Geospatial Distribution of Toxoplasmosis Prevalence among Livestock, Pets and Humans in China, 1984-2020

Yajing Su

General Hospital of Ningxia Medical University

Xia Qiao

General Hospital of Ningxia Medical University

Wei Jia

General Hospital of Ningxia Medical University

Pengtao Wang

General Hospital of Ningxia Medical University

Yuting Kang

General hospital of Ningxia Medical University

Ningai Yang

General Hospital of Ningxia Medical University

Zhijun Zhao (✉ 937000560@qq.com)

General Hospital of Ningxia Medical University

Research

Keywords: Toxoplasma gondii, seroprevalence, GIS, geospatial distribution, China

Posted Date: May 10th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-442724/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background: *Toxoplasma gondii* (*T. gondii*) is an important foodborne zoonotic parasite with respect to abortion, intracranial calcifications, congenital hydrocephalus, retinochoroiditis, and toxoplasmic encephalitis in severely immunosuppressed individuals. Undercooked/raw meat containing cyst-stage bradyzoites and contaminated pets are presumed to constitute a major source of human infection. Although many seroprevalence studies have been performed in humans and different animal species in China, data on the geospatial distribution of toxoplasmosis prevalence are extremely scarce. The aim of the present study was to investigate the prevalence and geospatial distribution of toxoplasmosis among livestock, pets and humans in China using geographic information system (GIS) for the prevention and control of toxoplasmosis.

Methods: This article is based on the data from PubMed, China National Knowledge Infrastructure (CNKI) and Baidu Scholar databases from 1984 up to 2020 regarding prevalence data of toxoplasmosis among livestock (sheep and goats, swines, cattle and yaks), pets (cats, dogs) and humans in China. Geospatial distribution of the prevalence of toxoplasmosis in these hosts was performed using the GIS visualization techniques.

Results: Analysis revealed wide geospatial variation of toxoplasmosis in China. The estimated pooled seroprevalence of *T. gondii* was ranged from 3.98% to 43.02% among sheep and goats in China, 0.75% to 30.34% in cattle and yaks, 10.45% to 66.47% in swines, 2.50% to 60.00% in cats, 0.56% to 27.65% in dogs, and 0.72% to 23.41% in humans. The higher seroprevalences of *T. gondii* were observed in districts Chongqing, Zhejiang and Beijing in sheep and goats. The infection rates of *T. gondii* in cattle and yaks were higher in districts Guizhou, Zhejiang and Chongqing. Moreover, the swines from districts Chongqing and Guizhou were also most severely infected with *T. gondii*. In cats, districts Shanxi, Hebei and Yunnan had higher seroprevalences of *T. gondii* and, the infections among dogs were higher in districts Yunnan and Hebei as well. Furthermore, higher infection pressure of *T. gondii* exists in districts Taiwan and Tibet in humans.

Conclusion: The present study indicated that the infection with *T. gondii* was widely spread in China, with a wide range of variation. The investigation of *T. gondii* infection in livestock, pets and humans can be useful for assessing *T. gondii* environmental contamination and the risk for public health. Certain measures can be taken to prevent the prevalence of *T. gondii* infection in China, such as strengthening the management of livestock farms, keeping the barn clean, preventing feline excreta from polluting environment, using filtered water or water boiling, wearing gloves when handling raw meat and improving the practice of good hand hygiene.

Background

Toxoplasmosis one of the world's most common parasitic zoonoses, caused by the obligate apicomplexan intracellular protozoan *Toxoplasma gondii* (*T. gondii*). Infections occur among most

genera of warm-blooded animal species and humans with a complex life cycle and pathogenic mechanism. About 30–50% of the global human population is estimated to be chronically infected with this parasite [1]. Whilst the infections are generally either asymptomatic or develop mild symptoms that are self-limited, in some immunocompromised individuals and developing fetuses *T. gondii* can cause hydrocephalus, chorioretinitis and even death. Hence, the prevalence of *T. gondii* makes it one of the most damaging zoonotic diseases in the world [2–3].

Country-specific environmental conditions, eating habits, hygiene, and host susceptibility all contribute to global differences in the prevalence of toxoplasmosis in humans, with previous studies have reported country-specific prevalence rates of 6.7% in Korea; 12.3% in China; 46.0% in Tanzania; 61.0% in France and 84.5% in Brazil [4–5]. Worldwide, serological studies in livestock revealed that the average *T. gondii* prevalence is 14.0% in cattle; 27.0% in goats; 66.0% in sheep; and 25.0% in pigs. For 2000–2017, the overall prevalence of *T. gondii* in livestock in China has been estimated to be 9.1% in cattle and yaks, 11.8% in sheep, 17.6% in goats, and 32.9% in swines [3].

Toxoplasmosis has a complex epidemiology being transmitted by vertical and horizontal. Vertical transmission of infection from mother to fetus through the placenta during pregnancy. Horizontal transmission of *T. gondii* is even more common than congenital, which occurs primarily via ingestion of water, soil and crops contaminated with oocysts or consumption of undercooked/raw meat from livestock (e.g. cattle, sheep and swine) containing cyst-stage bradyzoites [6–8]. Regrettably, *T. gondii* infection cannot be detected by routine meat inspection, and there has been relatively little emphasis on the prevention in the food chain. Meat of infected animals is presumed to constitute a major source of human infection [8].

On the other hand, contaminated pet cats and dogs can also transmit toxoplasmosis to humans. This transmission is generally complex, requiring close contact with pets or their excretions and frequently violating hand hygiene procedures [9]. Notably, cats and other felidae, considered the single definitive host of *T. gondii*, are able to excrete oocysts. The oocysts is an environmentally resistant life cycle stage from infected cat faeces, which can remaining infectious for periods up to 18 months or longer and transmitting the infection when ingested orally [10].

Geographic information system (GIS) covers iconology, geographic information science and computer science, used for inputting, storing, managing, displaying and analyzing geographic or spatial data. GIS have been become an essential component of modern disease surveillance systems [11–12]. Investigation using GIS technologies coupled with spatial analysis, provide an important method of establishing a prompt and precise understanding of local data on disease spread, which can help us understand where disease and illness spread and how they may be minimized or stopped. Previous research on toxoplasmosis of livestock and humans has identified high-risk geographical areas; however, no study has assessed the prevalence and geospatial distribution among livestock, pets and humans of toxoplasmosis in China using a large population-based data. Here, we aimed to identify the epidemiology and geospatial distribution of toxoplasmosis among livestock (sheep and goats, swines, cattle and yaks),

pets (cats, dogs) and humans in China from 1984–2020 using GIS technologies in order to provide suggestions on the prevention and control of this foodborne pathogen.

Methods

Data collection

To gather all epidemiological data of toxoplasmosis in China from articles that are published in English and Chinese covering a period from January 1984 to December 2020, PubMed, China National Knowledge Infrastructure (CNKI) and Baidu Scholar databases were searched using the keywords that included “toxoplasmosis, China” or “*Toxoplasma gondii*, China”. Results were then checked for duplicates in the same research group, incomplete original data were reviewed in order to exclude all inadequate articles. Furthermore, the seroprevalence of *T. gondii* researches was limited to the detection of specific anti-toxoplasma immunoglobulin IgG in serum, which include indirect hemagglutination (IHA), enzyme-linked immunoabsorbent assay (ELISA), and modified agglutination test (MAT). Each report was used to extract information on the survey dates, locations (geo-coded to provide a longitude and latitude) of the survey cities, infected number, examined number, publication time and other information.

Spatial orientation and expression

To identify the spatial attribute information of the survey cities, the global positioning system (GPS) (<http://www.toolzl.com/tools/gps.html>) was used to obtain the latitude and longitude coordinates of each survey city. Meanwhile, we used the longitude and latitude coordinates of provincial capitals for the survey sites only introduced to the survey provinces. ArcGIS 10.2 geographic information system was used to map the geospatial distribution of toxoplasmosis prevalence in China. All the data collected were processed geographically. ArcGIS 10.2 was then used to match the venue of the survey cities with the geographic locations. The administrative map was sourced from Chinese Academy of Sciences Resource and Environment Science Data Center (<http://www.resdc.cn/>).

Statistical analysis

For prevalence estimates, *T. gondii* for each survey city was estimated as: number of infected hosts/number of sampled hosts × 100, using Excel software. The results are presented as adjusted rate ratios with 95% confidence intervals (CI).

Results

Geospatial distribution of livestock exposed to *T. gondii* in China

Geospatial distribution of sheep and goats exposed to *T. gondii*

Small ruminants are intermediate hosts of *T. gondii*, which are highly susceptible to *T. gondii* and, chronically infectious for life. It is believed that the parasite is a major cause of abortion and neonatal

mortality in sheep and goats, resulting in economic loss [13–14]. Furthermore, consumption of raw or undercooked meat from these animals has been regarded as a major route of *T. gondii* transmission to humans, especially in countries and regions where mutton and beef is regularly eaten [15]. According to the epidemiological data of toxoplasmosis in administrative districts, a map showing geospatial distribution of *T. gondii* for sheep and goats was generated (Fig. 1 and Table 1). Where Xizang (5.71%,26/455, 95%CI 3.58–7.84%), Hebei (5.96%,34/570, 95%CI 4.02–7.90%) and Qinghai (6.89%,1729/25100, 95%CI 6.58–7.20%) had low seroprevalences of *T. gondii* infection in sheep and goats. Otherwise, the seroprevalence of *T. gondii* in districts with higher levels was 37.78% (85/225, 95%CI 31.58–43.98%) in Zhejiang, 35.19%(183/520, 95%CI 31.08–39.30%) in Beijing and 31.67% (19/60, 95%CI 19.91–43.43%) in Hubei. Among them, the highest seroprevalence was observed in Chongqing (43.02%,296/688, 95%CI 39.30–46.74%), and the lowest in Ningxia (3.98%,46/1156, 95%CI 2.85–5.11%). Moreover, there were no epidemiological survey of toxoplasmosis in sheep and goats in districts Tianjin, Jiangxi, Anhui, Shanxi, Jilin, Hainan, Sichuan, Taiwan, Hong Kong, and Macao (Fig. 1 and Table 1).

Table 1
Seroprevalence of *T. gondii* infection in sheep and goats from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
NingXia	46	1156	3.98	2.85–5.11%
XiZang	26	455	5.71	3.58–7.84%
HeBei	34	570	5.96	4.02–7.90%
QingHai	1729	25100	6.89	6.58–7.20%
LiaoNing	231	2993	7.72	6.76–8.68%
HuNan	592	7594	7.80	7.21–8.39%
GuangDong	11	140	7.86	3.39–12.33%
XinJiang	1106	11896	9.30	8.78–9.82%
FuJian	37	331	11.18	7.79–14.57%
HeNan	765	6012	12.72	11.89–13.55%
JiangSu	100	780	12.82	10.50–15.14%
Nei Mongol	369	2745	13.44	13.04–13.84%
GuangXi	131	729	17.97	15.18–20.74%
ShaanXi	277	1415	19.58	17.52–21.64%
GanSu	1765	8938	19.75	18.92–20.58%
ShangHai	34	170	20.00	13.99–26.01%
HeiLongJiang	77	280	27.50	22.28–32.72%
GuiZhou	3691	12897	28.62	27.85–29.39%
ShanDong	115	398	28.89	24.42–33.36%
YunNan	2400	8096	29.64	29.64–30.64%
HuBei	19	60	31.67	19.91–43.43%
BeiJing	183	520	35.19	31.08–39.30%
ZheJiang	85	225	37.78	31.58–43.98%
ChongQing	296	688	43.02	39.30–46.74%
^a 95% Confidence Interval				

Geospatial distribution of cattle and yaks exposed to *T. gondii*

Beef and dairy products are widely consumed by humans worldwide, which observed from relevant statistics that the annual consumption of beef in China was > 8 million tons in 2016 and the consumption of dairy products was 40–43 million tons in 2014 [16]. Yak is an iconic species of the Qinghai-Tibet Plateau and, China has 1.3 million yaks accounting for 90% of the world's yak population [17]. It has been reported that isolating *T. gondii* from seropositive cattle were often unsuccessful, however Dubey JP [18] showed that viable tissue cysts can remain in cattle for up to 1 191 days. Hence, the contaminated cattle and yaks may be an important source for *T. gondii* transmitted to other animals and humans in China [14]. The geospatial distribution of toxoplasmosis in cattle and yaks in China is shown in Fig. 1. The results indicated that the infection rates of toxoplasmosis in cattle and yaks were highest in Guizhou (30.34%, 162/534, 95%CI 26.42–34.26%), then Zhejiang (27.64%, 76/275, 95%CI 22.34–32.94%) and Chongqing (27.25%, 94/345, 95%CI 22.57–31.93%). Whereas the present study also revealed very low seroprevalences of *T. gondii* in cattle and yaks in Shandong (0.75%, 2/266, 95%CI -0.29–1.79%), Ningxia (0.91%, 8/878, 95%CI 0.29–1.53%), and Jiangsu (0.96%, 2/208, 95%CI -0.37–2.29%). In addition, districts Jiangxi, Hubei, Hong Kong, Macao and Taiwan had no epidemiological study of toxoplasmosis in cattle and yaks (Fig. 1 and Table 2).

Table 2
Seroprevalence of *T. gondii* infection in cattle and yaks from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
ShanDong	2	266	0.75	-0.29–1.79%
NingXia	8	878	0.91	0.29–1.53%
JiangSu	2	208	0.96	-0.37–2.29%
Nei Mongol	7	474	1.48	0.41–2.55%
HeLongJiang	57	2244	2.54	-1.89–3.19%
ShanXi	1	26	3.85	-3.54–11.24%
HaiNan	1	25	4.00	-3.68–11.68%
GuangDong	24	537	4.47	2.72–6.22%
ShaanXi	4	84	4.76	0.21–9.31%
HeNan	414	8304	4.99	4.53–5.45%
FuJian	54	1029	5.25	2.16–8.34%
LiaoNing	39	646	6.04	0.42–7.88%
BeiJing	5	82	6.10	0.91–11.29%
HeBei	26	366	7.10	4.47–9.73%
SiChuan	139	1674	8.30	6.99–9.61%
QingHai	1529	18207	8.40	8.01–8.79%
TianJin	7	80	8.75	2.56–14.94%
ShangHai	69	696	9.91	7.68–12.14%
JiLin	271	2629	10.31	9.15–11.47%
XinJiang	739	6528	11.32	10.93–11.71%
AnHui	23	200	11.50	7.12–15.88%
GuangXi	1063	8037	13.23	12.50–13.96%
YunNan	1875	10587	17.71	16.98–18.44%
GanSu	772	3918	19.70	18.46–20.94%
XiZang	486	1987	24.46	22.57–26.35%

^a 95% Confidence Interval

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
HuNan	13	53	24.53	12.93–36.13%
ChongQing	94	345	27.25	22.57–31.93%
ZheJiang	76	275	27.64	22.34–32.94%
GuiZhou	162	534	30.34	26.42–34.26%
^a 95% Confidence Interval				

Geospatial distribution of swines exposed to *T. gondii*

China is the world's largest pork consumer, as well as the world's largest pork producer with nearly 50% of the world's total production. Swines exposed to *T. gondii* play an important role as a source of infection for humans [18–19]. The epidemiological data and spatial distribution of *T. gondii* are presented in Fig. 1 and Table 3. Results showed that the swines from Chongqing (66.47%,12485/18782, 95%CI 65.32–66.68%) were the most severely infected with *T. gondii*, followed by the Guizhou (42.00%,3197/7612, 95%CI 41.89–43.11%), and Xinjiang (35.82%,1404/3920, 95%CI 31.32–37.32%). Whilst districts Heilongjiang (10.45%,198/1894, 95%CI 9.08–11.82%), Qinghai (11.77%,888/7544, 95%CI 11.04–12.50%) and Guangdong (12.02%,4798/39928, 95%CI 11.70–12.34%) had lower rates of toxoplasmosis in swines. Moreover, there were no epidemiological study of *T. gondii* in swines in districts Inner Mongolia, Hong Kong, Macao and Taiwan (Fig. 1 and Table 3).

Table 3
Seroprevalence of *T. gondii* infection in swines from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
HeiLongJiang	198	1894	10.45	9.08–11.82%
QingHai	888	7544	11.77	11.04–12.50%
GuangDong	4798	39928	12.02	11.70–12.34%
NingXia	167	1284	13.01	11.17–14.85%
JiangXi	321	2156	14.89	13.38–16.40%
ShaanXi	169	1092	15.48	13.33–17.63%
BeiJing	369	2215	16.66	15.14–18.18%
JiLin	365	2038	17.91	16.27–19.55%
FuJian	2321	12135	19.13	18.42–19.84%
XiZang	126	649	19.41	16.41–22.41%
LiaoNing	2887	14228	20.29	19.64–20.94%
HeNan	7288	32694	22.29	21.84–22.74%
ShanDong	508	2195	23.14	21.38–24.90
AnHui	315	1308	24.08	21.76–26.40%
HuNan	705	2836	24.86	23.28–26.44%
ShanXi	321	1247	25.74	23.34–28.14%
YunNan	4119	15792	26.08	25.40–26.76%
TianJin	63	241	26.14	20.60–31.68%
HuBei	1225	4681	26.17	24.93–27.41%
SiChuan	249	940	26.49	23.72–29.26%
GanSu	1226	4517	27.14	25.84–28.44%
JiangSu	2152	7851	27.41	26.43–28.39%
GuangXi	2537	8623	29.42	28.46–30.38%
ShangHai	1997	6426	31.08	32.21–29.98%
ZheJiang	8853	28474	31.09	30.55–31.63%

^a 95% Confidence Interval

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
HeBei	682	2148	31.75	29.79–33.71%
HaiNan	144	436	33.03	28.60–37.46%
XinJiang	1404	3920	35.82	31.32–37.32%
GuiZhou	3197	7612	42.00	41.89–43.11%
ChongQing	12485	18782	66.47	65.32–66.68%
^a 95% Confidence Interval				

Geospatial distribution of pets exposed to *T. gondii*

Geospatial distribution of cats exposed to *T. gondii*

Cats and other felids, as a definitive host have a major role in the epidemiology of toxoplasmosis in human and animals, shedding infective oocysts in faeces. Cats and dogs are the most common pets in China, the population of pet cats and dogs are approaching 100 and 200 million, respectively [20]. The study herein showed that the cats from Shanxi (60.00%,54/90, 95%CI 49.82–70.18%) were the most severely infected with *T. gondii*. Secondly, there were those from districts Hebei (57.33%,43/75, 95%CI 46.07–68.59%) and Yunnan (43.64%,24/55, 95%CI 30.49–56.79%) (Fig. 1 and Table 4). Lowest seroprevalence of *T. gondii* in cats was recorded in districts Sichuan (2.5%,3/120, 95%CI -0.27–5.27%), then followed by Fujian (2.71%,6/221, 95%CI 0.57–4.85%) and Guangxi (4.50%,5/111, 95%CI 0.63–8.37%) shown in the Fig. 1 and Table 4. Moreover, districts Anhui, Jiangxi, Hainan, Shaanxi, Qinghai, Xizang, Tianjin, Taiwan, Hong Kong, and Macao haven't yet been inspected on epidemiological of toxoplasmosis in cats (Fig. 1 and Table 4).

Table 4
Seroprevalence of *T. gondii* infection in cats from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
SiChuan	3	120	2.50	-0.27–5.27%
FuJian	6	221	2.71	0.57–4.85%
GuangXi	5	111	4.50	0.63–8.37%
Nei Mongol	9	87	10.34	3.84–16.84%
BeiJing	903	8330	10.84	8.88–12.80%
GuangDong	62	503	12.33	9.56–15.10%
ChongQing	11	78	14.10	6.26–21.94%
ShanDong	144	954	15.09	12.86–17.32%
NingXia	37	244	15.16	10.78–19.54%
ShangHai	75	431	17.40	14.01–20.79%
JiLin	43	235	18.30	13.50–23.10%
GanSu	186	950	19.58	17.02–22.14%
HeiLongJiang	69	352	19.60	15.44–23.76%
LiaoNing	61	277	22.02	17.22–26.82%
JiangSu	137	558	24.55	20.99–28.11%
Xinjiang	47	169	27.81	21.02–34.60%
HuNan	21	75	28.00	17.82–38.18%
HeNan	351	1223	28.70	26.14–31.26%
ZheJiang	193	657	29.38	25.99–32.77%
GuiZhou	48	154	31.17	23.84–64.66%
HuBei	159	487	32.65	28.49–36.81%
YunNan	24	55	43.64	30.49–56.79%
HeBei	43	75	57.33	46.07–68.59%
ShanXi	54	90	60.00	49.82–70.18%
^a 95% Confidence Interval				

Geospatial distribution of dogs exposed to *T. gondii*

The dog, an intermediate host for *T. gondii*, may play an instrumental role in mechanically transmitting toxoplasma infection to humans, occurring from dogs via their body surface, mouth and feet [21]. The geographical distribution map of epidemiology of toxoplasmosis among dogs in China is illustrated in Fig. 1. There was no data about *T. gondii* prevalence among dogs in districts Shanxi, Anhui, Jiangxi, Hainan, Xizang, Tianjin, Hong Kong, Macao and Taiwan. In dogs, the higher seroprevalences of *T. gondii* infections were detected in districts Yunnan (27.65%, 425/1537, 95%CI 25.42–29.88%), Hebei (26.92%, 21/78, 95%CI 17.12–36.72%) and Xinjiang (20.44%, 657/3214, 95%CI 19.05–21.83%). In contrast, the infection of *T. gondii* was lowest in districts Shaanxi (0.56%, 3/537, 95%CI -0.06–1.18%), then Guangxi (2.94%, 6/204, 95%CI 0.62–5.26%) and Heilongjiang (5.11%, 18/352, 95%CI 2.79–7.43%) were next (Fig. 1 and Table 5).

Table 5
Seroprevalence of *T. gondii* infection in dogs from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
ShaanXi	3	537	0.56	-0.06–1.18%
GuangXi	6	204	2.94	0.62–5.26%
HeiLongJiang	18	352	5.11	2.79–7.43%
ChongQing	41	732	5.60	3.94–7.26%
NingXia	57	934	6.10	4.58–7.62%
FuJian	34	512	6.64	4.49–8.79%
QingHai	61	882	6.92	5.25–8.59%
SiChuan	69	901	7.66	5.92–9.40%
ShanDong	108	1284	8.41	6.90–9.92%
HeNan	420	4367	9.62	8.75–10.49%
GanSu	234	2415	9.69	8.51–10.87%
GuiZhou	103	1013	10.17	8.31–12.03%
GuangDong	253	2433	10.40	9.19–11.61%
ShangHai	1489	10756	13.84	13.19–14.49%
LiaoNing	310	2145	14.45	12.96–15.94%
HuBei	128	867	14.76	12.48–17.04%
Nei Mongol	94	629	14.94	12.17–17.71%
BeiJing	1039	6904	15.05	14.20–15.90%
HuNan	703	4514	15.57	14.51–16.63%
ZheJiang	266	1512	17.59	15.68–19.50%
JiLin	47	301	15.61	11.55–19.67%
JiangSu	243	1538	15.80	13.98–17.62%
XinJiang	657	3214	20.44	19.05–21.83%
HeBei	21	78	26.92	17.12–36.72%
YunNan	425	1537	27.65	25.42–29.88%
^a 95% Confidence Interval				

Geospatial distribution of humans exposed to *T. gondii*

T. gondii is widely prevalent in China, and its prevalence rate varies widely throughout the country. Humans can acquire the parasite through consumption of undercooked/raw meat infected by *T. gondii*. In fact, eating raw or undercooked meat have, respectively, 1.2–1.3 times the risk and 1.7–3.0 times the odds of *T. gondii* infection compared to those who thoroughly cook meat [22]. The geographical distribution map of epidemiology of toxoplasmosis in humans in China is illustrated in Fig. 1. The highest infection pressure of *T. gondii* in humans exists in district Taiwan (23.41%, 346/1478, 95%CI 21.26–25.56%) followed by Xizang (16.75%, 380/2268, 95%CI 15.23–18.27%) and Jilin (12.14%, 2046/16858, 95%CI 11.66–12.62%), whereas humans of district Beijing (0.72%, 591/81750, 95%CI 0.67–0.78%) had a lowest infection pressure of *T. gondii*, then Shanghai (1.59%, 13023/817739, 95%CI 1.56–1.62%), Hebei (1.64%, 7015/427910, 95%CI 1.60–1.68%) and Liaoning (1.80%, 3978/220492, 95%CI 1.75–1.86%) were next (Fig. 1 and Table 6). Moreover, district Macao had no epidemiological data of toxoplasmosis in humans.

Table 6
Seroprevalence of *T. gondii* infection in humans from China

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
BeiJing	591	81750	0.72	0.67–0.78%
ShangHai	13023	817739	1.59	1.56–1.62%
HeBei	7015	427910	1.64	1.60–1.68%
LiaoNing	3978	220492	1.80	1.75–1.86%
NingXia	182	5572	3.27	2.80–3.74%
GuangDong	8439	231321	3.65	3.57–3.73%
ChongQing	2219	56721	3.91	3.75–4.07%
ZheJiang	15529	371748	4.18	4.12–4.24%
ShaanXi	2699	60888	4.43	4.27–4.59%
GuangXi	3191	71182	4.48	4.33–4.63%
ShanDong	8123	179505	4.53	4.43–4.63%
HeNan	7633	149271	5.11	5.00–5.22%
SiChuan	3812	71630	5.32	5.16–5.48%
FuJian	620	11395	5.44	5.02–5.86%
HuNan	2102	37118	5.66	5.34–5.89%
TianJin	481	8428	5.71	5.21–6.21%
QingHai	324	5508	5.88	5.26–6.50%
HuBei	26649	428685	6.22	6.15–6.29%
XinJiang	1985	30894	6.43	6.16–6.70%
AnHui	1727	23598	7.32	6.99–7.65
JiangSu	10297	140055	7.35	7.21–7.49%
GanSu	1110	14101	7.87	7.43–8.31%
JiangXi	4274	51043	8.37	8.13–8.61%
HeiLongJiang	2268	26622	8.52	8.19–8.85%
YunNan	12077	139962	8.63	8.48–8.78%

^a 95% Confidence Interval

Districts	Infected (n)	Examined (n)	Seroprevalence (%)	95% CI ^a
ShanXi	1929	22189	8.69	8.32–9.06%
Nei Mongol	596	6730	8.86	8.18–9.54%
Hong Kong	246	2499	9.84	8.66–11.02%
GuiZhou	3029	29512	10.26	9.92–10.60%
HaiNan	391	3686	10.61	9.61–11.61%
JiLin	2046	16858	12.14	11.66–12.62%
XiZang	380	2268	16.75	15.23–18.27%
TaiWan	346	1478	23.41	21.26–25.56%
^a 95% Confidence Interval				

Discussion

Toxoplasmosis is the most widespread zoonosis and a significant public health problem. Its prevalence varies depends on many factors, including geographical status, climate, environmental influence, living conditions, age ,eating habits and life style [4]. This zoonosis was studied over the last three decades in China, demonstrating that the epidemiological cycle of *T. gondii* is very well maintained in this region. Although many seroprevalence studies have been performed in humans and animals in China, data on the geospatial distribution of *T. gondii* in humans and animals are extremely scarce. For these reasons, this study is innovative because it collected the data on *T. gondii* infection in livestock, pets and humans from China, and showing the geographical distribution map of epidemiology of toxoplasmosis in a period of thirty years.

Livestock accounts for 60% of the mammals worldwide and is mostly used for meat production, milk and dairy products. Consumption of meat containing viable *T. gondii* tissue cysts is regarded as important sources of human infection by *T. gondii* [23]. Among livestock, *T. gondii* has been found more prevalent in sheep, goats and pigs, than in cattle [4]. Sheep and goats are perceived as biological indicators for the contamination of the environment with sporulated oocysts of *T. gondii*, because they usually opt for grasses closer to the ground or leaves of shrubs [24–25]. In the present work, the seroprevalence of toxoplasmosis among sheep and goats ranged from 3.98–43.02% in China. Similar work has been published by Dima El Safadi [26] who have worked on the same animal species of North Lebanon, reported that the prevalence of *T. gondii* infection in 42% of sheep and 34% of goats. Moreover, M Sharif [27] had reported a prevalence of 31% for *T. gondii* infection in Iran, which was in the same range as the prevalence of infection in this study. Spatial investigations demonstrated variation in seroprevalence of infection in sheep and goats between different regions in China. The prevalence of toxoplasmosis were

greater in districts Chongqing, Zhejiang, Beijing and Hubei, because maybe of the climatic conditions are adequate for the sporulation of *T. gondii* oocysts, due to the hot and humid climate.

Infection with *T. gondii* is very common in swine. Raw and undercooked meat accounts for 30–63% of *T. gondii* infections in humans, and according to the prevalence estimates of *T. gondii* in meat producing animals/meats, pork consumption was estimated to account for 12–15% of *T. gondii* infections in humans [28]. We further analyzed seroprevalence of *T. gondii* in swines. The results showed that seroprevalence was ranged from 10.45–66.47%, a higher than those reported in Mexico (8.9%) and Canada (9.4%) [5]. Furthermore, *T. gondii* is widely prevalent in swines in most areas of China, which may be related to the oocysts from cats or from soil, water, feed; infected rodents and oocysts from kitchen garbage.

Although greater resistance to the *T. gondii* has been reported in cattle, in the present study the seroprevalence of toxoplasmosis ranged from 0.75–30.34% from cattle and yaks in China. This is in accordance with Tonouhewa [29] who reported that the lowest prevalence rate of *T. gondii* infections in cattle than in swine and sheep. In cattle, higher prevalence (36.6 and 50%, respectively) had been reported in Colombia and Northern Portugal, and lower seroprevalence rates had been covered in Brazil and Switzerland (2 and 3.8%, respectively) [30]. Moreover, the prevalence in cattle and yaks were higher in Guizhou, Zhejiang, Chongqing, Hunan and, especially Tibet. Tibet has the highest average elevation on earth and, as the representative livestock of Tibet are economically important domestic animals to local herdsman. To our knowledge, yaks have more chances to ingest *T. gondii* oocysts through the fecal-oral route, because of free-grazing in the pasture and living together with other wild and domesticated animals. Previously, Kun Li [31] had suggested that the seroprevalence of yaks in the plateau were 21.7% during 2012–2013 that is similar to our results.

Toxoplasmosis, in addition, is also a health problem in pets such as cats and dogs. In cats, the seroprevalence of *T. gondii* (2.50–60.00%) in the present study was higher than those reported in other studies in Korea (1.6–6.0%) and Japan (5.4–8.7%). Moreover, in Spain, the positivity of *T. gondii* in cats reported was 27.2%, in the Poland, 68.1% was antibody-positive, and 87.72% of cats had antibodies in Ethiopia. A study performed in mainland China, showed a 24.5% seroprevalence of *T. gondii* in cats from 1991 to 2015 [32–33].

On the other hand, seroprevalence in dogs has been found in many studies conducted in different parts of the world including those conducted in Mexico (67.3%), Brazil (69.8%), Sweden (23%), Pakistan (28.43%) and Thailand (9%) [34]. Our results revealed that the seroprevalence of *T. gondii* has ranged from 0.56–27.65% among dogs in China. A previous study had reported a seroprevalence of 1.9% among dogs in Japan in the period 2009–2011 [32]. Cats had higher seroprevalences than dogs, may reflect that cats are better hunters of rodents and small birds than dogs and thus have higher opportunity to be infected with *T. gondii*.

T. gondii varies greatly between countries and even within different regions of the same country in which may be due to the distribution of the infection source, cultural practices, or hygiene habits. The overall

seroprevalence of *T. gondii* in humans in China from 2000 to 2017 was 8.2%, much lower than the prevalence recorded in Brazil (84.5%), France (61.0%), and United States (38.0%) [5]. The present results indicate that the prevalence of *T. gondii* infection in humans ranged from 0.72–23.41% in China. The seroprevalence of toxoplasmosis in humans at the level of geographical regions showed the highest infection rate in Taiwan, and the lowest in Beijing.

GIS maps, as critical tools in tracking and combating contagion, has been shown to be very effective to investigate the spatial distribution of disease outcomes, the graphical analysis of epidemiological indicators, the associated social factors, and environmental exposures. Indeed, the functions of GIS also plays a very important role in understanding of the new disease source, dynamics and epidemiology, early warning and forecasting of epidemic diseases and evaluating the effectiveness of disease in the prevention [35]. Haroon Ahmed used the GIS system to study the toxoplasmosis in sheep and goats in North-Eastern Region of Pakistan. They found that widespread environmental contamination with *T. gondii* oocysts, and undercooked meat of infected small ruminants could be a potentially important source of *T. gondii* infection [1]. Similar work has been conducted at Serbia to investigate the spatial epidemiology of *T. gondii* in goats, which showed that rainfall favored seropositivity of *T. gondii*, whereas temperature, humidity and elevation did not [26]. Studies in Middle Java using a GIS system identified some important factors, low elevation, unfiltered water sources, contact with raw meat and the high density of cats are supposed to be risk factors of toxoplasmosis in Middle Java [4].

Taken together, this study identified that *T. gondii* infection was common in livestock (sheep and goats, swines, cattle and yaks), pets (cats, dogs) and humans in China. As an important foodborne zoonotic parasite, *T. gondii* poses a great threat to human health and animals with various routes of infection. Hence, great attention should be paid to the prevention and control of *T. gondii* in livestock, pets and humans in China. Certain measures can be taken to prevent the prevalence of *T. gondii* infection in China. Some of these measures are strengthening the management of livestock farms, keeping the barn clean, preventing feline excreta from polluting environment, using filtered water or water boiling, wearing gloves when handling raw meat, and improving the practice of good hand hygiene.

Conclusion

Information on the prevalence of infection in livestock, pets and humans can be useful for assessing *T. gondii* environmental contamination and the risk for public health. The use of GIS geographic information system has become a key method to map the geospatial distribution of toxoplasmosis and evaluating the effectiveness of disease in the prevention. The present study, providing the geographical distribution map of epidemiology of *T. gondii*, indicated that infection with *T. gondii* was widespread in China, with a wide range of variation. However, there are also some limitations in this study. Some experiments data haven't published in the journal due to a variety of reasons, as such restricted the search for this part of the data. But it would hardly influence the spatial distribution of toxoplasmosis from a macro view. Therefore, effective prevention and control strategies of toxoplasmosis are proposed to include strengthening the management of livestock farms, keeping the barn clean, preventing feline

excreta from polluting environment, using filtered water or water boiling, wearing gloves when handling raw meat and improving the practice of good hand hygiene.

Declarations

Acknowledgements

We would like to thank the members of the Ningxia Key Laboratory of Clinical and Pathogenic Microbiology.

Authors' contributions

Conceptualisation: YJS,WJ,ZJZ, Writing, reviewing and editing: YJS, Data Collection: YJS,XQ,PTW,YTK, NAY, Spatial Orientation and Expression: YJS, All authors have read and approved the final manuscript.

Funding

This study was supported by the Natural Science Foundation of Ningxia (No.2019AAC03227), the forth Batch of Ningxia Youth Scientific Talents Supporting Program (No.TJGC2019089).

Availability of data and materials

All the data are included within the article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

¹ Ningxia Key Laboratory of Clinical and Pathogenic Microbiology, General Hospital of Ningxia Medical University, Yinchuan, China. ² The Center of Laboratory Medicine, General Hospital of Ningxia Medical University, Yinchuan, Ningxia, China.

References

1. Tuladhar S, Kochanowsky JA, Bhaskara A, Ghotmi Y, Chandrasekaran S, Koshy AA. The ROP16III-dependent early immune response determines the subacute CNS immune response and type III *Toxoplasma gondii* survival. *PLoS Pathog.* 2019;15(10):e1007856.
<https://doi.org/10.1371/journal.ppat.1007856>.
2. Smith NC, Goulart C, Hayward JA, Kupz A, Miller CM, van Dooren GG. Control of human toxoplasmosis. *Int J Parasitol.* 2021 Feb;51(2–3):95–121.
3. <https://doi.org/10.1016/j.ijpara.2020.11.001>.
4. Retmanasari A, Widartono BS, Wijayanti MA, Artama WT. Prevalence and Risk Factors for Toxoplasmosis in Middle Java. *Indonesia Ecohealth.* 2017;14(1):162–70.
<https://doi.org/10.1007/s10393-016-1198-5>.
5. Dong H, Su R, Lu Y, Wang M, Liu J, Jian F, Yang Y. Prevalence, Risk Factors, and Genotypes of *Toxoplasma gondii* in Food Animals and Humans (2000–2017) From China. *Front Microbiol.* 2018;9:2108. <https://doi.org/10.3389/fmicb.2018.02108>.
6. Olsen A, Berg R, Tagel M, Must K, Deksnė G, Enemark HL, Alban L, Johansen MV, Nielsen HV, Sandberg M, Lundén A, Stensvold CR, Pires SM, Jokelainen P. Seroprevalence of *Toxoplasma gondii* in domestic pigs, sheep, cattle, wild boars, and moose in the Nordic-Baltic region: A systematic review and meta-analysis. *Parasite Epidemiol Control.* 2019;5:e00100.
<https://doi.org/10.1016/j.parepi.2019.e00100>.
7. Milne G, Webster JP, Walker M. Towards improving interventions against toxoplasmosis by identifying routes of transmission using sporozoite-specific serological tools. *Clin Infect Dis.* 2020;71(10):e686–93. <https://doi.org/10.1093/cid/ciaa428>.
8. Cornelissen JB, van der Giessen JW, Takumi K, Teunis PF, Wisselink HJ. An experimental *Toxoplasma gondii* dose response challenge model to study therapeutic or vaccine efficacy in cats. *PLoS One.* 2014;9(9):e104740. <https://doi.org/10.1371/journal.pone.0104740>.
9. Felin E, Hälli O, Heinonen M, Jukola E, Fredriksson-Ahomaa M. Assessment of the feasibility of serological monitoring and on-farm information about health status for the future meat inspection of fattening pigs. *Prev Vet Med.* 2019;162:76–82. <https://doi.org/10.1016/j.prevetmed.2018.11.009>.
10. Bastos BF, Brener B, Gershony L, Willi L, Labarthe N, Pereira C, Mendes-De-Almeida F. Seroprevalence of *Toxoplasma gondii* (Nicole & Manceaux, 1909) and retroviral status of client-owned pet cats (*Felis catus*, Linnaeus, 1758) in Rio de Janeiro, Brazil. *Rev Inst Med Trop Sao Paulo.* 2014;56(3):201–3.
<https://doi.org/10.1590/S0036-46652014000300004>.
11. Boyda DC, Holzman SB, Berman A, Grabowski MK, Chang LW. Geographic Information Systems, spatial analysis, and HIV in Africa: A scoping review. *PLoS One.* 2019;14(5):e0216388.
<https://doi.org/10.1371/journal.pone.0216388>.
12. Rex FE, Borges CAS, Käfer PS. Spatial analysis of the COVID-19 distribution pattern in São Paulo State, Brazil. *Cien Saude Colet.* 2020;25(9):3377–84.
13. <https://doi.org/10.1590/1413-81232020259.17082020>.

14. Jankowska MM, Natarajan L, Godbole S, Meseck K, Sears DD, Patterson RE, Kerr J. Kernel Density Estimation as a Measure of Environmental Exposure Related to Insulin Resistance in Breast Cancer Survivors. *Cancer Epidemiol Biomarkers Prev.* 2017;26(7):1078–84. <https://doi.org/10.1158/1055-9965.EPI-16-0927>.
15. Gharekhani J, Yakhchali M, Esmaeilnejad B, Mardani K, Majidi G, Sohrabi A, Berahmat R, Hazhir Alaei M. Seroprevalence and Risk Factors of *Neospora caninum* and *Toxoplasma gondii* in Small Ruminants in Southwest of Iran. *Arch Razi Inst.* 2018;73(4):305–10. <https://doi.org/10.22092/ari.2017.109958.1119>.
16. Tzanidakis N, Maksimov P, Conraths FJ, Kiossis E, Brozos C, Sotiraki S, Schares G. *Toxoplasma gondii* in sheep and goats: seroprevalence and potential risk factors under dairy husbandry practices. *Vet Parasitol.* 2012;190(3–4):340–8. <https://doi.org/10.1016/j.vetpar.2012.07.020>.
17. Gong QL, Li J, Li D, Tian T, Leng X, Li JM, Shi K, Zhang NZ, Du R, Zhao Q. Seroprevalence of *Toxoplasma gondii* in cattle in China from 2010 to 2019: A systematic review and meta-analysis. *Acta Trop.* 2020;211:105439. <https://doi.org/10.1016/j.actatropica.2020.105439>.
18. Li K, Gao J, Shahzad M, Han Z, Nabi F, Liu M, Zhang D, Li J. Seroprevalence of *Toxoplasma gondii* infection in yaks (*Bos grunniens*) on the Qinghai-Tibetan Plateau of China. *Vet Parasitol.* 2014;205(1–2):354–6. <https://doi.org/10.1016/j.vetpar.2014.07.014>.
19. Dubey JP, Lago EG, Gennari SM, Su C, Jones JL. Toxoplasmosis in humans and animals in Brazil: high prevalence, high burden of disease, and epidemiology. *Parasitology.* 2012;139(11):1375–424. <https://doi.org/10.1017/S0031182012000765>.
20. Su R, Jiang N, Lu Y, Jian F, Wang H, Zhang G, Zhang L, Yang Y. Low prevalence of viable *Toxoplasma gondii* in swine from slaughter houses in the central of China. *Parasitol Int.* 2020;76:102090. <https://doi.org/10.1016/j.parint.2020.102090>.
21. Cong W, Elsheikha HM, Zhou N, Peng P, Qin SY, Meng QF, Qian AD. Prevalence of antibodies against *Toxoplasma gondii* in pets and their owners in Shandong province, Eastern China. *BMC Infect Dis.* 2018;18(1):430. <https://doi.org/10.1186/s12879-018-3307-2>.
22. Dubey JP, Murata FHA, Cerqueira-Cézar CK, Kwok OCH, Yang Y, Su C. *Toxoplasma gondii* infections in dogs: 2009–2020. *Vet Parasitol.* 2020;287:109223. <https://doi.org/10.1016/j.vetpar.2020.109223>.
23. Zhou P, Chen Z, Li HL, Zheng H, He S, Lin RQ, Zhu XQ. *Toxoplasma gondii* infection in humans in China. *Parasit Vectors.* 2011;4:165. <https://doi.org/10.1186/1756-3305-4-165>.
24. Pereira DC, Dubey JP, Da Mata A, Neto H, Cardoso L, Lopes AP. Seroepidemiology of *Toxoplasma gondii* in domestic cattle, sheep, goats and pigs from São Tomé and Príncipe. *Rev Bras Parasitol Vet.* 2020;29(1):e014819. <https://doi.org/10.1590/S1984-29612019101>.
25. Djokic V, Klun I, Musella V, Rinaldi L, Cringoli G, Sotiraki S, Djurkovic-Djakovic O. Spatial epidemiology of *Toxoplasma gondii* infection in goats in Serbia. *Geospat Health.* 2014;8(2):479–88. <https://doi.org/10.4081/gh.2014.37>.
26. Amdouni Y, Rjeibi MR, Rouatbi M, Amairia S, Awadi S, Gharbi M. Molecular detection of *Toxoplasma gondii* infection in slaughtered ruminants (sheep, goats and cattle) in Northwest Tunisia. *Meat Sci.*

- 2017;133:180–4. <https://doi.org/10.1016/j.meatsci.2017.07.004>.
27. Al-Kappany YM, Abbas IE, Devleesschauwer B, Dorny P, Jennes M, Cox E. Seroprevalence of anti-Toxoplasma gondii antibodies in Egyptian sheep and goats. BMC Vet Res. 2018;14(1):120. <https://doi.org/10.1186/s12917-018-1440-1>.
28. El Safadi D, Abi Chahine D, Al Tarraf A, Raii O, Mesto K, Ismail MB, Hamze M. First report on seroprevalence and risk factors of Toxoplasma gondii infection in sheep and goats in North Lebanon. J Infect Dev Ctries. 2019;13(9):831–6. <https://doi.org/10.3855/jidc.11425>.
29. Sharif M, Sarvi Sh, Shokri A, Hosseini Teshnizi S, Rahimi MT, Mizani A, Ahmadpour E, Daryani A. Toxoplasma gondii infection among sheep and goats in Iran: a systematic review and meta-analysis. Parasitol Res. 2015;114(1):1–16. <https://doi.org/10.1007/s00436-014-4176-2>.
30. Rahman M, Devriendt B, Gisbert Algaba I, Verhaegen B, Dorny P, Dierick K, Cox E. QuilA-Adjuvanted T. gondii Lysate Antigens Trigger Robust Antibody and IFN γ + T Cell Responses in Pigs Leading to Reduction in Parasite DNA in Tissues Upon Challenge Infection. Front Immunol. 2019;10:2223. <https://doi.org/10.3389/fimmu.2019.02223>.
31. Tonouhewa AB, Akpo Y, Sessou P, Adoligbe C, Yessinou E, Hounmanou YG, Assogba MN, Youssao I, Farougou S. Toxoplasma gondii infection in meat animals from Africa: Systematic review and meta-analysis of sero-epidemiological studies. Vet World. 2017;10(2):194–208. <https://doi.org/10.14202/vetworld.2017.194-208>.
32. Amdouni Y, Rjeibi MR, Rouatbi M, Amairia S, Awadi S, Gharbi M. Molecular detection of Toxoplasma gondii infection in slaughtered ruminants (sheep, goats and cattle) in Northwest Tunisia. Meat Sci. 2017;133:180–4. <https://doi.org/10.1016/j.meatsci.2017.07.004>.
33. Li K, Gao J, Shahzad M, Han Z, Nabi F, Liu M, Zhang D, Li J. Seroprevalence of Toxoplasma gondii infection in yaks (Bos grunniens) on the Qinghai-Tibetan Plateau of China. Vet Parasitol. 2014;205(1–2):354–6. <https://doi.org/10.1016/j.vetpar.2014.07.014>.
34. Oi M, Yoshikawa S, Maruyama S, Nogami S. Comparison of Toxoplasma gondii Seroprevalence in Shelter Cats and Dogs during 1999–2001 and 2009–2011 in Tokyo, Japan. PLoS One. 2015;10(8):e0135956. <https://doi.org/10.1371/journal.pone.0135956>.
35. Ding H, Gao YM, Deng Y, Lamberton PH, Lu DB. A systematic review and meta-analysis of the seroprevalence of Toxoplasma gondii in cats in mainland China. Parasit Vectors. 2017;10(1):27. <https://doi.org/10.1186/s13071-017-1970-6>.
36. Ahmad N, Ahmed H, Irum S, Qayyum M. Seroprevalence of IgG and IgM antibodies and associated risk factors for toxoplasmosis in cats and dogs from sub-tropical arid parts of Pakistan. Trop Biomed. 2014;31(4):777–84.
37. Shaw N, McGuire S. Understanding the use of geographical information systems (GIS) in health informatics research: A review. J Innov Health Inform. 2017;24(2):940. <https://doi.org/10.14236/jhi.v24i2.940>.

Figures

Figure 1

Geospatial distribution of epidemiology of toxoplasmosis in livestock (sheep and goats, swines, cattle and yaks), pets (cats, dogs) and humans from 1984-2020 in China. XJ: XinJiang; XZ: XiZang (Tibet); QH: QingHai; GS: GanSu; NMG: Nei Mongol (Inner Mongolia); NX: NingXia; HB: HeBei; BJ: BeiJing; TJ: Tianjin; LN: LiaoNing; JL: JiLin; HLJ: HeiLongJiang; SD: ShanDong; HN: HeNan; SX: ShanXi; SaX: ShaanXi; SC: SiChuan; YN: YunNan; CQ: ChongQing; GZ: GuiZhou; GX: GuangXi; HuN: HuNan; HuB: HuBei; AH: AnHui; GD: GuangDong; JX: JiangXi; FJ: FuJian; ZJ: ZheJiang; JS: JiangSu; SH: ShangHai; HaN: HaiNan; TW: TaiWan. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.