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

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Research

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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](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/](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 1191 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 |
|-----------|-------------|-------------|--------------------|--------|
| 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 95% Confidence Interval |
|-----------|--------------|--------------|-------------------|--------|---------------------------|
| 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 depending on many factors, including geographical status, climate, environmental influence, living conditions, age, eating habits and lifestyle [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 herdsmen. 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

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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.

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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.

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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.