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Geographic information system based analysis of the spatial distribution and epidemiology of anthrax in Mongolia (1964-2024)

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Objective: Anthrax is a zoonotic disease that continues to pose a significant public health threat in Mongolia. This study aimed to conduct a spatiotemporal analysis of the geographic distribution and epidemiological characteristics of anthrax using geographic information system (GIS)–based methods **Methods:** A retrospective descriptive epidemiological study was performed using national surveillance data on human and animal anthrax cases reported between 1964 and 2024 by the National Center for Zoonotic Diseases and the General Authority for Veterinary Services. GIS-based spatial analyses incorporated natural landscape zoning, historical outbreak records, and microbiological evidence from environmental samples to identify anthrax natural foci and risk zones. **Results:** Natural foci were found in 187 soum districts across 18 provinces and major cities, based on overlapping human and animal cases and confirmed isolations of Bacillus anthracis. High-risk zones were mainly around Khuvsgul Lake, the Khangai Mountain Plateau, the Orkhon–Selenge Basin, and the Onon–Ulz River region. Overall, anthrax affected about 44.5% of Mongolia's area, roughly 689,100 km^2. Most B. anthracis strains carried both Px01 and Px02 virulence plasmids. **Conclusion:** Anthrax remains endemic in Mongolia, with distinct ecological clustering. GIS-based analysis supports targeted surveillance and control within a One Health framework.

Key words: Anthrax, Zoonosis, Human and animal health, GIS, Mongolia

Introduction

Nomadic livestock herding has been a central part of life in what is now Mongolia since at least the third century B.C. As a result, Mongolian society has developed traditional methods for controlling zoonotic infections over many centuries. During the era of Genghis Khan, environmental regulations were introduced, including strict prohibitions against polluting water sources. Traditional practices contributed significantly to reducing health risks, for instance, people avoided drinking raw water or milk, and did not eat meat from animals that died from unknown causes or were killed by predators. Animal skin or hair were also avoided in consumption. Waste management was carefully practiced- before relocating, communities would bury waste, fill pits, and clean their surroundings.[1]

One of the most serious diseases historically recognized by Mongolians was referred to as the "soil disease", known today as anthrax – severe bacterial infection caused by *Bacillus anthracis*.[2] Anthrax remains endemic in many regions where animal husbandry is prevalent, with infection foci reported across Asia, Africa, North and South America, and Southern and Eastern Europe.[3-5]

The causative agent, *Bacillus anthracis*, is a gram-positive, spore-forming bacterium from the family Bacillaceae, measuring 5-8 μm in length and 1.5-2 μm in diameter.[6-8] According to the International Classification of Diseases (ICD-10), anthrax is classified under the code A22 "Infections caused by *B. anthracis*", with clinical subcategories ranging from A22.1 to A22.9. Notably, *B. anthracis* is listed among the top three pathogens with potential use in international bioterrorism. The 2001 anthrax attack in the United States underscored its global threat.[9]

In Mongolia, anthrax have affected approximately 689.100 km2 or 44.5% of the national territory, encompassing 18 provinces, 187 soums, one city, and multiple districts of the capital. The Khangai region, in particular, serves as an active natural focus. Strains carrying the virulence plasmids Px01 and Px02 have been identified in provinces such as Khentii, Dornod, Tuv, Ulaanbaatar, Selenge, Bulgan, Orkhon, Arkhangai, Uvurkhangai, Khuvsgul, Bayankhongor, Zavkhan, Uvs, Hovd, Bayan-Ulgii, and the northern part of Gobi-Altai.[10-12] Anthrax incidence shows seasonal variations, with cutaneous anthrax (the skin form) being the most prevalent clinical form. The recorded mortality rate stands at 0.6%, the most cases occuring among males, typically due to exposure during household or occupational activities.[13-15]

Geographic information systems (GIS) play a vital role in the surveillance and control of zoonotic diseases by enabling spatial analysis and visualization of disease patterns. GIS facilitates the integration of epidemiological data with environmental and demographic information, supporting the identification of natural foci, transmission pathways and disease hotspots. This capabilities are essential for conducting risk assessments, planning targeted interventions, and optimizing the allocation of public health resources. GIS has proven effective in tracking diseases such as anthrax, brucellosis, and avian influenza, significantly improving both outbreak prediction and prevention strategies.[10, 11] This study is the first in Mongolia to comprehensively integrate data on human and livestock anthrax cases, including laboratory diagnostic results, to map the spatial distribution and identify natural foci of the disease from a medical geographic perspective. The findings of this study contribute to the monitoring, planning, and epidemiological assessment of anthrax natural foci. Therefore, the aim of this study is to determine the occurrence, geographical distribution, key characteristics, and temporal dynamics of human anthrax in Mongolia.

Material and Methods

Study Design and Setting

A retrospective, descriptive-epidemiological study was conducted to analyze the geographical and temporal patterns of anthrax in Mongolia between 1964 and 2024. The analysis covered all 21 provinces and the capital city, Ulaanbaatar, with a focus on identifying natural foci and high-risk zones, the distribution of animal and human cases, and the molecular characteristics of *Bacillus anthracis* strains.

Data sources and Collection

Data were obtained from multiple official and scientific sources. The General Authority for Veterinary Services maintains surveillance records of anthrax in animals and humans at the National Center for Zoonotic Diseases.

Data sources and Collection

To assess the environmental and landscape-related risk of anthrax, Mongolia was divided into natural landscape zones (e.g., forest-steppe, steppe, desert-steppe, and arid zones). Spatial mapping of anthrax occurrence was conducted using GIS software to identify natural foci of anthrax based on the coincidence of animal and human cases and confirmed *B. anthracis isolations* from environmental samples. Risk zones were categorized as high, medium, low, or no risk based on historical disease frequency and ecological features such as soil type, humidity, and elevation.

Statistical Analysis

Descriptive statistics were applied to assess the distribution of human cases by province, sex, age group, and employment type. Human incidence and mortality rates were calculated per 10,000 population using census data in Microsoft Excel. Spatial distribution maps of anthrax foci and strain types were generated in ArcView-10.5 to visualize regional patterns.

Ethical Statement

The Biomedical Ethics Subcommittee of the Mongolian National University of Medical Sciences reviewed the research methodology at its meeting held on May 19, 2017. As the research methodology was found to be consistent with the ethical guidelines and regulations for research currently in force internationally and in Mongolia, ethical approval for conducting the study was granted under Biomedical Ethics Approval No. 2017/3-07.

Results

Ecological Characteristics of Anthrax in Mongolia

Anthrax is an anthropozoonosis that circulates in natural foci, exhibiting distinct characteristics, seasonality, and ecological patterns.[16-18] From 1977 to the present, 68.8% of all reported cases of animal anthrax occurred in the forested provinces of Khuvsgul, Zavkhan, Bulgan, and Arkhangai.[19-20] The frequency of outbreaks and the number of infected animals were higher in these forested regions compared to other areas. (Figure 1) Between 1984 and 2024, a total of 3,753 animals were studied, 79.5% were cattle, 6.2% horses, 10.6% sheep, and 3.5% goats. Among the studied animals, 3,862 (75.4%) were infected with anthrax. The infected animals were idebtified in the provinces of Khuvsgul, Bulgan, Zavkhan, and Uvurkhangai. These findings support the hypothesis that the causative agent of anthrax can remain dormant while retaining its pathogenicity for extended periods in landscapes with black soil and a humid climate.[21] (Figure 1)

Geographical Zoning and Natural Foci

According to natural landscape zoning, a high risk of anthrax infection is predicted for the areas surrounding Lake Khuvsgul, the Khangai Mountain Plateau, the Orkhon-Selenge Basin, and the Onon-Ulz River region. A medium risk is assumed for the Khentii Mountain Plateau, the Ikh Nuur Depression, and eastern Mongolia. A low risk is predicted for the Mongolian Altai and the central region of the country. The Gobi-Altai, Altai Inner Gobi, south-eastern Mongolia, and western arid region are considered to have no risk of anthrax, as no animal or human cases have been recorded in these areas since 1964. (Figure 2) In Mongolia, natural foci of anthrax have been identified in 187 sum districts across 18 provinces and cities based on the occurrence of animal and human cases, and the isolation of bacterial cultures from environmental samples. (Figure 2)

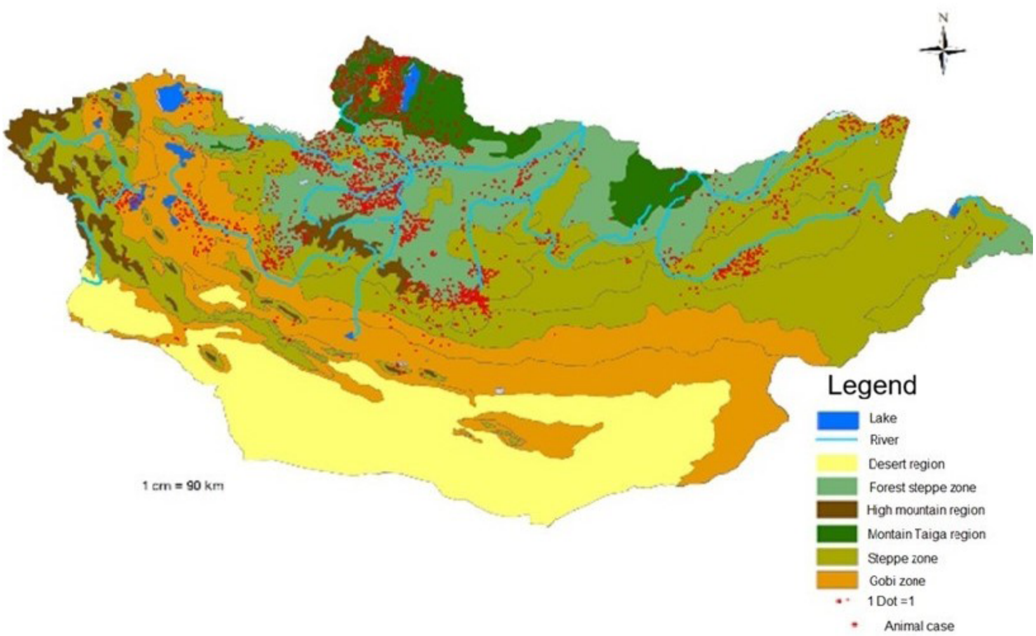

Figure 1. The occurrence of animal anthrax in 1964-2024 is mapped over the major natural landscape zones of Mongolia

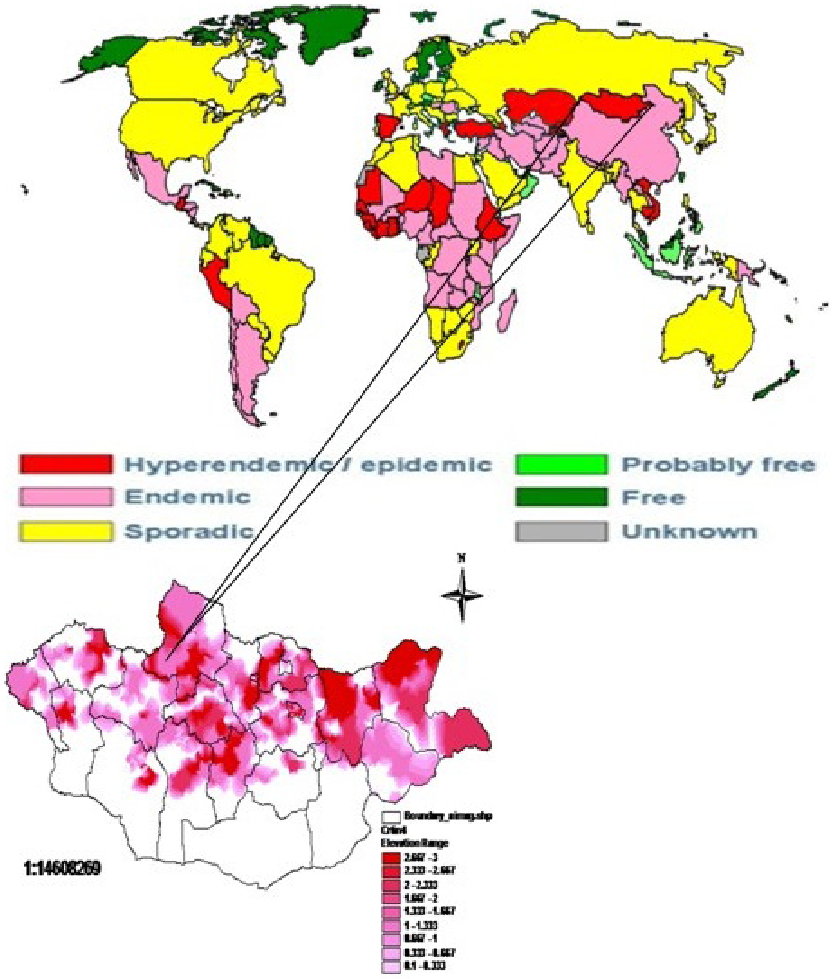

Figure 2. Spatial distribution of natural foci of anthrax in Mongolia

Isolation of *B. anthracis* from Environmental Sources

Strains of the anthrax agent were isolated from natural sources in the following years and locations: in 1964, 1970, 1971 and 2009 in Bayangol, Zuunkharaa, Yeroo, Mandal, Khuder, and Khushaat sum of Selenge province; in 1984, 1996, 1997, 1999, 2000, 2001, 2002, 2004 and 2005 in Khuvsgol province; in 1987 and 1997 inTarialan, Arbulag, and Jargalant sums of Khuvsgol province; in 2009 in Uvs province; in 1996, 2000, and 2009 in Kharkhorin, Taragt, Zuunbayanulaan, and Hujirt sums of Uvs province.[22-23]

Human Anthrax Cases in Mongolia

From 1964 to 2024, a total of 333 human anthrax cases were diagnosed and recorded across 108 soums and districts in 18 provinces and cities of Mongolia. Among these, 311 cases (93.6%) recovered, while 22 cases (6.3%) resulted in death. No human anthrax cases were reported in the provinces of Umnugovi, Govisumber, Dornogovi, and Sukbaatar. The provincial and city-level distribution of human anthrax cases was as follows: Selenge, 50 (15.1%); Arkhangai, 35 (10.5%). Uvurkhangai 30 (9%), Bulgan 27 (8.1%), Ulaanbaatar 28 (8.4%), Khuvsgul 26

(7.5%), Khentii 24 (7.2%), Dornod 22 (6,6) Tuv 20 (6.1%), Zavkhan 14 (3.9%), Uvs 14 (4.2%), Bayankhongor 10 (3.01%), Darkhan-Uul,Khovd and Orkhon 9 (2.7%), Govi-Altai 4 (1.2%), Bayan-Ulgii and Dundgovi 1 (0.3%). The incidence rate of human anthrax per 10,000 population was Selenge 0.0047, Bulgan 0.0045, Arkhangai 0.0038, Khentii 0.0030, Dornod and Uvurkhangai 0.0026, Tuv 0.0022, Khuvsgul 0.0019, Zavkhan 0.0018, Uvs 0.0017, Bayankhongor 0.0011, Khovd 0.0010, Darkhan-Uul and Orkhon 0.0008, Govi-Altai 0.0007, Dundgovi and Ulaanbaatar 0.002, Bayan- Ulgii 0.0001. The mortality rate from human anthrax was distributed as follows: Ulaanbaatar 4 (19%), each province of Uvurkhangai, Bayankhongor, and Arkhangai 3 (14.2%), each province of Selenge, Khuvsgul, and Khentii 2 (9.5%), and each province of Darkhan-Uul, Orkhon, and Zavkhan 1 (4.6%). Human cases of anthrax have been officially registered in Mongolia since 1964.[24-28] (Table 1)

Table 1. Distribution of human anthrax cases and mortality by province in Mongolia, 1964–2024

Provinces	Human anthrax cases	Percent	Mortality of human anthrax	Percent
Arkhangai	35	10.5	3	13.6
Bayan-Ulgii	1	0.3	0	0
Bayankhongor	10	3.01	3	13.6
Bulgan	27	8.1	0	0
Govi-Altai	4	1.2	0	0
Govisumber	0	0	0	0
Darkhan-Uul	9	2.7	1	4.6
Dornogovi	0	0	0	0
Dornod	22	6.6	0	0
Dundgovi	1	0.3	0	0
Zavkhan	14	3.9	1	4.6
Orkhon	9	2.7	1	4.6
Uvurkhangai	30	9	3	13.6
Umnugovi	0	0	0	0
Sukhbaatar	0	0	0	0
Selenge	50	15.1	2	9.1
Tuv	20	6.1	0	0
Uvs	14	4.2	0	0
Khovd	9	2.7	0	0
Khuvsgul	26	7.5	2	9.1
Khentii	24	7.2	2	9.1
Ulaanbaatar	28	8.4	4	18.2
Total	333	100	22	100

Source of Infection and Transmission Routes

A review of 352 cases revealed that 250 (75.3%) were infected through contact with or consumption of meat, hides, skins, and wool from infected or dead livestock, identifying infected animals as the primary source. Additionally, 35 cases (10.5%) were linked to environmental exposure, such as working with contaminated soil, building or repairing livestock pens, or cleaning manure pits. In 47 cases (14.1%), the source of infection could not be determined. Among the 332 recorded human anthrax cases between 1964 and 2024, 238 (71.6%) were male and 94 (28.3%) were female. By age group, 38 individuals (11.4%) were children aged 0-16, 243 (73.2%) were of working-age adults (17-54), and 51 (15.4%) were elderly (55 and older). These figures indicate that anthrax predominantly affects men and those of working age.

Regarding the occupational characteristics of human anthrax cases, the majority of cases were herdsmen (148 cases, 44.5%), followed by artisanal miners (64 cases 19.2%), unemployed individuals (46 cases 13.8%), miners (34 cases 10.2%), civil servants (14 cases 4.2%), students (13 cases 3.9%), and others (13 cases 3.9%). (Table 2)

Table 2. Demographic and employment characteristics of human anthrax cases in Mongolia, 1964–2024

Characteristics of patients	Number	Percent
Sex		
Male	238	71.6
Female	94	28.3
Age group		
0-16	38	11.4
17-54	243	73.2
55<	51	15.4
Employment		
Herdsman	148	44.5
Miners	34	10.2
Artisanal miners	64	19.2
Civil servants	14	4.2
Students	13	3.9
Others	13	3.9
Unemployed	46	13.8

Molecular Characteristics of *B. anthracis* Strains

Anthrax endotoxin, known as anthratoxin, is regulated by a plasmid.[30] The endotoxin molecule consists of three components: the inflammatory factor (edema factor, EF), the lethal factor (LF), and the protective antigen (PA). The plasmids responsible for synthesizing the endotoxin are classified by molecular weight as P60 kDa and P110 kDa. Based on the nucleotide sequences, the P60 plasmid corresponds to the virulence factor Px01, while the P110 plasmid corresponds to Px02.

In 2007, researchers A. Erdenebat and P. Nyamdavaa, et al identified the causative agent of anthrax in Mongolia using PCR and determined the plasmid composition through molecular biology methods. The molecular biological analysis was performed on original materials preserved in the anthrax bacterial culture museum since 1964. These samples were collected during surveillance and control efforts and included human, animal, and environmental specimens.

As a result, B. anthracis strains carrying the Px01 and Px02 plasmids were found in the provinces of Khentii, Dornod, Tuv, Ulaanbaatar, Selenge, Bulgan, Orkhon, Arkhangai, Uvurkhangai, Khuvsgul, Bayankhongor, Zavkhan, Uvs, Khovd, Bayan-Ulgii, and the northern parts of Gobi-Altai and Dundgobi. In addition, B. anthracis strains lacking the Px02 plasmid were detected in Arkhangai, Khentii, Uvs, and Uvurkhangai. In contrast, strains lacking the Px01 plasmid were described in Bayankhongor, Umnugobi, Khentii, Bulgan, and Uvs provinces. In summary, B. anthracis strains found across most of Mongolia contain both virulence plasmids, Px01 and Px02. However, the loss of these plasmids has been observed in the provinces of Arkhangai, Khentii, Uvs, Bayankhongor, Umnugobi, Bulgan, and Uvurkhangai. (Figure 3)

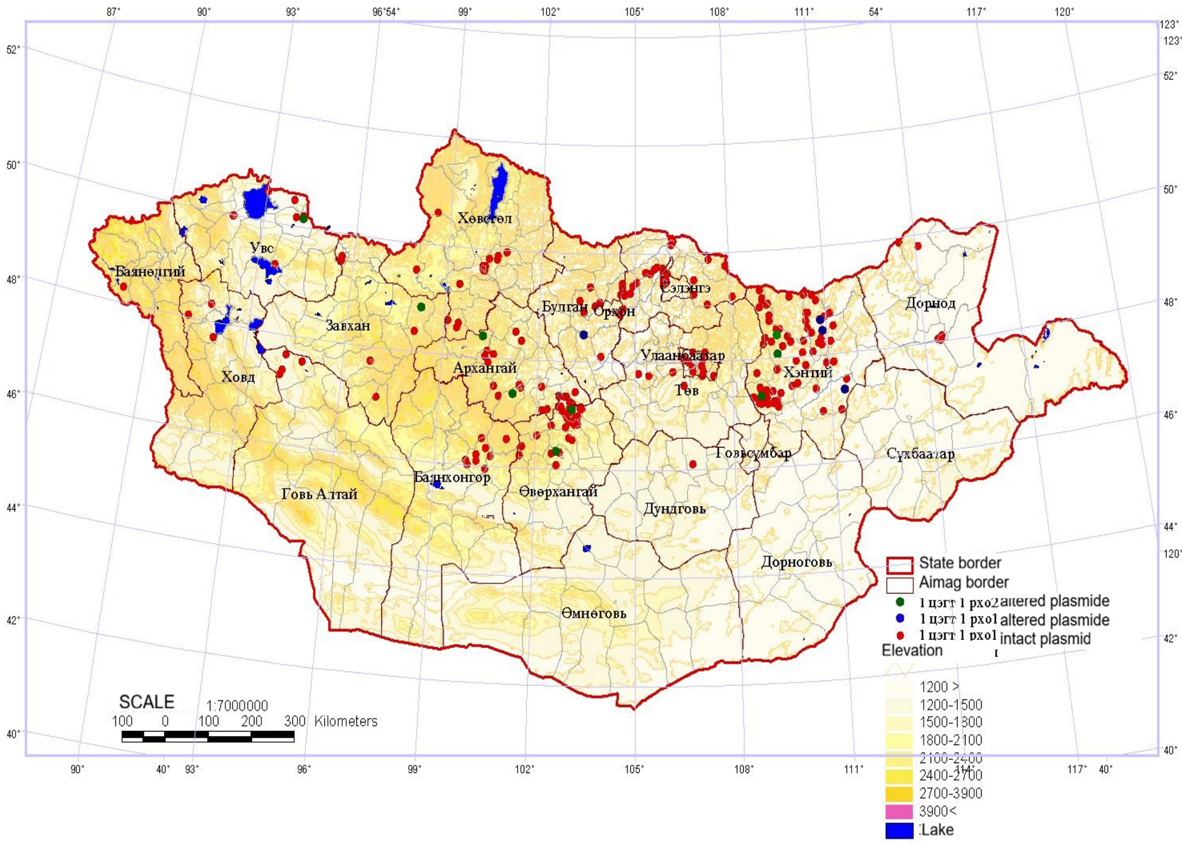

Figure 3. Spatial distribution of B. anthracis strains with different compositions of Px01 and Px02 plasmids

Discussion

The widespread distribution of anthrax in Mongolia, as evidenced by its registration in 187 soums across 18 provinces, highlights the endemic nature of the disease and its significant public health implications. Several environmental and epidemiological factors including the presence of animal anthrax foci, disease prevalence in livestock, seasonal patterns, and climate conditions contribute to the transmission risk among human populations. These findings emphasize the importance of a multisectoral One Health approach to anthrax prevention and control in Mongolia.[9] Human anthrax cases have been reported in 108 soums and districts, with the majority (76.9%) of infections linked to direct contact with contaminated soil or involvement in the slaughtering and processing of infected animals and animal products such as hides, hair, and wool. All these cases were confirmed by laboratory diagnostics, underscoring the reliability of surveillance data. Alarmingly, 6.1% of working-age male patients succumbed to the disease, indicating not only the severity of infection but also the potential socioeconomic impact on rural households dependent on livestock-related livelihoods.[11-12]

Molecular analysis of *Bacillus anthracis* strains across various provinces revealed the widespread presence of two key virulence plasmids pXO1 and pXO2 in strains isolated from Khentii, Dornod, Central, Ulaanbaatar, Selenge, Bulgan, Orkhon, Arkhangai, Övörkhangai, Khuvsgul, Bayankhongor, Zavkhan, Uvs, Khovd, Bayan-Ölgii, the northern region of Gobi-Altai, and Dundgovi. However, plasmid loss has also been observed: strains lacking the pXO2 plasmid were found in the aforementioned provinces, while pXO1-deficient strains were isolated in Bayankhongor, Umnogovi, Khentii, Bulgan, and Uvs. The geographical clustering of plasmid-deficient strains raises important questions about environmental or selective pressures that may drive such genetic changes, which in turn could influence virulence and transmissibility.[10]

Overall, the findings point to a complex and evolving epidemiological landscape of anthrax in Mongolia. This warrants continuous monitoring using both classical epidemiology and molecular tools to inform targeted interventions, improve livestock vaccination strategies, and enhance public awareness and response capacity.

One of the main advantages of a GIS is its ability to enhance information about an object with maps, and vice versa, enrich maps with related data. This integration makes the information more comprehensive and less biased, enabling a wide range of functionalities such as visualization, analysis, and printing. As a result, it becomes a powerful modern tool to organize and conduct work efficiently and productively. For the first time in Mongolia, GIS is being used in research to map natural foci of anthrax outbreaks by incorporating various factors such as human and animal infection cases and soil-detected bacterial presence.[29-31] Our study provides a scientifically grounded mapping of soil contamination, contributing to public health by enabling continuous monitoring and prevention of anthrax outbreaks, reducing incidence rates, monitoring effectiveness, and organizing timely and efficient response actions. This marks the beginning of an important contribution to protecting public health.

A considerable body of research has been undertaken by Mongolian scientists focusing on *Bacillus anthracis*, the etiological agent of anthrax, using animal models. These investigations have addressed diverse biological and pathological dimensions, including the bacterium's morphological characteristics, growth dynamics, biochemical and molecular properties, antimicrobial and disinfectant resistance, organ-specific pathological alterations in experimentally infected sheep, virulence profiles, and the critical role of vaccination in mitigating anthrax outbreaks.[17,19] In a 2003 study titled "*Assessment of the Spread and Risk Level of Certain Bacterial Zoonoses in Mongolia*," N. Batsuuri proposed a four-tier classification system for anthrax risk zones: (1) high-risk zones with persistent and active transmission; (2) moderate-risk zones with intermittently active foci; (3) low-risk zones with sporadic and localized cases; and (4) no-risk zones with an absence of infection foci. According to his findings, the Onon-Ulz River basin and the Khentii Highlands were categorized within the moderate-risk zone.[20] Subsequent work by M. Darmaa and colleagues further refined regional risk stratification by delineating Mongolia into infected and uninfected areas. The infected areas were further subdivided into high, medium, and low-risk zones based on integrated criteria, including human and livestock morbidity data, pathogen isolation, and laboratory confirmation.[23,25] Drawing on existing classification frameworks, the researchers quantified the spatial extent of each risk zone and produced a comprehensive geographical risk map.

This study is subject to several limitations. This analysis was based on long-term retrospective records (1964–2024), and variations in surveillance intensity, diagnostic practices, and reporting completeness may have influenced case detection over time. The use of administrative-level spatial units constrained geographic detail. Incomplete exposure information and uneven availability of environmental and molecular data across regions may have limited precise identification of transmission pathways and natural anthrax foci.

To effectively manage and prevent anthrax outbreaks in Mongolia, it is essential to implement a multi-faceted approach grounded in both surveillance and intersectoral coordination. Regularly updating spatial maps that reflect the epizootiological and epidemiological patterns of anthrax can provide a strong foundation for strategic planning and targeted interventions. These maps should be revised annually and utilized for official decision-making processes. In addition, laboratory-based surveillance is critical for assessing the activity level of natural foci and ensuring timely response measures. Preventive efforts must also extend to potential human exposure routes, particularly in urban and rural meat processing plants, retail outlets, and tourism areas, where meat and meat products should be routinely inspected to mitigate transmission risks. Finally, joint surveillance between human and veterinary health sectors is crucial. By analyzing surveillance data collectively and organizing coordinated, cross-sectoral activities, Mongolia can enhance its capacity to respond to anthrax threats more effectively and sustainably.

Conflict of Interest

The authors state no conflict of interest.

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