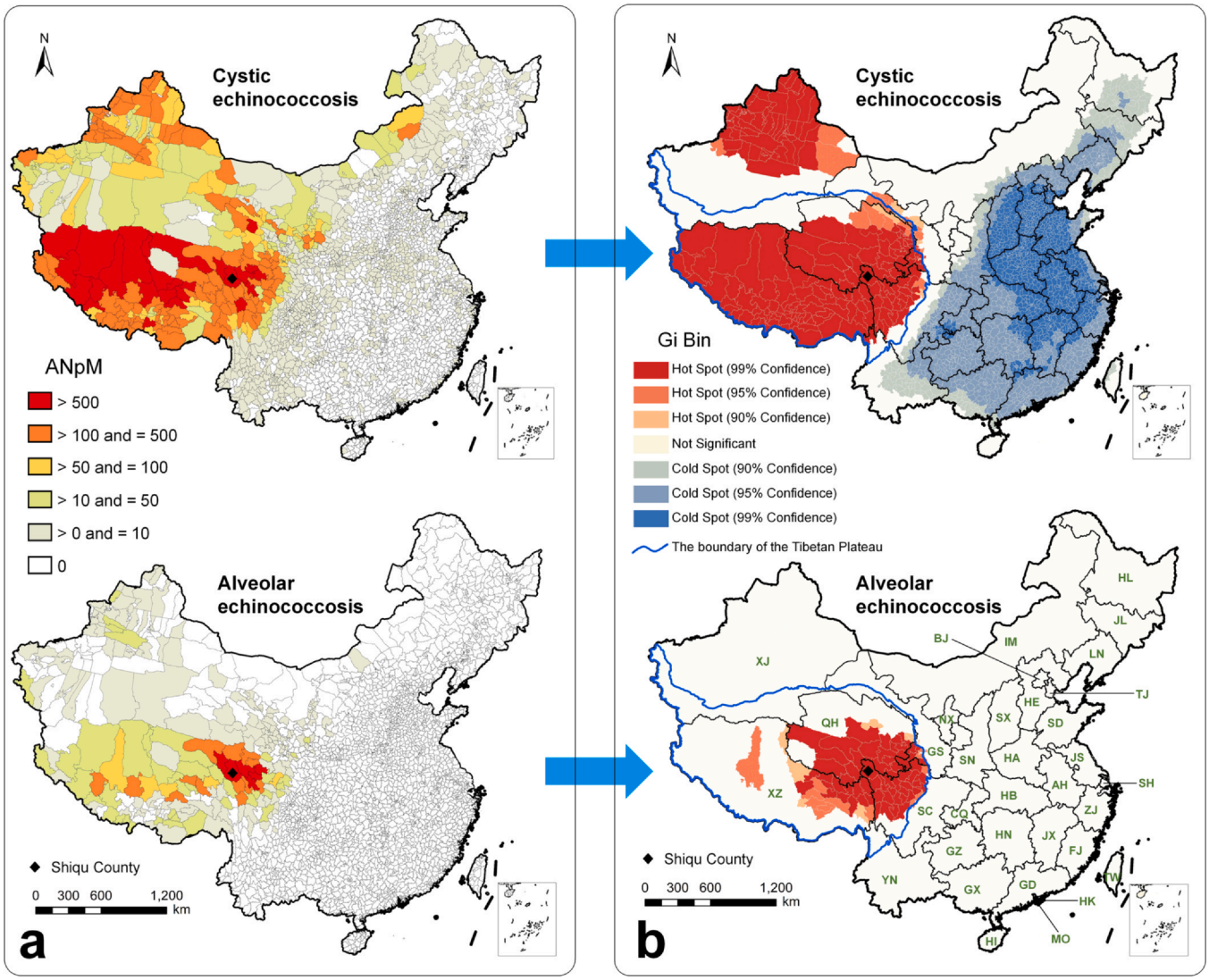

Fig. 3. Distribution map for echinococcosis at the county level. **a**: Spatial distribution map showing the county-level incidences (ANpMs) of cystic echinococcosis and alveolar echinococcosis. **b**: Clustering map of cystic echinococcosis and alveolar echinococcosis based on their ANpMs using the Getis-Ord (G_i^*) statistic. **AH**: Anhui; **BJ**: Beijing; **CQ**: Chongqing; **FJ**: Fujian; **GD**: Guangdong; **GS**: Gansu; **GX**: Guangxi; **GZ**: Guizhou; **HA**: Henan; **HB**: Hubei; **HE**: Hebei; **HI**: Hainan; **HK**: Hongkong; **HL**: Heilongjiang; **HN**: Hunan; **IM**: Inner Mongolia; **JL**: Jilin; **JS**: Jiangsu; **JX**: Jiangxi; **LN**: Liaoning; **MO**: Macao; **NX**: Ningxia; **QH**: Qinghai; **SC**: Sichuan; **SD**: Shandong; **SH**: Shanghai; **SN**: Shaanxi; **SX**: Shanxi; **TJ**: Tianjin; **XZ**: Xizang; **XJ**: Xinjiang; **YN**: Yunnan; **ZJ**: Zhejiang. **Note**: The ANpMs of both cystic echinococcosis and alveolar echinococcosis included the number of mixed CE/AE infection cases in the calculation.

which 121 counties (59.02%) were located on the Tibetan Plateau. The annual incidence of CE and AE in the Tibetan Plateau region of China was 155.51 and 46.95, respectively, both of which were the highest ever registered. In particular, Shiqu, a county located in northwestern Sichuan and on the eastern Tibetan Plateau, had the highest ANpMs for both CE (2787.55) and AE (2008.63). Overall, there was a statistically significant difference in the incidence rates among the four surveillance areas (χ^2 = 3,679,784.48, P < 0.0001). The KSRs demonstrated significantly higher ANpMs than the PSRs, especially on the Tibetan Plateau, where a significantly higher incidence rate was observed than that in other regions (Table 3).

Discussion

Epidemiology in the past

The average annual incidence of echinococcosis in China is 3.45 new cases per million people. For CE, the most common form, the incidence rate of ANpM is 2.79, comparable with that in South America (including Argentina, Brazil, Chile, Peru, and Uruguay from 2009 to 2014) (2.8), higher than that in North America (mainly Canada from 2000 to 2020) (0.2), and lower than that in Europe (including most European countries from 1997 to 2019) (6.4).[16–18] For AE, the most fatal form, the ANpM in Chinese Mainland, is 0.44, similar to that in Europe (from 2018 to 2022) (0.41) and higher than that in Canada (from 2000 to 2020) (0.06).[17,19] In terms of neighboring countries or regions, particularly in Central Asia, the annual incidences of CE in Kazakhstan (from 2007 to 2013) and Kyrgyzstan (from 2014 to 2016) were 50 and 131 per million population, respectively, higher than that in Xinjiang (49.31); similarly, the incidences of AE (8 and 30, respectively) were also higher than that in Xinjiang (0.83).[20,21] In North Asia, the ANpM incidences of CE in Mongolia (10.6 from 2008 to 2015) and The Sakha (Yakutia) Republic in Russia (about 7.9 in 2015) were higher than that in Inner Mongolia (2.83).[22,23] However, according to population data released by the United Nations, the total populations of Kazakhstan and Kyrgyzstan in 2022 were only 75% and 25% of that of Xinjiang, respectively, and those of Mongolia and Sakha were only 14% and 4% of Inner Mongolia.[24] Therefore, the total number of echinococcosis cases in China's border provinces was much higher than that in neighboring

Table 3
Incidence of cystic echinococcosis (CE) and alveolar echinococcosis (AE) at county level in the Chinese Mainland for the period 2004–2022 (n = 89,844).

Regions	The number of counties (proportion)	Population		The number of accumulated cases (proportion)					Annual average number of cases / million people [95% CI]		
		Pop 6	Pop 7	Only CE	Only AE	Mixed infection with CE and AE	Without distinguishing between CE and AE	Total	CE*	AE#	Total
TP-KSRs	161 (5.64%)	11,708,782	12,581,394	35,884 (49.38%)	10,833 (94.49%)	570 (84.07%)	4435 (88.26%)	51,722 (57.57)	155.51 [153.90–157.11] Ca	46.95 [46.06–7.83] Aa	224.14 [222.21–226.07] Ea
OT-KSRs	201 (7.05%)	46,742,571	51,071,074	34,796 (47.88%)	632 (5.51)	107 (15.78%)	590 (11.74%)	36,125 (40.21)	37.45 [37.05–37.84] Cb	0.68 [0.63–0.73] Ab	38.88 [38.48–39.28] Eb
BS-PSRs	494 (17.32%)	192,287,927	198,609,817	1208 (1.66%)	0	1 (0.15%)	0	1209 (1.35)	0.33 [0.31–0.34] Cc	0.00 [0.00–0.00] Ac	0.33 [0.31–0.34] Ec
OT-PSRs	1997 (70.00%)	1,082,071,589	1,147,516,439	788 (1.08%)	0	0	0	788 (0.88)	0.04 [0.03–0.04] Cd	0 Ac	0.04 [0.03–0.04] Ed
Total	2853	1,332,810,869	1,409,778,724	72,676	11,465	678	5025	89,844	2.79 [2.77–2.81]	0.44 [0.43–0.45]	3.45 [3.43–3.47]
χ^2 tests									χ^2 = 4,511,070.59 **P** < 0.0001	χ^2 = 1,145,243.97 **P** < 0.0001	χ^2 = 3,679,784.48 **P** < 0.0001

* The number of CE cases includes the numbers of Only CE and Mixed infection with CE and AE; #The number of AE cases includes the numbers of Only AE and Mixed infection with CE and AE; Ca, Cb, Cc, Cd, Aa, Ab, Ac, Ea, Eb, Ec, and Ed represent the results of post-hoc tests, in which the same letter indicates that there is no statistical significance between the two groups; Pop 6 and Pop7 represent populations from the results of the 6th and 7th national population censuses in 2010 and 2020, respectively; TP-KSRs: Tibetan Plateau of key surveillance regions; OT-KSRs: other area of key surveillance regions; BS-PSRs: buffer area of passive surveillance regions; OT-PSRs: other area of passive surveillance regions; Annual average number of cases / millionpeople = The number of cases / [(The population of the corresponding counties based on the results of the 6th national population census in 2010 + The population of the corresponding counties based on the results of the 7th national population census in 2010) / 2] × 1,000,000 / 19.

countries, indicating that China require greater medical and health resources. In addition, the ANpM of CE was 0.42 in Nepal (from 2000 to 2012) and 13.9 in Pakistan (in 2016), which were much lower than that in neighboring Xizang (281.78).[25,26] In Southeast Asia, a total of 49 cases of echinococcosis was identified from 1885 to 2015, much lower than 346 cases diagnosed in neighboring Yunnan Province from 2004 to 2022.[27]

The global incidence of CE was estimated to be 26.0 per million population in 2019, which is higher than that across the Chinese Mainland (2.79) and PSRs (0.04). However, it is lower than that in KSRs (75.73), especially in the Tibetan Plateau (155.51), a region higher than almost anywhere else in the world.[28] According to Torgerson et al.,[29] there are approximately 18,235 new cases of AE globally per year, with 16,629 (91%) occurring in China. These data were likely overestimated. Based on the findings of this study, the average annual increases in CE and AE cases in China were 3720 and 678, respectively, which were more accurately derived from active screening programs for echinococcosis developed by the NPES, which requires coverage of 70% (counties with more than 100,000 people) to 90% (counties with less than 100,000 people) of the resident population every five years.[30] The mortality rate (4.05 per million population) and case fatality rate (5.23%) of echinococcosis (including AE and CE) suggested in this study are nearly double those previously described (0.2 per 100,000 population and 2.2%, respectively).[6] This difference may be attributed to the high incidence of AE in China.

Issues at the present

First, this study revealed a significantly higher incidence of echinococcosis in females than in male residents, especially among individuals aged > 20 years. This pattern is attributed to traditional labor roles, where women often handle tasks like cooking and dog feeding. These activities increase their exposure to *Echinococcus* eggs through contaminated food ingredients and infected dogs. This confirms other findings that females had a higher risk of CE and AE, which is an almost global epidemic feature of echinococcosis.[17,19–22,31] This highlights the need to prioritize women's health in echinococcosis-endemic areas.

Second, the incidence of echinococcosis in China gradually increased from east to west and from south to north, which was the inevitable result of the gradual geographical transition from agricultural to pastoral areas. The Tibetan Plateau, with an average altitude exceeding 4000 m, has the highest incidence of both CE and AE. This is due to the predominance of traditional animal husbandry, characterized by large livestock farming and high dog populations, which are favorable conditions for CE transmission. The region's alpine meadows and wetlands, shaped by water vapor from the Pacific and Indian Oceans, create a habitat favorable for wildlife, including voles, pikas, and foxes, which can transmit *E. multilocularis*.[32]

Third, the incidence of human echinococcosis is observably higher in pastoral than agricultural areas, which is consistent with global patterns, especially for CE. However, in China, uniquely, the northern agricultural areas manifest a higher incidence than the southern agricultural areas. This may be attributed to the fact that before the mechanization of Chinese agriculture, northern dry-land agricultural farming had a higher demand for animal power (cattle), which simultaneously increased the exposure and spread of echinococcosis from the northwestern pastoral areas.

Fourth, the diversity of *Echinococcus* species in China adds complexity to the epidemiological landscape, presenting various scenarios regarding the geographical distribution and host suitability of different species. According to genetic analyses conducted by Hua et al.[33] and data from the present study, cumulative cases of CE from 2004 to 2022 were estimated to be 71,440 cases caused by

Echinococcus granulosus, 1018 cases caused by *E. intermedius*, 145 cases caused by *E. canadensis*, and 73 caused by *E. ortleppi*. Additionally, 11,310 AE cases were caused by *E. multilocularis*. These *Echinococcus* species often have different transmission modes, thus increasing the difficulty of investigation, control, and prevention.

Challenges for the future

Based on the number of uncured cases reported at the end of 2022 and the estimated cases for the period 2023–2030, approximately 45,323 patients with echinococcosis may require treatment, and more than 60 million people in KSRs could be directly exposed to the risk of echinococcosis infection in China. These large numbers highlight the challenges China faces in managing the echinococcosis burden in the near future.

The primary challenge is reducing the number of current cases and controlling the occurrence of new cases in KSRs. Achieving this requires continuous and further implementation of early screening and diagnosis, free medical treatment policies, and fully funded comprehensive control strategies (e.g., dog deworming programs, management of livestock slaughter, and health education). In this process, AE treatment must be prioritized, as there is currently no highly effective surgical method or targeted medication developed to cure this highly pathogenic form of echinococcosis. At the end of 2022, 71.25% of AE cases diagnosed between 2004 and 2022 had not been cured, underscoring the urgency of addressing this issue. Furthermore, *E.multilocularis* is transmitted independently through wildlife reservoirs, but can also spill over into domestic dogs, resulting in a high number of human AE cases. Therefore, active and effective control strategies (such as leash management of dogs, surveillance of echinococcosis in wildlife, and safety of drinking water in pastures) should be adopted to progressively address this complex situation. Striking a balance between ecological health and human health will be a topic for future exploration.

Cross-regional transmission of echinococcosis also requires attention. Epidemiological investigations in China indicated three main potential transmission pathways contributing to the spread of echinococcosis from KSRs to PSRs: (a) direct importation of cases, often derived from population migration or travel,[34] (b) local infection directly caused by the cross-regional smuggling of infected dogs,[35] and (3) local infection caused by potential short-term transmission cycles formed by trades in infected livestock.[36] Addressing these issues requires targeted measures, such as source tracing and follow-up management of patients, combating dog smuggling, and implementing quarantines for domestic animals from hyperendemic areas of echinococcosis.

Another problem is missed diagnosis in PSRs due to the unfamiliarity of medical technicians and the limitations of diagnostic experience for echinococcosis in these low-risk areas. Therefore, the following factors need to be prioritized on the health-promotion agenda: i) enhancing public awareness of echinococcosis prevention by disseminating health knowledge to people, with a particular focus on travel transmission from KSRs to PSRs, and ii) developing diagnostic and detection techniques with simple, effective and practical operations.

On the positive side, the Chinese government's continued attention has ensured steady allocation of funds and resources for echinococcosis control. This investment has been a key factor in the recent and continuous decline in the number of human cases, as well as in the echinococcosis prevalence among livestock, rodents, and dogs. Nonetheless, controlling echinococcosis is a long-term effort that requires persistence. The One Health approach to protecting health and addressing health challenges based on collaboration across sectors and disciplines has been widely promoted by WHO and FAO. Recently applied to echinococcosis control, this strategy could be key for effective management in the future. The Chinese government is currently practicing a multi-sectoral echinococcosis health plan and is committed to increasing international cooperation and exchange, such as learning from the experiences of Europe, Australia, and New Zealand; collaborating with neighboring countries along the Belt and Road Initiative (new infrastructure to connect China with the rest of the world); and participating in global efforts on echinococcosis control.[37]

Limitations

Echinococcosis is a slowly developing chronic parasitic zoonosis, often taking several years for infected persons to exhibit clinical symptoms. This lag limits the assessment of the historical epidemiological characteristics reflected in the current data. To overcome this, a span of 19 years was considered for the analysis. Additionally, data produced from the NEESP and annual active surveillance from the NPES were used to revise NHIS information, thus improving data reliability. Furthermore, the number of cases in PSRs, especially AE, might be underestimated. However, this limitation is unlikely to cause significant fluctuations in the overall data trends, as PSR data account for only a small proportion (2.22%) and thus exhibit limited impact. For the time trend analysis, the 2012–2016 national epidemiological survey detected a large number of asymptomatic echinococcosis cases, leading to an apparent peak outbreak around 2017. In reality, these cases could have been infected at any time before the survey.[38] The subsequent implementation of a population-wide screening strategy improved data accuracy for the final five years (2018–2022). However, the occurrence of unexpected future events, such as the recent emergence of the COVID-19 pandemic, may disrupt this trend, as they have impacted the control efforts of other infectious diseases. Despite these limitations, this study is the most comprehensive analysis of echinococcosis epidemiology to date and reflects extensive realistic data on accessibility in China.

Conclusions

Echinococcosis is regarded as a significant public health problem and one of the parasitic diseases of major concern to the Chinese government. Recent efforts have alleviated the severe endemic status of echinococcosis in China, owing to improvements in health services, lifestyle transformation, intensification of agriculture and husbandry, and the implementation of the national comprehensive echinococcosis control program. However, emerging risks that were previously less apparent pose new challenges. These include the lack of major breakthroughs in diagnostic and treatment technologies, the risk of transboundary spread with increasing social mobility, and the difficulties in effectively controlling echinococcosis in wildlife. Addressing these problems will be critical for achieving long-term control and eventual elimination of echinococcosis.

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Author contributions

XW (X Wang), SH, XZ, SL, and JC conceived the study. XW (X Wang), YK, CX and SH extracted and interpreted the data from NHIS.

QW, CZ, JZ, YY, XJ, QG, XM, YF, XW (X Wu), SC, FL, WY and BL (B Li) extracted the data from NPES. SH, XW (X Wang), YK, CX, SY, YW, LW and BL (B Liu) performed statistical analyses. XW (X Wang) and SH drafted the manuscript. ZW, WH, YS, WZ, PSC, WW, NX, HW, PSC, WW, NX, XZ, SL and JC revised the manuscript. SH, XZ, SL, and JC reviewed all the data and the manuscript. All authors reviewed the article and approved submission.

Data availability

The data is confidential. To gain access, data requestors will need to sign a data access agreement, upon reasonable request. Proposals should be directed to the corresponding author (hanshuai@nipd.-chinacdc.cn).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jinf.2025.106445.

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