Recollection

Retrospective Analysis of the Epidemiological Evolution of Brucellosis in Animals — China, 1951–1989 and 1996–2021

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ABSTRACT

Brucellosis poses a significant threat to public health in China. This study utilized a range of epidemiological indices, including seroprevalence and the number of reported cases, to illustrate the epidemic profile of the disease. Although the seroprevalence of brucellosis in animals (including sheep, goats, cattle, and swine) steadily decreased from a severe epidemic level in the 1950s to a low endemic level by 1989, the disease reemerged in 2000. Subsequently, there has been a persistent increase in the frequency of outbreaks and the number of reported cases from 2006 to 2021, with over 98% of reported cases occurring in sheep and cattle. During this period, the culling rate declined, while infection rates increased, nearly reversing their respective trajectories. The decrease in the culling rate of positive animals coincided with an increase in infection rates, indicating that infection among these animals was persistent and circulating. In the southern regions of China, 6.34% (34,070 of 537,797) of cases were reported between 2006 and 2021, whereas in the northern regions, 93.67% (503,727 of 537,797) of cases occurred during the same timeframe. Each time cases increased in the south, they lagged 2 to 5 years behind those in the north, suggesting that stringent control measures for sheep and cattle in the north should be prioritized. These findings provide critical insights into developing control strategies to mitigate the spread of the disease.

Brucellosis is a zoonotic disease that threatens livestock economies in many low-income countries, causing considerable economic losses due to animal abortions and reduced productivity (*1*–*2*). In 1887, David Bruce first isolated *B. melitensis* from the spleens of four deceased soldiers on Malta Island who had consumed raw goat milk (*3*). In the past 136 years, brucellosis has become a globally spread zoonotic disease present on all 6 continents, especially in Asia and Africa, which harbor the highest disease burden. This poses a severe public health risk to farmers and animal owners (*4*–*5*). *Brucella* spp. invade the genital systems of animals, leading to abortion or stillbirth at the end of pregnancy, and present with epididymitis or orchitis, affecting the productive capacity of male animals (*6*). Infected animals and their products are the main source of infection in humans. Currently, brucellosis is still expanding in low-income countries due to many socioeconomic factors, including international trade, immigration, travel to endemic areas, and the developing breeding industry aimed at increasing the income of farmers, including those in China (*7*–*8*).

Brucellosis, a significant public health concern in China, has a long history marked by an initial animal epidemic documented in 1936 (*9*). This first epidemic, spanning from 1950 to 1984, was followed by a period of declining infection rates, nearly reaching China's control standards between 1985 and 1995. However, as an emerging infectious disease, brucellosis has reemerged with cases reported across 31 provincial-level administrative divisions (PLADs) in the Chinese mainland (*10*). Growth of the livestock industry, particularly in sheep and goat farming, coupled with economic development, has contributed to frequent animal brucellosis outbreaks in numerous PLADs from 2006 to 2021 (*11*). Retrospective analysis of both epidemic stages is crucial to understand the epidemiological evolution of animal brucellosis. This study aims to investigate these epidemic trends in China and define the regional distribution of circulating *Brucella* strains across different periods, providing insights for targeted brucellosis control measures.

METHODS

Data Source, Processing, Analysis, and Visualization

In this study, surveillance data from two epidemic phases (I: 1951–1989 and II: 2006–2021) of brucellosis in animals were collected and analyzed to illustrate the epidemiological profile. Epidemic data on animal brucellosis were collected from the *Annals of Animal Diseases in China* (1951–1989) and the *Official Veterinary Bulletin* (2006–2021). The seroprevalence of animal brucellosis and the number and biotypes of *Brucella* strains in different PLADs were extracted from *Animal Diseases in China* (1952–1989). Five epidemic items were extracted from the *Official Veterinary Bulletin* [2006–2021 (September), http://www.agri.gov.cn]: 1) the total number of outbreaks each month, 2) number of cases each month, 3) animal species (hosts), 4) number of animal deaths each month, and 5) number of animals destroyed each month. Excel 2016 (Microsoft, Redmond, WA, USA) was used for data curation, processing, analysis, and visualization. A semi-logarithmic curve was used to depicte the changing trends in the positive case rates and the culling rates. OmicShare tools (*12*) (https://www.omicshare.com/tools/) were used for Pearson correlation analysis of the incidence of human brucellosis, the infected rates, and the livestock breeding situation.

RESULTS

Sheep and Goat Brucellosis Seroprevalence from 1951 to 1989

From 1951 to 1989, the seroprevalence of sheep brucellosis among 15 PLADs was 1.84% (993,609/54,068,364). The highest positive rate was 5.92% (520,140/8,788,690) in the 1960s (1960–1969), followed by 3.58% (234,154/6,543,382) in the 1950s (1951–1959), 2.18% in the 1970s (1970–1979), and 0.3% (95,582/32,129,518) in the 1980s (1980–1989) (Table 1). Sheep brucellosis was widespread from 1951 to 1959. The seroprevalence in Qinghai Province was 6.58% (16,280/247,365) from 1950 to 1959; in Heilongjiang Province was 8.5% from 1956 to 1958; and in Xinjiang Uygur Autonomous Region was 9.19% from 1956 to 1964. Sheep brucellosis was severe from 1961 to 1969, with seropositive rates in Qinghai and Xinjiang PLADs from 1960 to 1969 at 12.78% (16,280/247,365) and 4.16% (202,488/4,870,090), respectively. In Ningxia Hui Autonomous Region, the rate was 11.3% from 1963 to 1966.

Sheep brucellosis seroprevalence declined from 1970 to 1979. However, some regions remained heavily affected, with 9.26% seroprevalence in Qinghai Province and 3.98% in Xinjiang Uygur Autonomous Region. From 1980 to 1989, sheep brucellosis was gradually controlled in some initially high-epidemic regions. Seroprevalence decreased in Shaanxi, Gansu, Ningxia, Xizang, Jilin, Liaoning, and Qinghai PLADs. In Qinghai Province, the positive rate decreased from 9.26% in the 1970s to 3.06% in the 1980s, while in Gansu Province, it decreased from 4.66% in 1981 to 0.10% in 1986, and the positive rate decreased from 2.54% in the 1950s to 0.54% in the 1980s. Positive rate in Xinjiang Uygur Autonomous Region declined to 0.79% in the 1980s. From 1987 to 1989, the overall sheep seroprevalence in 30 PLADs (excluding Chongqing Municipality) was 0.59% (6,113/

TABLE 1. Seroprevalence of brucellosis in sheep/goats, cattle/cows, and swine from the 1950s to the 1980s.

Hosts	Numbers/cases/rate	1951–1959	1960–1969	1970–1979	1980–1989	Total
Sheep/goats	Tested number (heads)	6,543,382	8,788,690	6,606,774	32,129,518	54,068,364
	Positive cases (heads)	234,154	520,140	143,733	95,582	993,609
	Positive rate (%)	3.58	5.92	2.18	0.30	1.84
Bovine	Tested number (heads)	1,289,667	3,703,368	7,773,531	9,589,551	22,356,117
	Positive cases (heads)	59,701	110,020	89,214	53,197	312,132
	Positive rate (%)	4.63	2.97	1.15	0.55	1.40
Swine	Tested number (heads)	2,149	6,714	20,783	285,979	315,625
	Positive cases (heads)	524	687	906	9,566	11,683
	Positive rate (%)	24.83	10.23	4.36	3.35	3.70

Note: Tested data in sheep were from 15 PLADs, including Tianjin, Inner Mongolia, Hebei, Jilin, Heilongjiang, Shandong, Yunnan, Shaanxi, Gansu, Zhejiang, Qinghai, Ningxia, and Xinjiang. Tested data in cattle/cows were from 22 PLADs from 1952 to 1989, including Tianjin, Inner Mongolia, Hebei, Jilin, Heilongjiang, Liaoning, Hubei, Beijing, Jiangsu, Anhui, Fujian, Henan, Guangdong, Sichuan, Shandong, Yunnan, Shaanxi, Gansu, Zhejiang, Qinghai, Ningxia, and Xinjiang. Tested data in swine were from 11 PLADs from 1955 to 1989, including Tianjin, Hebei, Liaoning, Zhejiang, Hunan, Guangdong, Yunnan, Shaanxi, Gansu, Xinjiang, and Inner Mongolia.
Abbreviation: PLADs=provincial-level administrative divisions.

1,037,181), ranging from 0.10% (Jilin Province) to 7.44% (Jiangsu Province) (Table 2).

Bovine (Cattle) Brucellosis Seroprevalence from 1951 to 1989

The overall seroprevalence of brucellosis in cattle from 22 PLADs was 1.4% (312,132/22,316,117) from 1952 to 1989. The seroprevalence in cattle gradually declined from 4.63% (59,701/1,289,667) from 1952 to 1959, to 2.97% (110,020/3,703,368) from 1960 to 1969, to 1.15% (89,214/7,733,531) from 1970 to 1979, and to 0.55% (53,197/9,589,551) from 1980 to 1989. In the 1950s, brucellosis in cattle was common in the north. The infection rates were 46.43%, 19.3%, 11.57%, and 12.27% in Ningxia, Qinghai, Gansu, and Xinjiang PLADs, respectively. Subsequently, the seroprevalence in cattle gradually declined from the 1950s to the 1980s, with rates of 1.60% in Xinjiang,

TABLE 2. Seroprevalences in brucellosis of sheep/goats, cattle/cows, and swine from 1987 to 1989.

PLADs	Sheep/goats (heads)			Cattle/cow (heads)			Swine (heads)		
	Tested number	Number of positive cases	Positive rate (%)	Tested number	Number of positive cases	Positive rate (%)	Tested number	Number of positive cases	Positive rate (%)
Beijing	17,446	6	0.03	12,909	12	0.09	1,754	5	0.29
Tianjin	1,592	0	0	1,013	0	0	2,254	0	0
Hebei	22,791	130	0.57	4,474	64	1.43	25	0	0
Shanxi	13,446	312	2.32	4,185	35	0.84	3,548	12	0.38
Inner Mongolia	118,400	296	0.25	10,807	118	1.09	884	26	2.14
Liaoning	63,964	322	0.50	52,730	447	0.80	3,819	14	0.30
Jilin	46,434	5	0.01	32,733	48	0.15	0	0	0
Heilongjiang	246,946	461	0.19	288,841	1,683	0.56	9,879	40	0.14
Shanghai	949	0	0	52,135	8	0.02	152,613	407	0.27
Jiangsu	1,666	124	7.44	8,237	28	0.34	3,417	69	2.19
Zhejiang	13,975	11	0.08	36,328	53	0.15	15,388	3	0.02
Anhui	1,687	31	1.84	2,662	15	0.60	1,146	32	2.80
Fujian	8,051	28	0.35	15,961	170	1.07	10,228	154	1.51
Jiangxi	328	0	0	4,181	1	0.17	4,301	6	0.14
Shangdong	31,390	225	0.81	21,016	97	0.46	0	0	0
Henan	3,635	26	0.71	5,854	57	0.97	6,585	2	0.03
Hubei	5,448	93	1.71	9,577	165	1.72	10,043	249	2.48
Hunan	4,169	115	2.76	12,396	423	3.41	11,910	483	4.06
Guandong	0	0	0	8,442	2	0.02	27,788	443	1.59
Guangxi	781	1	0.12	3,671	4	0.11	4,385	56	1.27
Hainan	60	0	0	1,249	8	0.64	858	7	6.82
Sichuan	109,609	2,036	1.86	30,017	498	1.66	16,256	107	0.66
Guizhou	2,407	14	0.58	3,733	86	2.30	2,684	30	1.18
Yunnan	5,775	19	0.33	8,327	1	0.01	7,878	8	0.10
Xizang	0	0	0	10,975	262	2.38	0	0	0
Shaanxi	31,545	92	0.29	8,085	24	0.39	3,069	12	0.39
Gansu	14,439	30	0.20	11,748	56	0.47	1,500	0	0
Qinghai	43,506	343	0.79	5,175	503	9.72	1,733	55	3.17
Ningxia	76,337	524	0.69	23,625	118	0.59	1,090	28	2.57
Xinjiang	150,405	869	0.58	114,691	735	0.64	5,359	52	0.97

Abbreviation: PLADs=provincial-level administrative divisions.

1.05% in Ningxia, and 8.9% in Qinghai in the 1980s. Epidemics and outbreaks gradually decreased and were controlled in regions with high seroprevalence. Brucellosis was still endemic in some previously low-epidemic regions from 1980 to 1984, at rates of 7.22% in Jiangxi, 6.66% in Liaoning, 5.20% in Hubei, 4.53% in Henan, 3.52% in Hunan, and 2.30% in Guizhou. Finally, the overall seroprevalence in cattle in all 30 PLADs (except Chongqing) decreased to 0.71% (5,727/803,782), with the lowest being 0.02% in Guangdong and the highest being 3.41% in Hunan Province.

Brucellosis Seroprevalence in Swine and Dogs from 1951 to 1989

Swine brucellosis seroprevalence was 3.7% (11,683/315,443) in 11 PLADs from 1955 to 1989, with rates of 24.38% (524/2,149) in the 1950s, 10.23% (687/6,714) in the 1960s, 4.36% (906/20,783) in the 1970s, and 3.35% (9,565/285,797) in the 1980s. Before the 1980s, swine brucellosis was atypical but locally endemic in Guangxi and Guangdong, where breeding swine production was prominent. In 1952, the Guilin Liangfeng swine farm in Guangxi introduced four Berkshire breeding pigs from Hong Kong Special Administrative Region (SAR), China, resulting in numerous infections and swine abortions. The seroprevalence in Guangxi in 1952 was 51.5% (381/739). In 1980, the swine brucellosis seroprevalence increased, peaking in 1985 at 8.15%, and subsequently declined continuously to 0.74% (2,300/310,394) from 1987 to 1989. Rates were 0.03% (2/6,585) in Henan and 4.06% (483/11,910) in Hunan (Table 2). In the late 1980s, *Brucella canis* brucellosis was reported, and *B. canis* was isolated and identified. The average positivity rate in 8 PLADs was 6.72% (141/2,099). Dog seroprevalence was 14.74% in Xinjiang from 1965 to 1989 and 22.5% in Qinghai. Seroprevalence in horses, deer, camels, poultry, and wildlife, such as yaks, has also been reported (*13*).

Animal Brucellosis Outbreaks from 2006 to 2021

From 2006 to 2021, a total of 38,248 outbreak events were recorded. The number of outbreaks increased from 90 in 2006 to a maximum of 6,126 in 2011 and then declined to 3,133 in 2021 (Figure 1A). Outbreak events were observed each month, with 62.19% (23,787/38,248) recorded from June to October. Most outbreaks occurred in August (5,418), followed by September (*n*=5,181), July (*n*=4,710), and June (*n*=4,291), with the fewest occurring in February (*n*=794) (Figure 1B). The average number of reported outbreak events was 2,390.5 per year and 3,187.3 per month. Sheep and cattle accounted for approximately 99.2% of cases, with 218,168 in sheep, 11,625 in cattle, and 303,609 in both. The proportion of cases involving other animal species was low. Additionally, 1,759 cases included deaths caused by *Brucella* infection, accounting for 0.33% of deaths in Inner Mongolia, Shaanxi, and Xinjiang.

Time and Seasonal Distribution Profiles of Animal Cases From 2006 to 2021

Between 2006 and 2021, a total of 537,797 cases were reported. The number of cases was 2,031 in 2006, rapidly increased to 125,030 in 2011, and then declined to 59,494 in 2020. The lowest number of cases (*n*=1,280) was observed in 2007 (Figure 2A). Although the number of cases fluctuated and decreased after the 2011 peak, there were at least five times more cases in 2021 than in 2006. The range of case counts across months was 10,233–65,480, with 54.1% of cases reported from April to September. Most cases occurred in June, followed by August (*n*=54,828) and July (*n*=48,792), with the lowest number occurring in January (Figure 2B).

Geographic Distribution of Animal Cases, 2006–2021

Animal brucellosis outbreaks were reported in 28 PLADs from 2006 to 2021, excluding Tianjin, Hainan, and Xizang PLADs. Inner Mongolia reported the highest number of outbreaks (21,860) between 2006 and 2021 (Figure 3), with a dramatic increase from 215 in 2010 to 5,464 in 2011, followed by a decline to 609 in 2021. Xinjiang reported 8,985 cases during the study period, with the number of outbreaks gradually increasing annually from 2 in 2006 to 1,543 in 2021. A similar trend was observed in Shaanxi Province, with outbreaks gradually increasing from 3 in 2006 to 744 in 2021. In the south, Hubei (*n*=931) and Zhejiang (*n*=518) reported the most outbreaks, both exhibiting an initial increasing trend followed by a gradual annual decline. The fewest cases were reported in Anhui (*n*=11), followed by Sichuan (*n*=24), Beijing (*n*=39), Shanghai (*n*=43), Guangxi (*n*=52),

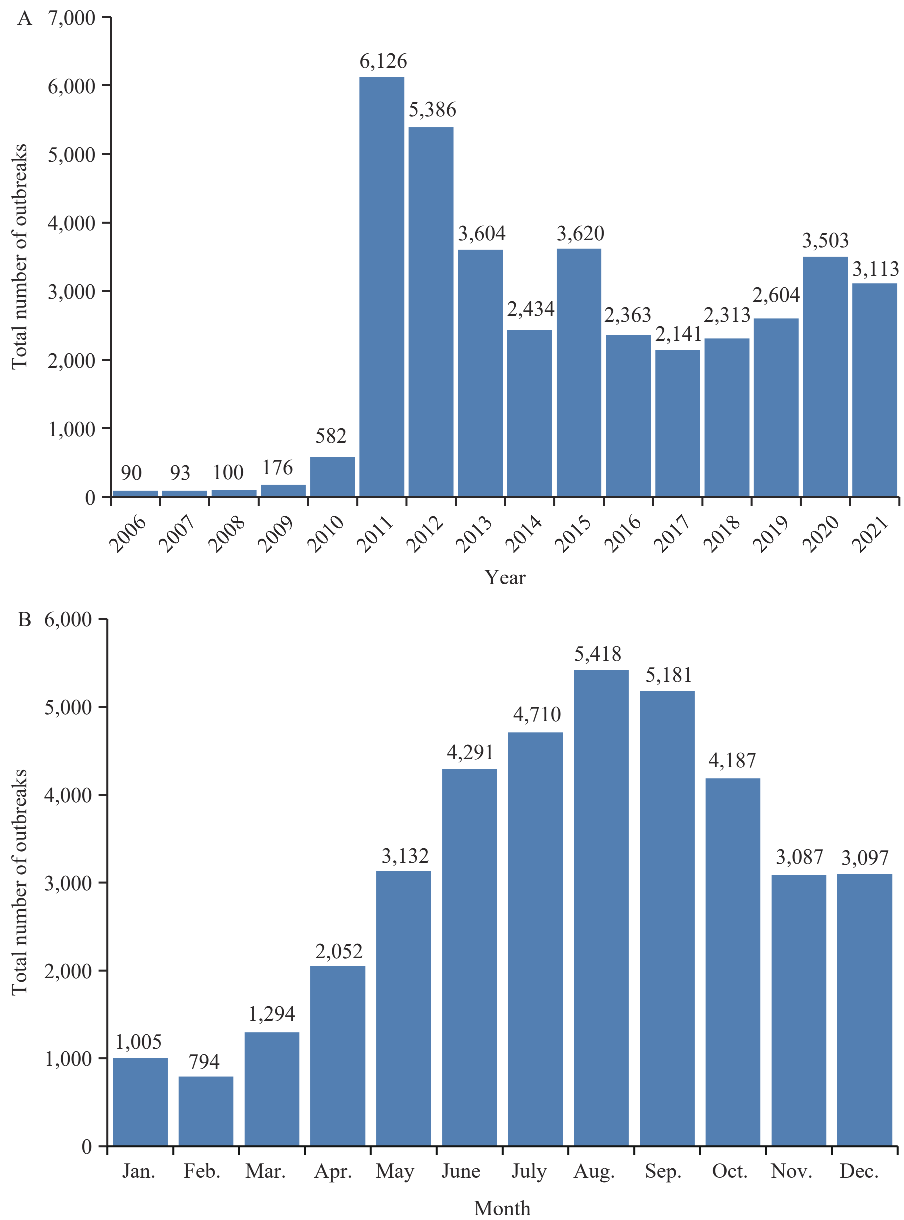

FIGURE 1. Brucellosis outbreak event in animals from 2006 to 2021. (A) Total number; (B) Seasonal distribution profile.
Note: Total outbreak number of brucellosis included the outbreak events from bovine, sheep, goats, and other hosts in this period.

Ningxia (*n*=57), and Guangdong (*n*=59). Other regions reported between 60 and 454 outbreaks. Approximately 40% of outbreaks occurred from 2011 to 2013, with 6,136 in 2011, 5,346 in 2012, and 3,604 in 2013. A total of 537,797 animal cases tested positive across 28 PLADs. Of these, 6.34% (34,070/537,797) were in the south and 93.67% (503,727/537,797) were in the north (Figure 4). Most cases were reported in Inner Mongolia (*n*=346,785), Xinjiang (*n*=105,367), and Shanxi (*n*=23,399), while Beijing reported the fewest (*n*=171). In the north, cases continuously increased from 1,797 in 2006 to 58,369 in 2020 before declining to 18,419 in 2021. In the south, Hubei reported the most cases (*n*=10,839), followed by Yunnan (*n*=5,888), Henan (*n*=4,841), and Zhejiang (*n*=4,536). Conversely, Sichuan recorded the lowest number (*n*=91). Southern cases rose from 234 in 2006, peaked in 2016 (*n*=8,014), and then fluctuated before declining to 741 in 2021. Notably, cases in the south increased with a lag of two to five years compared to the north. The peak occurred in the north in 2011 and in the south in 2016 (Figure 4).

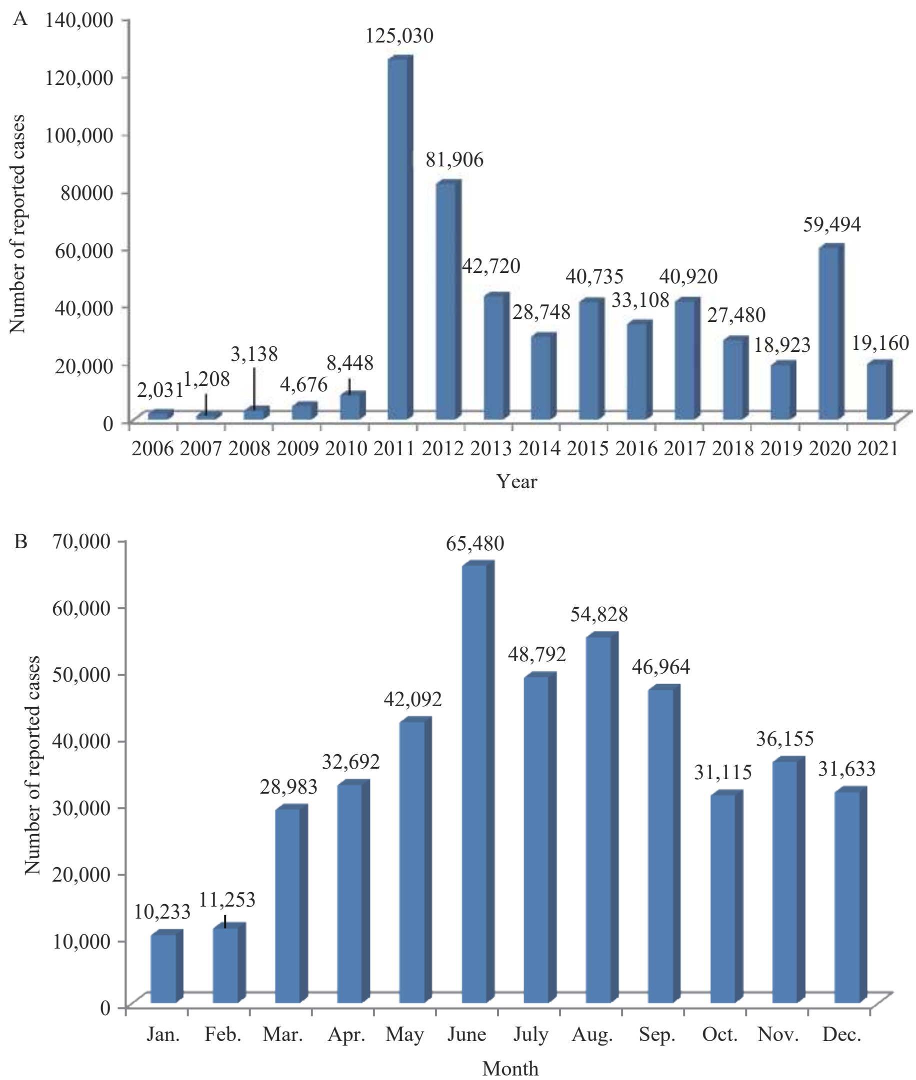

FIGURE 2. Reported brucellosis cases in animals from 2006 to 2021. (A) Total number; (B) Seasonal distribution profile.
Note: The total number of reported animal brucellosis cases included cases reported from bovine, sheep, goats, and other hosts in this period.

Time and Geographic Profile of Culled-Positive Animals from 2006 to 2021

The total culling rate of positive animals was 70.14% (377,230/537,797). The culling rate gradually declined from 103.3% in 2006 to 4.32% in 2017 and then fluctuated between 40.4% and 109.3% from 2017 to 2021 (Figure 5A). The trends in culling and infection rates between 2006 and 2021 were almost reversed. The culling rate of positive animals declined with an increase in the infection rate (Figure 5B). These data provide irrefutable evidence that the source of brucellosis infection is persistent and may move between herds and regions. Sichuan Province had the highest culling rate of positive animals (170.33%), followed by Anhui (157.29%), Beijing (156.73%), and Guangxi (155.35%) (Figure 5A). Additionally, the culling rates in nine PLADs were above 100%: Fujian, Shanghai, Jiangxi, Guangdong, Jiangsu, Jilin, Yunnan, Heilongjiang, and Guizhou (Figure 5A). However, the culling rates in 15 others PLADs were below 100%, with the lowest culling rate in Hubei [61.75% (6,693/10,839)], followed by 66.70% in Xinjiang, 68.98% in Ningxia, 70.77% in Shanxi, 78.26% in Shandong, 84.32% in Liaoning, and 84.69% in Inner Mongolia (Figure 5A). Furthermore, correlation analysis showed that the number of sheep and the infection rate of animal brucellosis were significantly correlated with the incidence rate and number of human brucellosis cases ($P \leq 0.001$) (Figure 6).

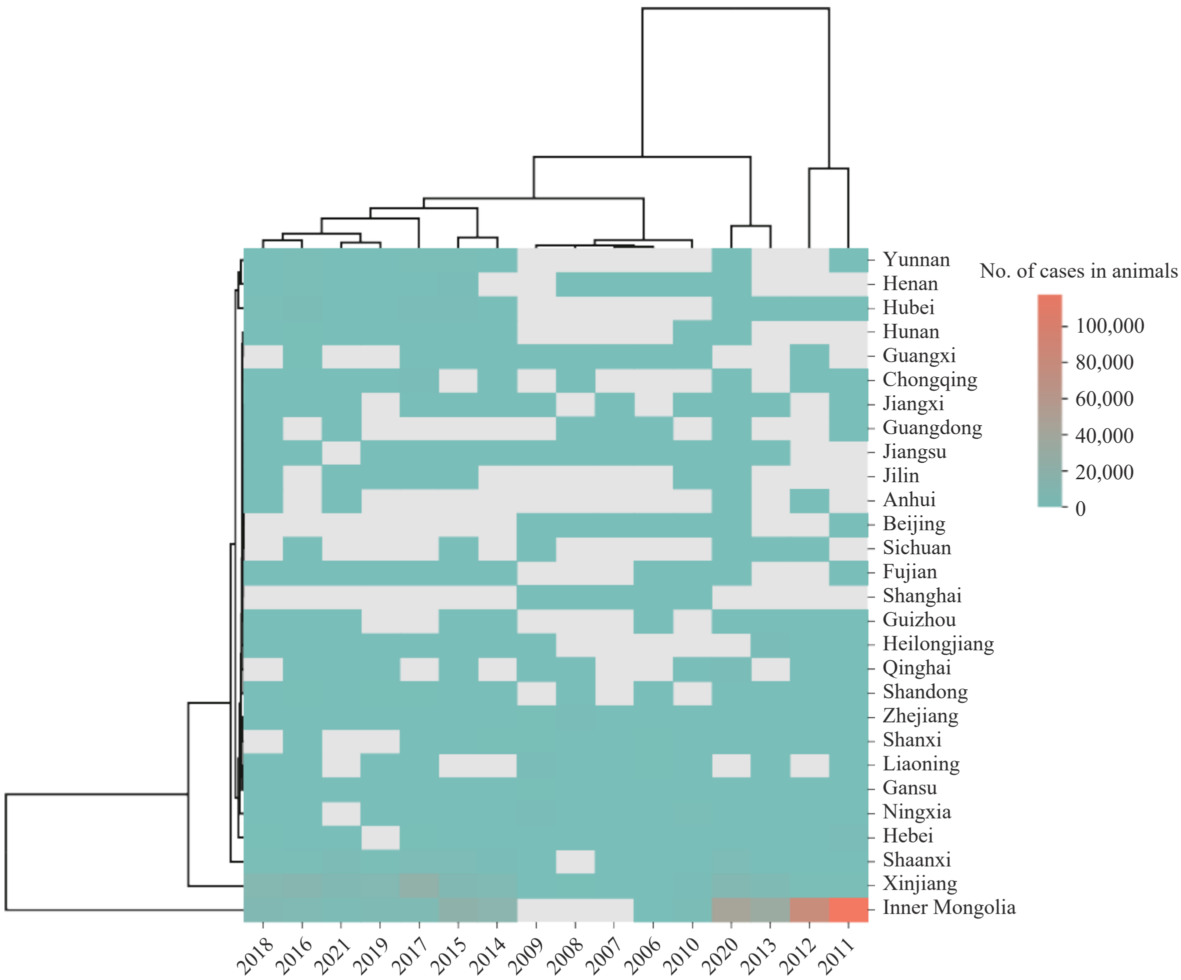

FIGURE 3. The distribution of reported brucellosis cases in animals at the PLADs level from 2006 to 2021.
Note: Number of cases reported in each province included those from bovine, sheep, goats, and other hosts in this period.
Abbreviation: PLADs=provincial-level administrative divisions.

District-Level Distribution of *Brucella* Species/Biovars

From 1951 to 1989, 2,015 *Brucella* strains were collected from animals, including 1,523 *B. melitensis* strains, 250 *B. abortus* strains, 208 *B. suis* strains, 32 *B. canis* strains, and 2 *B. ovis* strains. During this period, *B. melitensis* was mainly found in Xinjiang (*n*=286), followed by Shaanxi (*n*=217), Jilin (*n*=207), Henan (*n*=109), Sichuan (*n*=25), and fewer strains in Guangxi, Yunnan, and Fujian PLADs. *B. abortus* strains were dominant in Sichuan (*n*=122), Xinjiang (*n*=56), and Jilin (*n*=30). *B. suis* strains were distributed in Guangxi (*n*=98) and Guangdong (*n*=90). Fewer *B. canis* strains were observed in Sichuan, Fujian, Guangdong, and Guangxi PLADs (Supplementary Table S1, available at https://weekly.chinacdc.cn/). Additionally, only two *B. ovis* strains were isolated from Urumqi, Xinjiang. However, from 1996 to 2021, only 303 *Brucella* strains were isolated and identified from animals, with 254 *B. melitensis*, 26 *B. abortus*, and 23 *B. suis* strains. During this period, most *B. melitensis* strains were found in Xinjiang (*n*=101), Inner Mongolia (*n*=78), and Gansu (*n*=26). *B. abortus* strains were distributed in Hebei (*n*=11), Heilongjiang (*n*=10), and Xinjiang (*n*=5) PLADs. Additionally, 22 *B. suis* strains were isolated from animals in Inner Mongolia. The number and diversity of species/biotypes have gradually decreased, indicating a significant difference between the current serious epidemic situation of brucellosis and the number of strains in humans. Furthermore, the species/biotype distribution pattern of *Brucella* showed a pronounced shift from multiple co-driven species before the 2000s to a single dominant species, *B. melitensis*, after the 2000s.

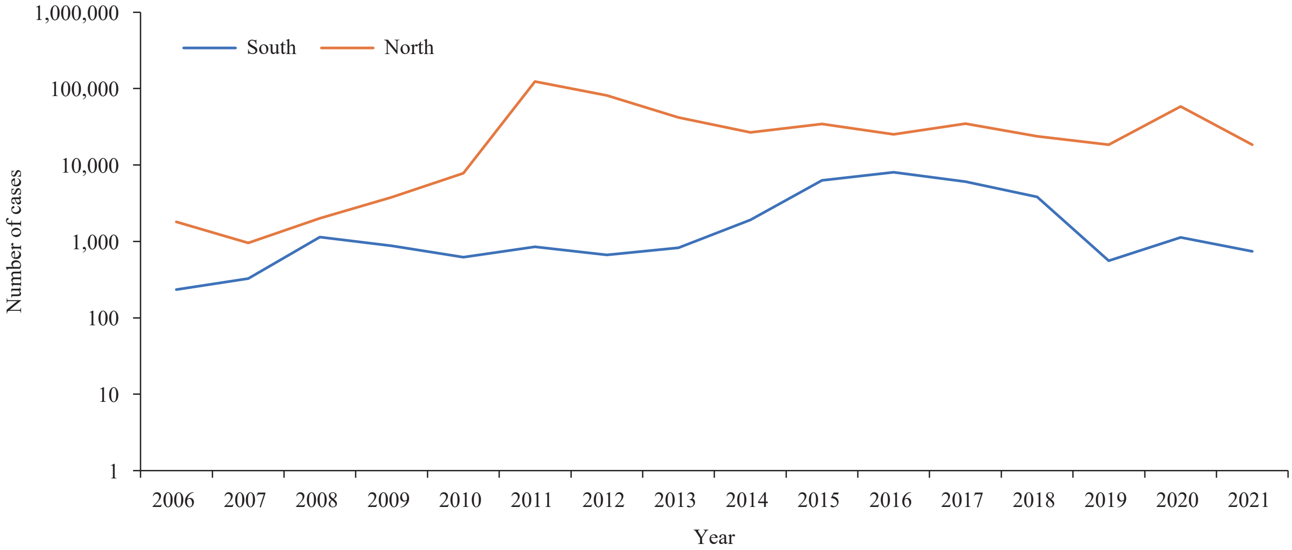

FIGURE 4. Distribution profile of reported brucellosis cases in animals between southern and northern regions from 2006 to 2021.
Note: Number of reported cases in southern and northern included cases from bovine, sheep, goats, and other hosts in this period.

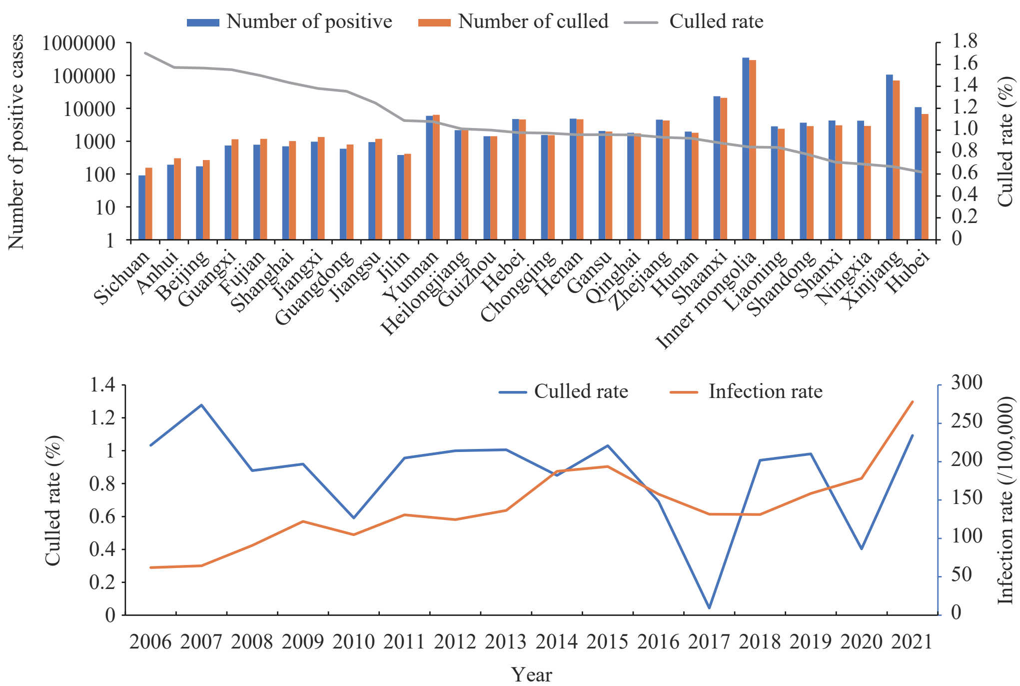

FIGURE 5. Brucellosis in animals from 2006 to 2021. (A) Change trend of culling rates; (B) Infection rates.
Note: Total number of culls in seropositive animals included bovine, sheep, goats, and other hosts each year.

DISCUSSION

This study involved a retrospective epidemiological evolution analysis of brucellosis in animals from the 1950s to the 2020s; the epidemic pattern was similar to that of human brucellosis (*10*). Two epidemic stages were identified during the examined period: the first from the 1950s to the 1980s and the second from 2006 to 2021. Almost all PLADs were involved in both stages, resulting in substantial harm to human health, the farming industry, and socioeconomic development (*9*). This study showed that brucellosis in

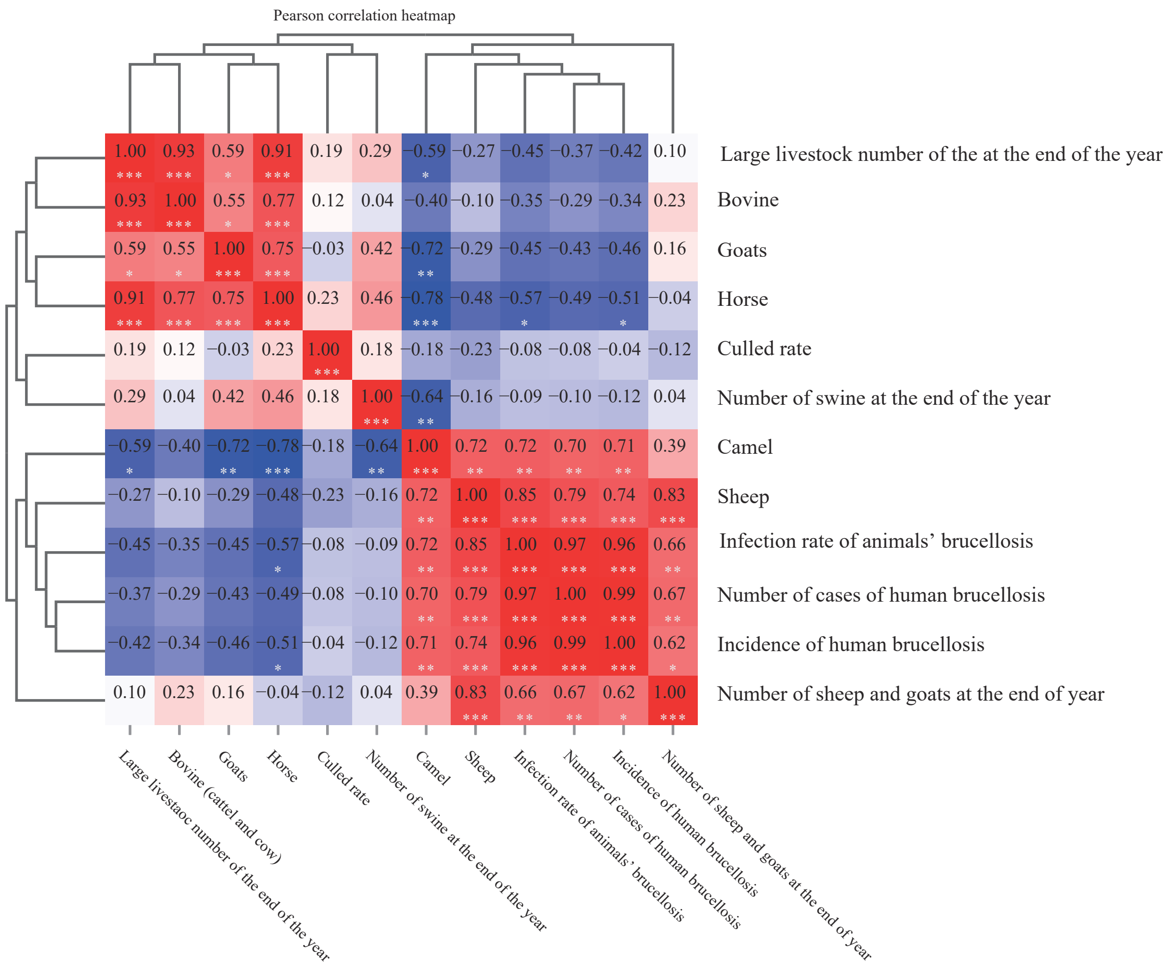

FIGURE 6. Pearson correlation analysis of incidence of human brucellosis and livestock breeding situation.
** $P≤0.01$;
*** $P≤0.001$.

sheep, goats, and cattle is dominant in mainland China, endemic areas are widespread in most PLADs, and swine brucellosis is predominant in Guangdong and Guangxi. Sheep, goats, and bovines were the only means of production and livelihood for thousands of people from the 1950s to the 1990s; cattle were the main production factor, including for farmland, cultivation, and transportation. After 2000, along with economic development, production pattern changes, and elevated living standards, sheep and goat breeding has continuously increased and expanded, and the incidence of brucellosis has worsened. Swine brucellosis was potentially introduced to mainland China and was dominant in Guangdong and Guangxi, where the breeding industry is large. Surveys showed that swine brucellosis became epidemic on farms and gradually spread to rural areas, further increasing the difficulty of control. In Guangxi, the seropositivity by SAT from 22,127 serum samples from breeding pigs between 2009 and 2011 was under 2.0%, but some historical epidemic areas have a re-emerging risk due to multiple factors (*14*). Currently, the epidemic features of brucellosis display a pronounced change in Guangxi; previously dominant circulating *B. suis* and *B. canis* strains have been replaced by *B. melitensis* strains (*15*).

Since the 1950s, some PLADs with high seroprevalence of animal brucellosis have organized and established institutes and groups for brucellosis surveillance and control according to government planning to implement surveillance and control strategies (*16*). From the 1950s to the 1960s, a set of comprehensive prevention and control measures primarily based on serological testing and vaccine immunization was implemented, including the culling and isolation of positive animals (*16*). In the 1970s, animal immunization was the main control tool, and all animals were vaccinated with the M5 (*17*) or *B. suis* strain 2 (S2) vaccine (*18*). In the 1980s, epidemic surveillance improved at the national and provincial levels, with the exception of vaccinated animals. Animal brucellosis has been preliminarily controlled since 1986 based on comprehensive control strategies, including immunization, quarantine, elimination, and culling, implemented over the past four decades (*9*,*19*). The incidence of human brucellosis has significantly decreased, and only a few cases have been reported. These data demonstrate that persistent immunization and quarantine measures for animals nationwide are still a priority for stopping human brucellosis (*20*). However, because current detection technology cannot discriminate between infection and vaccine immunization in animals, surveillance in animal immune zones present some puzzles. Therefore, we suggest that the implementation of mass vaccination in small ruminants in high-epidemic areas, and the surveillance and elimination of positive animals, is an option for control measures in zones with a low epidemic (*21*). In Kyrgyzstan, the introduction of mass vaccination in small ruminants has contributed to brucellosis control, thereby reducing the number of infections in animals and humans (*22*). Additionally, a vital reason for brucellosis control in the 1980s was that all breeding farms were collectively owned by the state, facilitating the implementation and purification of prevention and control strategies. Currently, the majority of livestock is owned by individuals, and transportation and transactions are extremely frequent, posing a severe challenge to brucellosis prevention and control (*23*). However, there was a considerable discrepancy in the reported cases between animals and humans, even though there was an almost reversed epidemic trend from 2006 to 2021. The incidence rate of human brucellosis increased during this period; however, the number of reported cases in the animal population gradually declined. These data revealed that testing and surveillance capacity for animal brucellosis was insufficient, and control measures were severely lacking. Testing and culling are very effective measures for animal disease prevention and control (*24*). There was a low positive animal culling rate in some regions with a high incidence rate, meaning that infected animals were not completely eliminated, resulting in the persistent circulation of the disease. The increased infection rate in the south was driven by the introduction of infected animals from the north, implying that control of the infected animal trade and transfer was inadequate. Currently, circulating *Brucella* species have obviously changed. Although a few *B. abrotus*, *B. suis*, and *B. canis* strains were occasionally isolated (*25*–*26*), *B. melitensis* strains were the predominant species in China and have expanded southward (*27*). *B. ovis* has only been historically isolated from Xinjiang; its epidemic situation needs further evaluation (*28*).

Despite incomplete surveillance data hindering accurate and timely prediction of brucellosis trends in animals, the nationwide growth of the animal breeding industry has increased the demand for animal products. Furthermore, the pursuit of economic benefits has driven changes in sheep breeding practices, which is another important factor to consider. For example, the “Small Tailed Han Sheep” breed gained recognition in China for its early maturity, high birth rates, and multiple offspring. This popularity increased the likelihood and frequency of human contact with infected sheep, contributing to the spread and rise in brucellosis infections.

In the Black Sea basin, ruminant health has been hindered by informal animal trade due to economic factors, insufficient support for developing formal trade, and sociocultural drivers (*29*). Animal trade movements were identified as a major transmission route for brucellosis spread between farms (*30*). Therefore, restricting the movement and trade of infected animals and implementing mass vaccination of small ruminants in regions with high incidence have been urged. Furthermore, strengthening surveillance, information exchange, risk assessment, and coordinated response capacity for animal brucellosis is urgent (*31*). In particular, grassroots veterinary departments must screen for and eliminate infected animals in a timely manner. Comprehensive intervention measures against brucellosis incidence in humans and animals are recommended. These measures include public awareness, effective hygiene management, and adequate quarantine or serological detection (e.g., SAT) for newly introduced animals (*32*–*33*). Given the high baseline prevalence, these measures should be based on vaccination combined with measures to promote hygiene and husbandry practices that minimize the risk of brucellosis spreading to low-endemic regions.

CONCLUSION

This study provides an updated epidemiological overview of animal brucellosis nationwide, which will aid government sectors in strengthening routine surveillance and vaccination to reduce disease occurrence and public health risks in China.

Additionally, a vast discrepancy was observed in the incidences of animal and human brucellosis after the 2000s. Therefore, strengthening the surveillance and control of diseased in animals is the most effective strategy. This includes persistent vaccination in high-incidence areas, implementing routine surveillance plans, and using strict animal movement restrictions to restrain further spread.

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REFERENCES

1. Donev DM. Brucellosis as priority public health challenge in south eastern European countries. Croat Med J 2010;51(4):283 – 4. https://doi.org/10.3325/cmj.2010.51.283.
2. Pisarenko SV, Kovalev DA, Volynkina AS, Ponomarenko DG, Rusanova DV, Zharinova NV, et al. Global evolution and phylogeography of *Brucella melitensis* strains. BMC Genomics 2018;19(1):353. https://doi.org/10.1186/s12864-018-4762-2.
3. Rossetti CA, Maurizio E, Rossi UA. Comparative review of brucellosis in small domestic ruminants. Front Vet Sci 2022;9:887671. https://doi.org/10.3389/fvets.2022.887671.
4. Liu ZG, Wang CL, Wei KJ, Zhao ZZ, Wang M, Li D, et al. Investigation of genetic relatedness of *Brucella* strains in countries along the silk road. Front Vet Sci 2021;7:539444. https://doi.org/10.3389/fvets.2020.539444.
5. Liu ZG, Gao LP, Wang M, Yuan M, Li ZJ. Long ignored but making a comeback: a worldwide epidemiological evolution of human brucellosis. Emerg Microbes Infect 2024;13(1):2290839. https://doi.org/10.1080/22221751.2023.2290839.
6. Mazlina M, Khairani-Bejo S, Hazilawati H, Tiagarahan T, Shaqinah NN, Zamri-Saad M. Pathological changes and bacteriological assessments in the urinary tract of pregnant goats experimentally infected with *Brucella melitensis*. BMC Vet Res 2018;14(1):203. https://doi.org/10.1186/s12917-018-1533-x.
7. Bagheri Nejad R, Krecek RC, Khalaf OH, Hailat N, Arenas-Gamboa AM. Brucellosis in the Middle East: current situation and a pathway forward. PLoS Negl Trop Dis 2020;14(5):e0008071. https://doi.org/10.1371/journal.pntd.0008071.
8. Garofolo G, Fasanella A, Di Giannatale E, Platone I, Sacchini L, Persiani T, et al. Cases of human brucellosis in Sweden linked to Middle East and Africa. BMC Res Notes 2016;9:277. https://doi.org/10.1186/s13104-016-2074-7.
9. Shang DQ, Xiao DL, Yin JM. Epidemiology and control of brucellosis in China. Vet Microbiol 2002;90(1-4):165 – 82. https://doi.org/10.1016/s0378-1135(02)00252-3.
10. Lai SJ, Zhou H, Xiong WY, et al. Changing epidemiology of human brucellosis, China, 1955-2014. Emerg Infect Dis 2017;23(2):184 – 94. https://doi.org/10.3201/eid2302.151710.
11. Yang HM, Chen QL, Li Y, Mu D, Zhang YP, Yin WW. Epidemic characteristics, high-risk areas and space-time clusters of human brucellosis - China, 2020-2021. China CDC Wkly 2023;5(1):17 – 22. https://doi.org/10.46234/ccdcw2023.004.
12. Mu HY, Chen JZ, Huang WJ, Huang G, Deng MY, Hong SM, et al. OmicShare tools: a zero - code interactive online platform for biological data analysis and visualization. iMeta 2024;3(5):e228. https://doi.org/10.1002/IMT2.228.
13. Tao ZF, Yang ZP, Chen YS, Yang SF, Xu JC, Wang Y, et al. Epidemiological survey of first human brucellosis outbreak caused by the Sika deer (*Cervus nippon*) - Guizhou Province, China, 2019. China CDC Wkly 2021;3(14):301 – 3. https://doi.org/10.46234/ccdcw2021.081.
14. Huang ZX, Chen YH, Lu JH, Liang YY, Zuo WS, Zhou GJ, et al. Epidemiological investigation and analysis of brucellosis in Guangxi pig breeds. Chin J Epidemiol 1986;5(1):48-51. https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CJFQ&filename=ZDFB198601017. (In Chinese).
15. Liu ZG, Wang M, Zhao HY, Piao DR, Jiang H, Li ZJ. Investigation of the molecular characteristics of *Brucella* isolates from Guangxi Province, China. BMC Microbiol 2019;19(1):292. https://doi.org/10.1186/s12866-019-1665-6.
16. Shang DQ. Progress in the study of prevention and control of Brucellosis in China in last 50 years. Chin J Epidemiol 2000;21(1):55 – 7. https://doi.org/10.3760/j.issn:0254-6450.2000.01.018.
17. Hou HH, Liu XF, Peng QS. The advances in brucellosis vaccines. Vaccine 2019;37(30):3981 – 8. https://doi.org/10.1016/j.vaccine.2019.05.084.
18. Zhu LQ, Feng Y, Zhang G, Jiang H, Zhang Z, Wang N, et al. *Brucella suis* strain 2 vaccine is safe and protective against heterologous *Brucella* spp. infections. Vaccine 2016;34(3):395 – 400. https://doi.org/10.1016/j.vaccine.2015.09.116.
19. Yang HX, Zhang SW, Wang TJ, Zhao CH, Zhang XY, Hu J, et al. Epidemiological characteristics and spatiotemporal trend analysis of human brucellosis in China, 1950-2018. Int J Environ Res Public Health 2020;17(7):2382. https://doi.org/10.3390/ijerph17072382.
20. Almuzaini AM. An epidemiological study of brucellosis in different animal species from the Al-Qassim Region, Saudi Arabia. Vaccines (Basel) 2023;11(3):694. https://doi.org/10.3390/vaccines11030694.
21. Herrera-López E, Suárez-Güemes F, Hernández-Andrade L, Córdova-López D, Díaz-Aparicio E. Epidemiological study of Brucellosis in cattle, immunized with *Brucella abortus* RB51 vaccine in endemic zones. Vaccine 2010;28 Suppl 5:F59-63. http://dx.doi.org/10.1016/j.vaccine.2010.03.057.
22. Kydyshov K, Usenbaev N, Sharshenbekov A, Aitkuluev N, Abdyraev M, Chegirov S, et al. Brucellosis in humans and animals in Kyrgyzstan. Microorganisms 2022;10(7):1293. https://doi.org/10.3390/MICROORGANISMS10071293.
23. Zeng H, Wang YM, Sun XD, Liu P, Xu QG, Huang D, et al. Status and influencing factors of farmers' private investment in the prevention and control of sheep brucellosis in China: a cross-sectional study. PLoS Negl Trop Dis 2019;13(3):e0007285. https://doi.org/10.1371/journal.pntd.0007285.
24. Nie YB, Sun XD, Hu HP, Hou Q. Bifurcation analysis of a sheep brucellosis model with testing and saturated culling rate. Math Biosci

Eng 2023;20(1):1519 – 37. https://doi.org/10.3934/mbe.2023069.
25. Wang H, Xu WM, Zhu KJ, Zhu SJ, Zhang HF, Wang J, et al. Molecular investigation of infection sources and transmission chains of brucellosis in Zhejiang, China. Emerg Microbes Infect 2020;9(1):889 – 99. https://doi.org/10.1080/22221751.2020.1754137.
26. Liu ZG, Wang LJ, Piao DR, Wang M, Liu RH, Zhao HY, et al. Molecular investigation of the transmission pattern of *Brucella suis* 3 from Inner Mongolia, China. Front Vet Sci 2018;5:271. https://doi.org/10.3389/fvets.2018.00271.
27. Zhu X, Zhao ZZ, Ma SY, Guo ZW, Wang M, Li ZJ, et al. *Brucella melitensis*, a latent "travel bacterium," continual spread and expansion from northern to Southern China and its relationship to worldwide lineages. Emerg Microbes Infect 2020;9(1):1618 – 27. https://doi.org/10.1080/22221751.2020.1788995.
28. Wang YZ, Chen CF, Cui BY, Liu JX. Comparative study on identity of *B.ovis* 019 strain by traditional methods and HOOF-prints technique. Acta Microbiol Sin 2007;47(2):240 – 3. https://doi.org/10.3321/j.issn:0001-6209.2007.02.011.
29. Arede M, Beltrán-Alcrudo D, Aliyev J, Chaligava T, Keskin I, Markosyan T, et al. Examination of critical factors influencing ruminant disease dynamics in the Black Sea Basin. Front Vet Sci 2023;10:1174560. https://doi.org/10.3389/fvets.2023.1174560.
30. Darbon A, Valdano E, Poletto C, Giovannini A, Savini L, Candeloro L, et al. Network-based assessment of the vulnerability of Italian regions to bovine brucellosis. Prev Vet Med 2018;158:25 – 34. https://doi.org/10.1016/j.prevetmed.2018.07.004.
31. Batsukh Z, Tsolmon B, Otgonbaatar D, Undraa B, Dolgorkhand A, Ariuntuya O. One health in Mongolia. In: Mackenzie JS, Jeggo M, Daszak P, Richt JA, editors. One health: the human-animal-environment interfaces in emerging infectious diseases. Berlin, Heidelberg: Springer. 2012; p. 123-37. http://dx.doi.org/10.1007/82_2012_253.
32. Merga Sima D, Abdeta Ifa D, Merga AL, Tola EH. Seroprevalence of bovine brucellosis and associated risk factors in western Ethiopia. Vet Med (Auckl) 2021;12:317 – 24. https://doi.org/10.2147/VMRR.S338930.
33. Moriyón I, Blasco JM, Letesson JJ, De Massis F, Moreno E. Brucellosis and one health: inherited and future challenges. Microorganisms 2023;11(8):2070. https://doi.org/10.3390/MICROORGANISMS11082070.

SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Distribution pattern of *Brucella* strains in 23 provinces from 1978 to 2019.

PLADs	Distribution pattern of *Brucella* strains from 1978 to 1989						Distribution pattern of *Brucella* strains from 1996 to 2019			
	B. melitensis	***B. abortus***	***B. suis***	***B. canis***	***B. ovis***	**Total**	***B. melitensis***	***B. abortus***	***B. suis***	**Total**
Hunan	−	1	1	1	−	3	−	−	−	−
Yunnan	4	2	1	−	−	7	−	−	−	−
Fujian	5	1	2	6	−	14	−	−	−	−
Heilongjiang	36	1	1	−	−	38	−	10	−	10
Shandong	53	−	−	−	−	53	12	−	−	0
Inner Mongolia	62	10	1	−	−	73	78	−	22	100
Guangdong	−		90	3	−	93	−	−	−	0
Qinghai	97	−	−	−	−	97	14	−	1	15
Ningxia	95	−	7	−	−	102	−	−	−	0
Xizang	87	14	2	−	−	103	−	−	−	0
Henan	109	1	−	−	−	110	2	−	−	2
Guangxi	7	−	98	6	−	111	−	−	−	0
Shanxi	119	1	1	−	−	121	1	−	−	1
Gansu	114	8	2	−	−	124	26	−	−	26
Sichuan	25	122	−	9	−	156	−	−	−	0
Shaanxi	207	3	−	−	−	210	−	−	−	0
Jilin	217	30	−	−	−	247	−	−	−	0
Xinjiang	286	56	2	7	2	353	101	5	−	106
Chongqing	−	−	−	−	−	−	3	−	−	3
Guizhou	−	−	−	−	−	−	3	−	−	3
Hainan	−	−	−	−	−	−	1	−	−	1
Hebei	−	−	−	−	−	−	5	11	−	16
Zhejiang	−	−	−	−	−	−	8		−	8

Note: "−" means no strain.
Abbreviation: PLADs=provincial-level administrative divisions.