Identification and mapping of objects targeted for surveillance and their role as risk factors for brucellosis in livestock farms in Kazakhstan

Aizada A. Mukhanbetkaliyeva,[1] Ablaikhan S. Kadyrov,[1] Yersyn Y. Mukhanbetkaliyev,[1] Zhanat S. Adilbekov,[1] Assylbek A. Zhanabayev,[1] Assem Z. Abenova,[1] Fedor I. Korennoy,[2,3] Sarsenbay K. Abdrakhmanov[1]

[1]S. Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan; [2]Federal Center for Animal Health (FGBI ARRIAH), Vladimir, Russia; [3]Federal Research Center for Virology and Microbiology, Branch in Nizhny Novgorod, Nizhny Novgorod, Russia

Abstract

Objects for Targeted Surveillance (OTS) are infrastructure entities that can be considered as focal points and conduits for transmitting infectious animal diseases, necessitating ongoing epidemiological surveillance. These entities encompass slaughterhouses, meat processing plants, animal markets, burial sites, veterinary laboratories, etc. Currently, in Kazakhstan, a funded research project is underway to establish a Geographic Information System (GIS) database of OTSs and investigate their role in the emergence and dissemination of infectious livestock diseases. This initial investigation examined the correlation between brucellosis outbreaks in cattle and small ruminant farms in the southeastern region of Kazakhstan and the presence of OTSs categorized as "slaughterhouses," "cattle markets," and "meat processing plants. The study area (namely Qyzylorda, Turkestan, Zhambyl, Almaty, Zhetysu, Abay and East Kazakhstan oblasts), characterized by the highest livestock density in the country, covers 335 slaughterhouses (with varying levels of biosecurity), 45 livestock markets and 15 meat processing plants. Between 2020 and 2023, 338 cases of brucellosis were reported from livestock farms in this region. The findings of the regression model reveal a statistically significant ($p<0.05$) positive association between the incidence of brucellosis cases and the number of OTSs in the region. Conversely, meat processing plants and livestock markets did not exhibit a significant influence on the prevalence of brucellosis cases. These results corroborate the hypothesis of an elevated risk of brucellosis transmission in regions with slaughterhouses, likely attributable to increased animal movements within and across regions, interactions with vehicles and contact with slaughterhouse staff. These outcomes mark a pivotal advancement in the national agricultural development agenda. The research will be extended to encompass the entire country, compiling a comprehensive OTS database.

Correspondence: S. Seifullin Kazakh Agro Technical Research University, 62 Jenis avenue, Astana 010011, Kazakhstan.
E-mail: s_abdrakhmanov@mail.ru

Key words: Kazakhstan, brucellosis, livestock, slaughterhouses, database, regression.

Conflict of interest: the authors declare no potential conflict of interest, and all authors confirm accuracy.

Availability of data and materials: all data generated or analyzed during this study are included in this published article.

Acknowledgments: this study was conducted within the framework of the project: AP19678128 "Development of measures to reduce the epidemiological risks of the spread of zooanthroponoses in Kazakhstan".

Received: 16 August 2024.
Accepted: 3 November 2024.

Geospatial Health 2024; 19:1335
doi:10.4081/gh.2024.1335

Introduction

Today, a significant proportion of contagious diseases affecting humans are zoonoses. Often, epizootics of zoonotic infections pose a real threat to the health and lives of the human population that can lead to substantial economic losses in agriculture. It is known that the dynamics of the epidemic process of many socially significant zoonoses in a certain territory are influenced by the presence of "epidemically significant veterinary facilities" (Dudnikov *et al.*, 2008; Counotte *et al.*, 2016) hereinafter referred to as "Objects for Targeted Surveillance" (OTS). Those objects are infrastructure facilities that require constant monitoring and surveillance because of the risk for disruption and deterioration of the epidemiological situation, which may lead to the emergence and spread of diseases with significant epidemiological, environmental, economic and social consequences. OTS can thus be understood as facilities that concentrate and increase the risk for the spread of contagious diseases (Dzhupina, 2004; Mamadaliyev *et al.*, 2010; An *et al.*, 2023)

The list of OTS includes animal burial grounds (Beccari pits), collection of animal carcasses, biological waste disposal facilities, slaughterhouses, veterinary laboratories, zoos, hunting grounds, meat processing plants, etc. They all require strict control and supervision because non-compliance with sanitary and hygienic requirements and deterioration of the epidemiological situation at these sites can facilitate the emergence and spread of diseases. This, in turn, will have a significant negative impact on the health and safety of animals and humans. In the Russian Federation, the following classification of veterinary OTSs is proposed: agricultural, veterinary, municipal and others (Dudnikov *et al.*, 2008; Belchikhina *et al.*, 2011). Information on OTS is essential for assessing and interpreting the intensity of the epizootic process and planning anti-epizootic measures.

Kazakhstan is traditionally considered an agrarian country. According to official statistics from 2023, agriculture accounts for 4.7% of the Gross Domestic Product (GDP) of the country, mainly producing meat, dairy products, wool and leather from livestock products (UNECE Data Portal, 2024). The industry's gross output structure shows a significant share of products from private, subsidiary farms. Approximately 80% of agricultural products in Kazakhstan are sold as raw materials without processing, while finished products often have low competitiveness (Muminov, 2019). The majority of farm animals are kept on private farms by the rural population (Shaikenov *et al.*, 2003). Owners of private farmsteads utilize livestock products for personal consumption. Simultaneously, some segments of the population sell a portion of these products through intermediaries in the market or directly to neighbours, acquaintances, and relatives. Industrial livestock breeding is also progressing in Kazakhstan. According to official statistics, currently, 10% of cattle and 5.8% of small ruminants are housed in large industrial enterprises, while 41.6% of cattle and 49.9% of small ruminants are owned by individual entrepreneurs and peasant farms (Beauvais *et al.*, 2017).

Brucellosis is one of the zoonotic infections, the registration and spread of which directly depends on human economic activity (Corbel, 1997; Rubach *et al.*, 2013). Humans become infected with brucellosis only through direct contact with infected animals. Such situations often occur during the calving of sheep and cows, slaughtering of animals, cutting of carcasses, etc. A person can also get infected by consuming dairy products from brucellosis-infected animals that have not undergone thermal treatment or alternatively by inhaling the pathogens present in the air (Pappas *et al.*, 2005; Papadatos *et al.*, 2017). The main causes of infection are violations of sanitary and hygienic rules and requirements at the relevant OTS such as livestock farms, enterprises for production and processing of livestock products, slaughterhouses, etc. (Corbel, 1997; Ergazina *et al.*, 2013).

Brucellosis in humans is characterized by a severe, chronic course and affects all organs of the human body, including the cardiovascular, nervous, and reproductive systems (Hasanjani Roushan & Ebrahimpour, 2015; Jin *et al.*, 2023). Globally, approximately 2.1 billion human cases are estimated annually (Laine, 2023). Brucellosis is currently a serious problem in Kazakhstan affecting both veterinary and public health. For many years, the country has experienced a high incidence and prevalence of this disease among animals, posing a significant risk of transmission to humans (Syrym *et al.*, 2019; Yespembetov *et al.,* 2019). According to numerous publications, the widespread occurrence of brucellosis in animals in Kazakhstan can be attributed to factors such as the low efficiency of preventive measures, non-compliance with sanitary and hygienic norms in livestock breeding, production, and processing of livestock products, inadequate provision of veterinary services, as well as natural and climatic factors (Shevtsova *et al.*, 2019; Syrym *et al.*, 2019; Yespembetov *et al.*, 2019; Abutalip *et al.*, 2024). The current epizootic situation on brucellosis shows 564 outbreaks among cattle and 135 outbreaks among small ruminants from 2020 to 2023. There is a consistent trend of a yearly decrease in the number of reported outbreaks. For instance, in 2020, there were 223 outbreaks of brucellosis in cattle, which decreased to 83 by 2023. A similar pattern is evident for brucellosis among small ruminants.

Although the disease is widespread throughout the country, different regions have varying levels of incidence among animals and humans. This discrepancy is attributed to the influence of various socioeconomic and natural-climatic factors (Shevtsova *et al.*, 2019; Syrym *et al.*, 2019).

According to Yespembetov *et al.* (2019), certain regions of Kazakhstan, particularly the southern and western areas, are more vulnerable to brucellosis due to factors, such as high livestock density, warmer climate and livestock production conditions. Ryskeldinova *et al.* (2021) reached similar conclusions; their research indicates that ineffective livestock husbandry practices, such as the lack of specific preventive measures and inadequate biological protection on farms, contributing to the transmission of brucellosis among animals.

In the last few years, the annual incidence in cattle has been about 0.6% and in small ruminants (sheep and goats) about 0.4% (Charypkhan *et al.*, 2019). Brucellosis in humans in Kazakhstan was first registered in 1932, and since then, the country has become endemic for this infection (Shevtsova *et al.*, 2016). Currently, the country has more than 1,300 registered cases of human brucellosis annually (7.6 per 100,000 inhabitants), and this rate is one of the highest in the world (Charypkhan *et al.*, 2019; Laine *et al.*, 2023). The most potentially dangerous objects are considered to be organized livestock farms engaged in breeding cattle, ruminants, camels, pigs, etc. Another category of infection spreaders is presented by small-scale private farms, mainly owned by the rural population (Shevtsova *et al.*, 2019)

Facilities engaged in animal slaughter (including sanitary slaughter of sick animals) and processing of slaughter products are another type of dangerous objects. At such facilities, contact with sick animals and their carcasses can infect workers, and the sale of meat products contaminated with *Brucella* bacteria creates a risk of transmission to consumers (Mioni *et al.*, 2018; Ayoola *et al.*, 2017; An *et al.*, 2023). Thus, Mioni (2018), in a study of the system of veterinary and sanitary control of slaughterhouses in Brazil, found that 2.2% of samples taken in slaughterhouses were positive for brucellosis, making them potential sources of transmission of brucellosis to humans through contaminated meat products. A specific issue is linked to the contamination of soil, water, and other environmental elements by the brucellosis pathogen due to the negligence of workers at livestock farms, processing plants, owners of infected animals on private farms, and veterinary workers providing services to infected animals. Charypkhan and Rüegg (2022) indicate that brucellosis can contaminate soil and water sources in areas where animals are buried or disposed of, potentially leading to the transmission of the disease to other animals and humans. Other studies also focus on assessing the prevalence of brucellosis at livestock-related facilities and its potential impact on their staff (Madut *et al.*, 2019; Bugeza *et al.*, 2024; Kakooza *et al.*, 2022).

According to Liu *et al.* (2024), veterinary laboratories that test and diagnose brucellosis may also be at risk of contamination and the spread of infection, necessitating stringent biosecurity measures to prevent the disease from spreading. In general, the presence (circulation and/or persistence) of the brucellosis pathogen in veterinary-related OTS will undoubtedly impact public health, animal welfare, and the economy of a region. To prevent the spread of the disease, these facilities must implement strict biosecurity measures, proper waste management practices, and regular monitoring and testing for brucellosis. Based on the above, the present pilot study aimed to examine the degree of influence of various "epidemiologically significant veterinary facilities" (or OTS) on the epidemiological situation of brucellosis in Kazakhstan. This would further enable the development of specific approaches to reduce the spread of the disease by these facilities and mitigate the risks to both public and livestock health.

Materials and Methods

Study area

Kazakhstan, situated in Central Asia, is one of the largest countries in the world, ranking 9th in terms of area. Despite being the largest landlocked country globally, Kazakhstan benefits from a strategic geographical location, sharing borders with key trade and economic partners, such as Russia and China. To the south, it borders Kyrgyzstan, Uzbekistan, and Turkmenistan, countries with which it maintains strong trade, economic and cultural relationships.

The study area includes seven first-level administrative units ("oblasts") in the southern and south-eastern parts of Kazakhstan: Abai, Almaty, East Kazakhstan, Kyzylorda, Turkestan, Zhambyl, and Zhetisu. These oblasts were chosen for two main reasons: firstly, because they appear in the most comprehensive database on Objects for Targeted Surveillance (OTS) available at the time of writing; and secondly, because of the highest livestock density, making this region the most at risk for the spread of contagious livestock diseases. Administratively, the study regions are divided into 70 second-level units (districts and urban areas), which were the units of analysis in our study (Figure 1). The area of the districts varies from 531 to 114,720 km². The cattle population density ranges from 0 to 161 heads/km² with an average value of 6.6 heads/km². The density of small ruminants ranges from 0 to 277 heads/km² with an average of 18.9 heads/km².

Objects for targeted surveillance

In this study, OTS were defined as infrastructure facilities that require constant veterinary control and supervision and can act as concentrators and facilitators of risk regarding the spread of contagious animal diseases. Following Dudnikov et al. (2008) and Belchikhina et al. (2011), we categorized all OTSs into four main

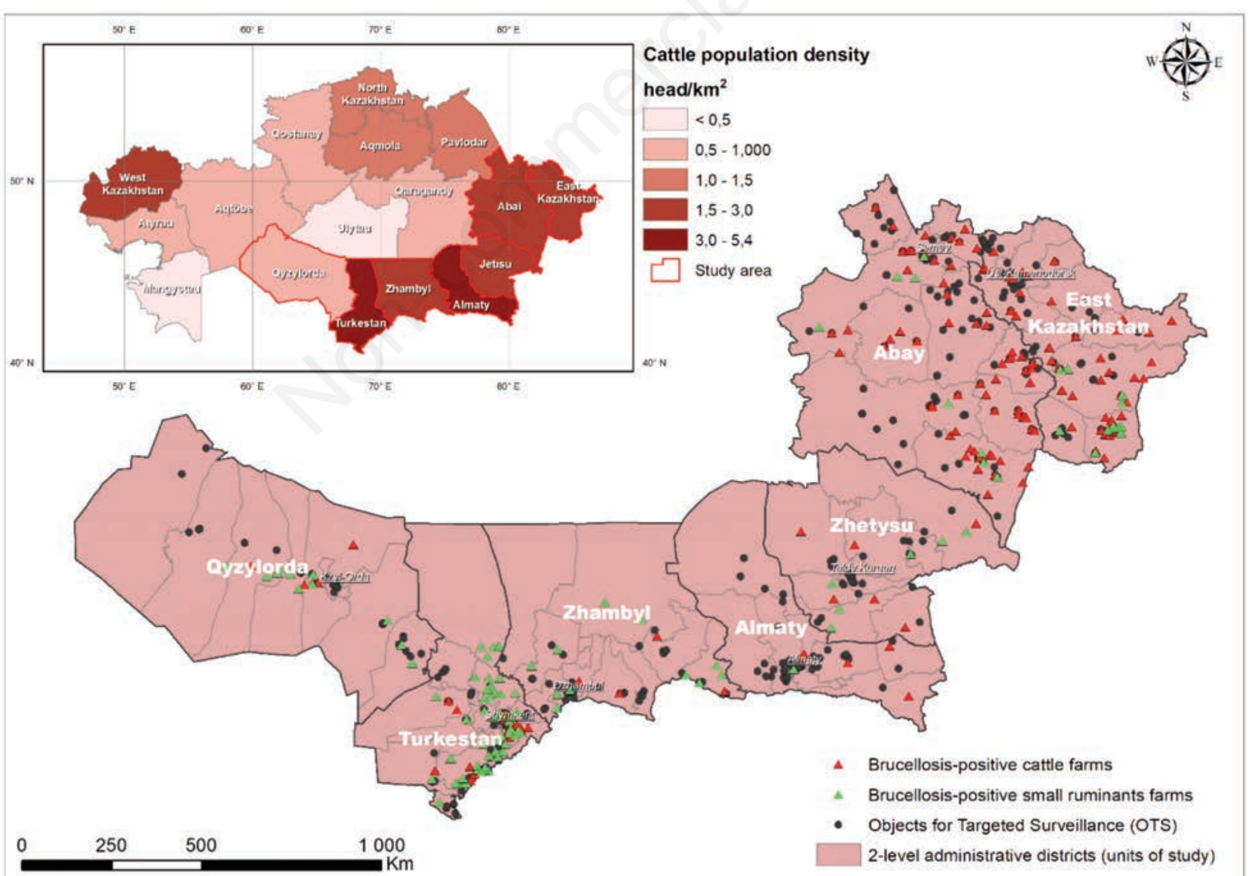

Figure 1. The study area in Kazakhstan, brucellosis cases at livestock farms, and Objects for Targeted Surveillance (OTS).

categories: i) veterinary facilities (veterinary laboratories, animal burial grounds, bio-waste disposal facilities, veterinary pharmacies, clinics, etc.); ii) agricultural or production facilities (farms, meat processing plants, agricultural storage facilities, slaughterhouses, etc.); iii) utilities (airports, train stations, research facilities, landfills); iv) other (animal exhibitions, nature reserves, zoos, hippodromes, hunting farms, kennels, etc.).

The study area was the first region in Kazakhstan, for which a complete database of OTS (slaughterhouses, processing plants and livestock markets) was collected. In Kazakhstan, two types of slaughter spots can be distinguished: i) slaughterhouses and ii) slaughter grounds. The former occupy well-equipped buildings and can be considered as high-biosecurity slaughterhouses (Figure 2), while the latter typically represent simpler locations with less equipment and biosecurity and can thus be considered low-biosecurity slaughterhouses (Figure 3).

Each OTS's name, geographical coordinates, and activity profile were entered into the geographical information systems (GIS) database. A scheme of cartographic visualization of OTS using unique symbology was developed using ESRI *.style file format.

Livestock farms

In the course of research activities aimed at creating a digital database of agricultural facilities in Kazakhstan, farms for keeping and breeding cattle and small ruminants in the country were located, georeferenced, and documented. In the study area, 2,704 cattle farms with populations ranging from one to 97,627 head (with an average of 1,634 head) and 1002 small ruminant farms with populations ranging from one to 167,918 head (with an average of 15,303 head) were identified. The GIS database would include attributes such as geographic coordinates and the livestock population on each farm.

Brucellosis data

In the period from 2020 to 2023, 339 cases of brucellosis were registered in the study region. Among these cases, 228 (67%) occurred on cattle farms, and 111 (33%) on small ruminant farms. In this study, a case is understood as a recorded and laboratory-confirmed emergence of brucellosis at a single farm, identified by geographical coordinates. Confirmation the of the diagnosis is made by district veterinary laboratories of RSE REM «Republican Veterinary Laboratory», which is part of the Committee of Veterinary Control and Supervision of the Ministry of Agriculture of the Republic of Kazakhstan using the Complement Fixation Test (CFT). Additionally, ELISA tests are performed when necessary. In accordance with the national brucellosis control strategy, the Republic conducts bi-annual testing to monitor 100% of cattle and small ruminants.

Figure 2. An example of a “high-biosecurity slaughterhouse” (Belkol village at Kyzylorda region). Images taken by the authors.

The research method

To identify the potential influence of OTS on the incidence of brucellosis in each district, we conducted regression analysis using a linear negative binomial regression model (Juarez-Colunga & Dean, 2024). The choice of this regression model was based on the over-dispersion of the dependent variable, which is the number of brucellosis cases in each district of the model region. The potential explanatory variables considered were the number and density of cattle, the number and density of small ruminants, the number of cattle and small ruminant farms, and the number of OTSs of each of the four types (livestock markets, meat processing plants, high-security slaughterhouses and low-security slaughterhouses) (refer to Table 1). The rationale behind including livestock number and population density was the natural assumption of a correlation between incidence and the number of susceptible animals and farms. To address multicollinearity, a preliminary correlation analysis of all variables was conducted, with a threshold value of $|r| < 0.7$. In order to develop the regression model, a stepwise exclusion of insignificant variables was employed to meet the minimum of Akaike's criterion (Venables and Ripley, 2002).

Software

The GIS ArcGIS Desktop 10.8.2 (ESRI, Redlands, CA, USA) was used for data visualization and spatial analysis. Data systematization and preparation were performed using the Microsoft Excel package (Redmond, WA, USA). Regression analysis was performed using statistically oriented R software, v 4.2.1 (R Core Team, 2022).

Figure 3. An example of a "low-biosecurity slaughterhouse" (Bayzak district of the Zhambyl region). Images taken by the authors.

Figure 4. An example of symbols for the cartographic representation of objects for targeted surveillance (OTS). From left to right: animal burial grounds, high-biosecurity slaughterhouses, low-biosecurity slaughterhouses, veterinary pharmacies, bio-waste disposal facilities, small ruminants farms, and meat processing plants.

Results

Database of objects for targeted surveillance

The OTS database compiled at this stage for the study region includes 395 objects categorized as follows: i) cattle markets (N = 45), ii) meat processing plants (N = 15), iii) high-biosecurity slaughter facilities (N = 112), iv) low-biosecurity slaughter facilities (N = 223). Figure 4 shows an example of the cartographic symbols representing some OTS. These symbols are intended for use on detailed maps to depict locations of OTSs and their associated epidemiological information.

Regression analysis

The preliminary correlation analysis revealed no significant correlation between the explanatory variables; therefore, all of them were used for modeling. The regression analysis conducted on the number of brucellosis cases in each of the study districts allowed us to obtain a model of satisfactory quality. After step-by-step exclusion of insignificant variables, the following factors remained: the number of cattle farms, the number of cattle populations, the number of meat processing enterprises, and the number of slaughterhouses of low and high biosafety (Table 2). All variables, except for the number of meat processing plants, demonstrated statistical significance.

Discussion

OTS are infrastructure facilities that can be considered as hubs and conductors for the risk of spreading animal diseases and require constant monitoring of the epidemic state. They can have a significant impact on the epizootic and epidemic situation of brucellosis at various scales: regional, district, or local. Facilities such as farms involved in livestock breeding, slaughterhouses, meat processing enterprises (particularly those involved in the sanitary slaughter of brucellosis-positive animals) and milk and dairy production enterprises play a crucial role in the epizootic process of brucellosis (Godfroid *et al.*, 2011; Al Jindan, 2021; An *et al.*, 2023). In our study, we made the first attempt in Kazakhstan to directly identify the relationship between the presence of OTSs in an area and the intensity of brucellosis cases among cattle and small ruminants. Although the applied regression model demonstrated a relatively low R^2 of 0.34, it was not intended to capture all possible factors influencing the occurrence of brucellosis on farms. Instead, it aimed to identify statistically significant relationships. The results demonstrate that the number of brucellosis-positive farms is correlated with the number of slaughterhouses of different biosafety levels at the level of statistical significance. This relationship can be explained by the greater intensity of animal movement in these regions towards slaughterhouses (including those from other areas), leading to more frequent contact and contributing to the spread of the disease (de Araújo *et al.*, 2022). Additionally, the spread of the disease can be facilitated by the contact of slaughterhouse staff with healthy animals, as well as contamination of the soil and the environment in general. The positive relationship with the number of cattle farms and negative relationship with the number of cattle may indicate a tendency for brucellosis to emerge in areas with a large number of farms with low livestock population, *i.e.* in areas with a predominance of small-scale production with a lower level of biosafety.

The presence and number of meat processing plants showed a negative relationship with the number of brucellosis cases.

Table 1. Variables used as potential explanatory factors in the regression model.

Variable	Measurement units	Range per district
Number of brucellosis positive farms	units	4.8 (0–36)
Number of cattle farms	units	38.6 (0–131)
Number of small ruminants farms	units	14.3 (0–30)
Cattle population	head	63,117 (0–187,280)
Small ruminants population	head	219,064 (0–836,037)
Cattle density	heads/km2	6.66 (0–161.03)
Small ruminants density	heads/km2	18.91 (0–276.97)
Number of meat processing plants	units	5.6 (0–24)
Number of livestock markets	units	0.6 (0–10)
Number of high biosafety slaughter facilities	units	1.6 (0–19)
Number of low biosafety slaughter facilities	units	3.2 (0–17)

Table 2. Regression metrics of the model that connects the number of brucellosis cases with the potential explanatory variables.

Variable	Regression coefficient	Standard Error	Z-value	p-value
(Intercept)	0.476	0.272	1.747	0.080
Number of cattle farms	0.031	0.008	4.009	<0.001
Cattle population	-0.00001	0.000004	-2.024	0.043
Number of meat processing plants	-0.190	0.101	-1.882	0.059
Number of HB slaughterhouses	0.335	0.132	2.535	0.011
Number of LB slaughterhouses	0.230	0.096	2.382	0.017

Note: Statistically significant dependencies are highlighted in bold (p<0.05)

pagepress

However, due to the lack of statistical significance of this factor (p>0.05), this is likely because meat processing enterprises constitute only 3.7% of the total number of OTS. However, this correlation cannot be explained within the scope of this study.

The conducted analysis is a pilot project aimed at identifying the impact of OTS on the occurrence of brucellosis in a region of the country with incomplete data on OTS categories. As additional data is collected on other categories of OTS, including the national scale, this analysis will be continued and conducted using advanced methods of spatial statistical analysis (such as analysis using a regular grid instead of linking to administrative districts).

In general, the pattern revealed at this preliminary stage confirms the initial hypothesis about the influence of the presence of OTS on the presence and intensity of an infectious disease. The results of our analysis can serve as a justification for the need to increase biosafety measures at slaughterhouses in the region, as well as further systematization and digitalization of OTS country-wise. This will enable a prompt assessment of the risks of the spread of particularly dangerous animal and human diseases.

References

Abutalip A, Bizhanov A, Matikhan N, Karabassova A, Orynbayeva B, 2024. Regional epidemiology of brucellosis infection in modern conditions of animal husbandry technology in Kazakhstan (by the degree of spread and incidence). Sci Horiz 27:20-31.

Al Jindan R, 2021. Scenario of pathogenesis and socioeconomic burden of human brucellosis in Saudi Arabia. Saudi J Biol Sci 28:272-9.

An C, Shen L, Sun M, Sun Y, Fan S, Zhao C, Nie S, Luo B, Fu T, Liu K, Shao Z, Chang W, 2023. Exploring risk transfer of human brucellosis in the context of livestock agriculture transition: A case study in Shaanxi, China. Front Public Health 27:1009854.

Ayoola MC, Akinseye VO, Cadmus E, Awosanya E, Popoola OA, Akinyemi OO, Perrett L, Taylor A, Stack J, Moriyon I, Cadmus SI, 2017. Prevalence of bovine brucellosis in slaughtered cattle and barriers to better protection of abattoir workers in Ibadan, South-Western Nigeria. Pan Afr Med J 28;10925.

Beauvais W, Coker R, Nurtazina G, Guitian J, 2017. Policies and livestock systems driving brucellosis re-emergence in Kazakhstan. Ecohealth 14:399-407.

Belchikhina AV, Shibayev MA, Dudorova MV, 2011. The development and approbation of the information system of identification, registration and mapping of epidemiologically significant veterinary objects in the regions of the Russian Federation. (in Russian). Veterinariya I Kormlenie 6:14-17.

Bugeza JK, Roesel K, Mugizi DR, Alinaitwe L, Kivali V, Kankya C, Moriyon I, Cook EAJ, 2024. Sero-prevalence and risk factors associated with occurrence of anti-Brucella antibodies among slaughterhouse workers in Uganda. PLoS Negl Trop Dis 18:e0012046.

Charypkhan D, Rüegg SR, 2022. One Health evaluation of brucellosis control in Kazakhstan. PLOS ONE 17:e0277118.

Charypkhan D, Sultanov AA, Ivanov NP, Baramova SA, Taitubayev MK, Torgerson PR, 2019. Economic and health burden of brucellosis in Kazakhstan. Zoonoses Public Health 66:487-94.

Corbel MJ, 1997. Brucellosis: an overview. Emerg Infect Dis 3:213-21.

Counotte MJ, Minbaeva G, Usubalieva J, Abdykerimov K, Torgerson PR, 2016. The Burden of Zoonoses in Kyrgyzstan: A Systematic Review. PLoS Negl Trop Dis 10:e0004831.

de Araújo LCSDSC, da Costa MM, do Nascimento JA, da Silva FDA, Peixoto RM, 2022. Bovine brucellosis seroprevalence and flow network analysis in slaughterhouses in the state of Ceará. Braz J Vet Med 44:e003521.

Dudnikov SA, Lyadsky MM, Belchikhina AV, Gulenkin VM, Vystavkina ES, Lisitcyn VV, 2008. Epidemically significant objects of the Vladimir Oblast. Veterinary Atlas. (in Russian). Rosselkhoznadzor. Accessed 01 Nov 2024. Available from: https://fsvps.gov.ru/sites/default/files/fsvps-docs/ru/iac/publications/iac_public8.pdf

Dzhupina SI, 2004. Lessons of epizootological studies (in Russian). Moscow, RUDN. 299 p.

Ergazina AM, Piontkovsky VI, Kazimieras L, 2013. Cattle brucellosis: epizootiology, diagnosis, prevention and control measures in Kazakhstan. World Appl Sci J 28:81-6.

Godfroid J, Scholz HC, Barbier T, Nicolas C, Wattiau P, Fretin D, Whatmore AM, Cloeckaert A, Blasco JM, Moriyon I, Saegerman C, Muma JB, Al Dahouk S, Neubauer H, Letesson JJ, 2011. Brucellosis at the animal/ecosystem/human interface at the beginning of the 21st century. Prev Vet Med 102:118-31.

Hasanjani Roushan MR, Ebrahimpour S, 2015. Human brucellosis: An overview. Caspian J Internal Med 6;46–47.

Jin M, Fan Z, Gao R, Li X, Gao Z, Wang Z, 2023. Research progress on complications of Brucellosis. Front Cell Infect Microbiol 13:1136674.

Juarez-Colunga E, Dean CB, 2024. Negative Binomial Regression. In Wiley StatsRef: Statistics Reference Online (eds N. Balakrishnan, T. Colton, B. Everitt, W. Piegorsch, F. Ruggeri and J.L. Teugels). doi:10.1002/9781118445112.stat08246

Kakooza S, Watuwa J, Ipola PA, et al., 2022. Seromonitoring of brucellosis in goats and sheep slaughtered at an abattoir in Kampala, Uganda. J Vet Diagnostic Investig 34:964-967.

Laine CG, Johnson VE, Scott HM, Arenas-Gamboa AM, 2023. Global Estimate of Human Brucellosis Incidence. Emerging Infect Dis 29:1789–97.

Liu Z, Gao L, Wang M, Yuan M, Li Z, 2024. Long ignored but making a comeback: a worldwide epidemiological evolution of human brucellosis. Emerg Microbes Infect 13:2290839.

Madut NA, Ocan M, Muwonge A, Muma JB, Nasinyama GW, Godfroid J, Jubara AS, Kankya C, 2019. Sero-prevalence of brucellosis among slaughterhouse workers in Bahr el Ghazal region, South Sudan. BMC Infect Dis 19:450.

Mamadaliyev SM, Matveeva VM, Koshemetov ZhK, Khairullin BM, Orynbayev MB, Sandybayev NT, Kydyrbayev ZhK, Zaitsev VL, Zhilin ES, Nurabayev SSh, Koryagina MI, 2010. The monitoring of especially dangerous viral diseases of animals and birds on the territory of Central Asian republics (in Russian). Actual problems of Veterinary Biology. 2(6).

Mioni MSR, Vicente AF, Peres MG, Appolinário CM, Ribeiro BLD, Pantoja JCF, de Almeida JP, Pinto N, Mathias LA, Megid J, 2018. Brucellosis Prevalence in Brazilian Slaughterhouses with Different Meat Inspection Systems. J Food Prot 81:1073-8.

Muminov A, 2019. Agriculture is a basis of a strong Economics. (in Russian). Accessed 16 Aug 2024. Available from: https://kapital.kz/economic/77001/sel-skoye-khozyaystvo-osnova-sil-noy-ekonomiki.html

Papadatos SS, Bazoukis G, Deligiannis G, Mylonas S, Zissis C,

2017. Respiratory symptoms as prominent manifestation of brucellosis: a case series. J Clin Diagnostic Res 11:OR01–3.

Pappas G, Akritidis N, Bosilkovski M, Tsianos E, 2005. Brucellosis. New Engl J Med 352:2325–36.

R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Accessed 01 Nov 2024. Available from: https://www.R-project.org/.

Rubach MP, Halliday JE, Cleaveland S, Crump JA, 2013. Brucellosis in low-income and middle-income countries. Curr Opin Infect Dis 26:404-12.

Ryskeldinova S, Zinina N, Kydyrbayev Z, Yespembetov B, Kozhamkulov Y, Inkarbekov D, Assanzhanova N, Mailybayeva A, Bugybayeva D, Sarmykova M, Khairullin B, Tabynov K, Bulashev A, Aitzhanov B, Abeuov K, Sansyzbay A, Yespolov T, Renukaradhya GJ, Olsen S, Oñate A, Tabynov K, 2021. Registered influenza viral vector based brucella abortus vaccine for cattle in Kazakhstan: age-wise safety and efficacy studies. Front Cell Infect Microbiol 1:669196.

Shaikenov BS, Torgerson PR, Usenbayev AE, Baitursynov KK, Rysmukhambetova AT, Abdybekova AM, Karamendin KO, 2003. The changing epidemiology of echinococcosis in Kazakhstan due to transformation of farming practices. Acta Trop 85:287-93.

Shevtsova E, Shevtsov A, Mukanov K, Filipenko M, Kamalova D, Sytnik I, et al., 2016. Epidemiology of Brucellosis and Genetic Diversity of Brucella abortus in Kazakhstan. PLoS ONE 11:e0167496.

Shevtsova E, Vergnaud G, Shevtsov A, Shustov A, Berdimuratova K, Mukanov K, Syzdykov M, Kuznetsov A, Lukhnova L, Izbanova U, Filipenko M, Ramankulov Y, 2019. Genetic Diversity of Brucella melitensis in Kazakhstan in Relation to World-Wide Diversity. Front Microbiol 13:1897.

Syrym NS, Yespembetov BA, Sarmykova MK, Konbayeva GM, Koshemetov ZhK, Akmatova EK, Bazarbaev M, Siyabekov ST, 2019. Reasons behind the epidemiological situation of brucellosis in the Republic of Kazakhstan. Acta Tropica 191:98-107.

UNECE Data Portal. Share of agriculture in GDP. Accessed 01 Nov 2024. Available from: https://w3.unece.org/PXWeb/en/Table?IndicatorCode=6

Venables WN, Ripley BD, 2002. Modern Applied Statistics with S. Fourth edition. XII, 498. Springer New York, NY.

Yespembetov BA, Syrym NS, Syzdykov MS, Kuznetsov AN, Koshemetov ZhK, Mussayeva AK, Basybekov SZ, Kanatbayev SG, Mankibaev AT, Romashev CM, 2019. Impact of geographical factors on the spread of animal brucellosis in the Republic of Kazakhstan. Compar Immunol Microbiol Infect Dis 67:101349.