



## Role of cross-border epizootic risks in ensuring veterinary safety and sustainable livestock development in Central Asia

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### ABSTRACT

Biosecurity and productivity issues involving porous borders, weak biosurveillance, and land changes challenge Central Asia's livestock sector. Kazakhstan, the region's largest livestock producer and trade hub, exemplifies these. This study integrates epidemiological data from the World Animal Health Information System (WAHIS), land-cover data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), and national statistics to assess relationships between grazing-land change, livestock productivity, and disease. Evaluation of WAHIS reports within a 200-km region around Kazakhstan from 2004 to 2024 identify epizootic threats including; Potential under-reporting of African swine fever for farms in Kostanay, North Kazakhstan, and Pavlodar (55% of swine stock); Highly pathogenic avian influenza risk along the north-south corridor of North Kazakhstan, Akmola, Karagandy, and Almaty (55% of poultry stock) with Lake Balkash migratory sites; Potential under-reported lumpy skin disease in Batys and Aktobe regions (~20% of cattle stock) given reports from Russia's Astrakan and Volga River basin; Potential foot-and-mouth vulnerability for ruminants between Almaty and Shymkent, complicated by transboundary practices, requiring joint biosurveillance with Kyrgyzstan. Grazing-land degradation observed by MODIS correlated with milk yield for household ( $r = 0.66$ ,  $p = 0.005$ ) and smallholder farms ( $r = 0.60$ ,  $p = 0.013$ ), but not for large enterprises ( $r = -0.07$ ,  $p = 0.79$ ). National calving-rate data, not available by industry level, showed a similar association ( $r = 0.69$ ,  $p = 0.003$ ).

**Keywords:** Biosecurity, Central Asia, Kazakhstan, Climate change, WAHIS, MODIS.

**Article type:** Perspective.

### INTRODUCTION

Modern Central Asia, consisting of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, has a long history (Rogers 2012) of trade and agriculture, encompassing many different cultures, geographies, and biospheres (Barisitz 2017). With trade and agricultural practices such as nomadism and transhumance pastoralism (Harris, 2024), the region is challenged by porous borders leading to biosurveillance (Walker & Blackburn 2015a) and management difficulties (Hay *et al.* 2016). Added to this, significant historical political disruption has slowed the establishment of strong protocols. This biosecurity status limits access to international agricultural markets and significantly limits economic progress (Walker & Blackburn 2015b; Mirzabaev *et al.* 2016). Organizations such as the World Organization for Animal Health (WOAH), the Food and Agriculture Organization of the United Nations (FAO), World Bank, and International Union for the Conservation of Nature contribute to projects that

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make significant improvements, including the One Health Central Asia project and the Central Asia One Health approach. However, challenges remain in opening the Central Asian region to further agricultural enterprise and generating evidence-based confidence in agricultural product quality and consistency from the region. Kazakhstan, with its proximity to China and being closest of the FSU countries to Russia, is a “gateway” to Central Asia. Kazakhstan’s trade relationships reflect this with the 2018-2023 data for live animal trade predominantly showing animal importation (cattle, horses, poultry, sheep and goats, and swine) from Russia, then exportation into Central Asia (primary partners being Uzbekistan and Tajikistan, UN comtrade data, Supplementary Table S1). Despite Kazakhstan’s regional dominance, its live cattle export sector remains underdeveloped. While Kazakhstan generally serves Central Asia as a net exporter and efforts to highlight the genetic characteristics of its herds are underway (Khamzina *et al.* 2025; Nursaule Dyussekenova *et al.* 2025), its engagement with global markets is limited and largely one-directional. This reflects a combination of structural barriers, including geopolitical constraints, logistical limitations, and the prevalence of productivity-limiting and zoonotic diseases (Tazhibayev *et al.* 2014). Kazakhstan also faces structural challenges in maintaining a self-sustaining national cattle herd. According to the Kazakhstan Bureau of National statistics, the calving rate in 2024 was just 45 births per 100 breeding-age females, significantly below the threshold required for herd replenishment. Low calving rates are symptomatic of nutritional deficits, herd stress, and persistent unmanaged endemic pathogens (Khussainov *et al.* 2024). As a rule of thumb, calving rates of ~60% are typically necessary to offset natural mortality, slaughter, and export, with ideal rates at ~90%. Kazakhstan’s calving deficit requires external influx for herd maintenance and growth, a significant burden on the agriculture industry. Despite this low birth rate, official figures show that live bovine imports accounted for less than 0.5% of total stock in 2023, suggesting that either unregistered inflows or undocumented population dynamics are compensating for the shortfall. These conditions significantly complicate national biosurveillance, undermine biosecurity, and lead to systemic weaknesses in disease control and reproductive management. Overall, Kazakhstan live exports destined for other Central Asian countries far outstrip its exports elsewhere, indicating an undercapitalized industry hampered by both biosurveillance challenges and geographical access to export seaports. However, the underdeveloped state of the industry enables adopting new practices for more environmentally friendly and resilient production (Tittonell *et al.* 2020). The work presented here combines epidemiological information from the World Animal Health Information System (WAHIS), industrial and statistical data from the Kazakhstan Bureau of Statistics, and climate data from the MODIS module on NASA’s Terra and Aqua satellites to identify fundamental aspects of the livestock and epidemiological status of Kazakhstan. We aim to support and inform regional policy development and the adoption of practices promoting regional food security and sustainable development goals.

## MATERIALS AND METHODS

### UN comtrade data and Kazakhstan National Livestock Statistics

International live-animal trade data were retrieved via the World Integrated Trade Solution (WITS; [wits.worldbank.org](https://wits.worldbank.org), accessed 24<sup>th</sup> May 2025), querying the UN Comtrade merchandise trade database with: reporter = Kazakhstan; trade flow = imports and exports; partner = all countries. HS 4-digit live-animal categories were used: 0101 (horses, asses, mules, hinnies), 0102 (bovine animals), 0103 (swine), 0104 (sheep and goats), and 0105 (poultry). Quantities were taken as number of head where reported. Annual quantities were aggregated over 2018-2023 by partner and flow; partner shares (%) equal the partner’s 2018-2023 total divided by the Kazakhstan total for the same HS code and flow. Partners were grouped as Central Asia (Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan) versus non-Central Asia, see Supplementary Table S1 and S2. Kazakhstan’s 2024 livestock demographic and production statistics were obtained from the Bureau of National Statistics of Kazakhstan (accessed 10<sup>th</sup> June 2025, Supplementary Table S3). Data were reported at the administrative-region level and by producer category (agricultural enterprise, smallholder, and household), including herd size, average milk yield per cow, and calving rate per 100 uteri. Producer category is classified by the Bureau of National Statistics definitions: agricultural enterprises (agricultural enterprises - legal entities engaged in agricultural production), peasant/farmer holdings (KFH) peasant (farm) households - a family-labor in which individual entrepreneurship is inseparable from the use of agricultural land to produce/market agricultural products), and household farms (households of the population - including personal subsidiary, garden, and dacha plots).

### WAHIS Data

Outbreak data for selected notifiable livestock diseases in Central Asia and a 200 km border region surrounding the Republic of Kazakhstan from 2010 to 2024 were compiled from the World Animal Health Information System

(WAHIS, accessed 26<sup>th</sup> March 2025). Data were filtered for completeness and consistency. Events without valid geolocation or with unresolved host classification were excluded. Final outbreak tables were georeferenced and converted to point shapefiles for spatial analysis. Summarized data corresponding to cases, year, disease, and country are noted in Supplementary Table S4.

### **Landscape and Environmental Data**

Geospatial datasets, including administrative boundaries and thematic shapefiles, were obtained from the Humanitarian Data Exchange (HDX, OCHA Services, accessed 10<sup>th</sup> April 2025). All layers were standardized to a common coordinate reference system. Spatial analyses were performed in Asia North Albers Equal Area Conic (ESRI:102025) to preserve area accuracy, while final maps and figures were rendered in WGS 84 (EPSG:4326) for geographic interpretability. Land-cover data were derived from the NASA MODIS MCD12Q1.061 dataset, which applies the FAO LCCS2 classification scheme (Supplementary Table S5). Annual land-cover classifications for 2010 and 2023 were processed in QGIS 3.42.0 (Münster). Raster tiles were clipped to Kazakhstan's national boundary and vectorized for integration with outbreak and administrative data. Analyses used Kazakhstan's current structure of 17 oblasts and 4 cities. Change detection employed a cross-tabulation of 2010 versus 2023 classes to identify pasture suitability transitions. Grazing suitability was defined by land-cover types 30 (Natural herbaceous), 35 (Natural herbaceous/cropland mosaics), and 40 (Shrublands). Relative productivity differences among these land types were not considered.

### **Statistics**

Statistical analyses were performed in GraphPad Prism (version 10.6.1, build 892). Variable distributions were assessed using Shapiro-Wilk, D'Agostino & Pearson, Anderson-Darling, and Kolmogorov-Smirnov tests against both normal and log-normal distributions (Supplementary Table S6), Pearson correlation and simple linear regression were also conducted with statistical significance set at  $\alpha = 0.05$  (Supplementary Table S7). Full test results and correlation outputs are provided in the Supplementary Materials.

## **RESULTS**

### **WAHIS database - Diseases of interest**

The WAHIS database is an invaluable resource for tracking disease events. First established as HandiSTATUS in 1991 in diskette form, it moved to an online interface, HandiSTATUS II, in 1996, and in 2006 transitioned to the WAHIS (Jebara *et al.* 2012). The combined efforts of 183 member countries, international organizations, alongside philanthropic and private funding sources enable consistent reporting for diseases of note. Kazakhstan's reported diseases are noted in Table 1. Kazakhstan is the most active Central Asian contributor to the WAHIS database. Table 1 presents data from a periodical WAHIS extraction retrieved on 31 March 2025. Although reporting activity is high, national biosurveillance remains constrained by the country's size and associated infrastructural limitations. Each listed disease is discussed in the following section. Conditions with comparatively greater relevance for trade (**bold**), reproductive performance (*italics*), or culling (underlined) are marked accordingly, with the expanded table including the 200 km region surrounding Kazakhstan noted in Supplementary Table S4.

### **Foot-and-mouth disease**

Foot-and-mouth disease (FMD) is classified by the World Organisation for Animal Health (WOAH) as a Category A transboundary animal disease, (WOAH, 2025) posing significant threats to livestock production systems, international trade, and ecosystem health. The virus comprises seven major serotypes (Alexandersen *et al.* 2003; Zhang *et al.* 2024), of which, O, A, and Asia-1 are endemic to Kazakhstan. It primarily affects cloven-hoofed animals, including cattle, sheep, goats, and pigs, as well as wild ungulate reservoirs such as saiga antelope (*Saiga tatarica*), roe and red deer, and wild boar. In Kazakhstan, the persistence of these wild populations and the prevalence of transhumance practices across porous borders represent substantial challenges to maintaining full FMD control (Walker & Blackburn 2015b; Abdrakhmanov *et al.* 2018). In 2017, Kazakhstan achieved FMD-free status in the central and western regions without vaccination, and southern to eastern regions with vaccination (WOAH, 2017; Sultanov *et al.* 2023a). Before achieving this, two major outbreak periods occurred, one in 2007 and the other between 2010 and 2013. The 2007 outbreak primarily affected the western regions of Batys Kazakhstan and Atyrau, as well as the central region of Ulytau (which was part of Karagandy until 2022). At this time, Batys Kazakhstan and Ulytau each accounted for 7% of the national herd, while Atyrau accounted for 3%.

During this outbreak, in Loubenka (Batys Kazakhstan), 442 cases were reported among cattle, with 3,544 animals considered susceptible resulting in two animal deaths and 442 culled. Kengir (then Karagandy region, now Ulytau), 60 cattle and 1,100 sheep were assessed as susceptible, with all affected cattle culled. In Sagyz (Atyrau), 2,001 cattle were affected, leading to ten deaths and the culling of 1,991 animals from a total susceptible population of 5,983. Additionally, 82 sheep were culled from a susceptible population of 23,583.

**Table 1.** World Animal Health Information System (WAHIS) reported outbreaks, cases, and mortalities in Kazakhstan (2005-2024).

Disease	2005-09	2010-14	2015-19	2020-24
Anthrax	2-(1/10)	4-(7/7)	9-(10/10)	8-(86/86)
Camelpox	-	-	3-(4/0)	-
<i>FMD</i>	3-(2,585/2,587)	20-(8,893/16,132)	-	1-(2/25)
HS	-	-	7-(134,857/135,300)	-
<u>HPAI</u>	1-(0/2,800)	-	2-(4/4)	19-(72,355/620,093)
<i>IBR/IPV</i>	-	-	-	8-(131/12)
<i>Lumpy skin d.</i>	-	-	1-(459/459)	-
Newcastle d.	-	1-(31/79)	2-(6/727)	-
Rabies	-	-	14-(16/16)	6-(6/6)
<i>Sheep/goat pox</i>	1-(99/99)	2-(21/21)	5-(395/395)	2-(0/0)

Notation: X-(Y/Z), where X = outbreaks, Y = cases, and Z = mortalities (dead, slaughtered, and culled). Diseases in bold indicate impact on trade, *italics* indicate reduce birth rates, and underline indicates high costs from culling.

FMD = foot-and-mouth disease; HS = haemorrhagic septicaemia; HPAI = highly pathogenic avian influenza; IBR/IPV = bovine rhinotracheitis/pustular vulvovaginitis.

Outbreaks between 2010 and 2013 extended into three epidemiologically significant zones. Region 1 included Western Kazakhstan (Batys); Region 2 spanned Zhambyl, Almaty, and the border of Kyrgyzstan; and Region 3 involved the southern portion of present-day Abay (formerly East Kazakhstan). At the time, these regions constituted approximately 40% of Kazakhstan's cattle herd. Across these areas the impact culling was considerable: 3,946 animals in Region 1 (2,978 sheep/goats and 972 cattle), 1,687 in Region 2 (1,077 sheep and 610 cattle), and 7,350 in Region 3 (5,020 sheep/goats and 2,330 cattle). However, protection of the 2.3 million cattle in the region, alongside goats and sheep, necessitated these measures. Official summaries don't explicitly note outbreak drivers, though uncontrolled animal movement, wildlife transmission, and insufficient cross-border coordination are likely contributors (Sytnik *et al.* 2013; Abdрахmanov *et al.* 2018; Sultanov *et al.* 2023b). In January 2022, despite control infrastructure improvements, FMD recurrence within a zone designated as FMD-free without vaccination led to the suspension of Kazakhstan's FMD-free status (WOAH 2022), with this suspension lifted in 2024 (WOAH 2024). Genetic analysis confirmed that the viral strain was consistent with one circulating in neighboring countries (Tyulegenov *et al.* 2022), underscoring the importance of regional cooperation in biosurveillance and outbreak prevention. Events in Russia, China, and Kyrgyzstan further illustrate the transboundary nature of the disease.

In 2021, an outbreak in Karagach (Orenburg, Russia), less than 25 km from Aktobe, resulted in the culling of 17 cattle and 22 sheep/goats, with 1,768 and 789 animals vaccinated, respectively. The Asku prefecture of Xinjiang, China, has also seen several events with a 2008 outbreak in Yingbake affecting 58 cattle and 106 sheep, all of which were culled, with a reoccurrence in 2016 resulting in the culling of 22 cattle. In 2010 an outbreak near Yingbazha lead to 355 swine being culled, and in 2017 at nearby Kumusumu, 1003 cattle were culled, alongside 32 dead from FMD. Smaller outbreaks were reported in Kyrgyzstan: Voznesenovka (2007) saw three cattle cases among 59 susceptible; Alamüdüin (2007) resulted in three cases among 990 susceptible; and Otmok (2014) yielded a single case among 40 cattle. Given the ease of FMD spread via aerosol, contact with infected fluids, or mechanical transmission, rigorous containment strategies are essential. Infected animals shed virus particles in excretions and secretions, contaminating feed, equipment, and clothing, facilitating inter-herd transmission. While Kazakhstan has progressed in surveillance and zoning, outbreaks within officially free zones highlights ongoing vulnerabilities, particularly in areas adjacent to international borders. To address the FMD threat, a coordinated regional strategy integrating wildlife monitoring, cross-border reporting, and harmonized vaccination policies in the area between Almaty, Zhambyl, and Turkistan with Kyrgyz veterinary services is critical to sustaining FMD-free status and securing trade pathways across Central Asia.

### Haemorrhagic septicaemia

Haemorrhagic septicaemia (HS), a bacterial infection caused by *Pasteurella multocida* serotype B:2 (Aktories *et al.* 2012), poses a significant threat to both wildlife and livestock populations when triggered by certain environmental conditions (Lestari *et al.* 2025). In 2015, a catastrophic outbreak of HS resulted in the death of approximately 200,000 saiga antelope (*Saiga tatarica*), equivalent to 62% of the global population at the time (Kock *et al.* 2018; Fereidouni *et al.* 2019). The event, centered in the northern regions of Kazakhstan, including Bokey hunting farm and the Altyn-Dala Nature Reserve near Lake Ozero Bokay in Kostanay, was characterized by acute septicaemia with total mortality in affected herds: 61,203 cases and deaths were recorded at Bokey and 52,106 at Altyn-Dala. Additional die-offs were documented in Aktobe (10,294 cases in Kuiyls) and Akmola (10,649 in the Ortakara area), further underscoring the scale of the event. The 2015 mortality was linked to extreme climatic conditions (Kock *et al.* 2018), specifically high temperature and humidity, coinciding with the calving season. These conditions are believed to have triggered the pathogenic activation of a dormant *P. multocida* strain harbored in the upper respiratory tract. Once activated, the bacterium rapidly disseminated systemically, leading to sudden death, especially in immunologically naïve or physiologically stressed animals. The interaction between environmental stressors and bacterial activation played a pivotal role in disease expression, with the mortality event widely considered a climatic-triggered epizootic of exceptional scale (Kock *et al.* 2018). Although *P. multocida* infects cattle, sheep, goats, and camels (Lestari *et al.* 2025), no confirmed livestock outbreaks were recorded with WAHIS within 200 km of the saiga die-off zone, raising the possibility of either under-reporting or an exceptional convergence of ecological and meteorological conditions unique to the saiga's calving habitat. Nevertheless, the bacterium's ability to cause disease across multiple species was demonstrated in subsequent years: in 2016, an outbreak in Zhaskayrat, Atyrau, affected multiple species including mixed-herd sheep and goats (571 cases, 388 deaths from 16,588 susceptible), alongside potentially vulnerable horses (504 susceptible), camels (101 susceptible), and cattle (2,141 susceptible). Also in 2016, 13 cattle cases and deaths were reported among 2,276 susceptible animals in Staraya Masra, Aktobe. While in 2017, a localized outbreak in Nura, Karagandy, resulted in 21 cattle deaths. *P. multocida* persists dormant in the upper respiratory tract until environmental or physiological stress (e.g., heat, crowding, malnutrition, and transport) precipitates clinical disease. Its reactivation potential underlies the importance of climatic triggers, particularly high humidity and temperature, as epidemiological risk factors. Given increased climatic variability and extreme weather events due to anthropogenic climate change, there is a persistent HS threat towards domestic livestock populations. High-risk scenarios include pathogen reservoirs in wildlife or imported animals, exposure to climatic stressors such as heat waves or flooding, high-density livestock operations with poor ventilation, and immunologically naïve herds lacking prior exposure or vaccination. While the 2015 saiga event remains the most dramatic expression of this disease in Kazakhstan's recent history, it also signals the need for integrative surveillance of wildlife health, environmental conditions, and domestic livestock systems.

### Capripoxviruses

Despite not being a zoonotic threat, Capripoxviruses are a critical threat to animal health and industry (Hamdi *et al.* 2021), with high morbidity (near 100% in naïve populations), mortality rates between 10-50%, and long-term economic impact through reductions in fertility, milk yield, by-product quality, and carcass weight. Lumpy Skin disease (LSD), Sheep pox (SPV), and Goat pox (GPV) are all antigenically related capripoxviruses with LSD differentiated by its specificity towards cattle, insect-dependent vector, and different symptoms. Although SPV and GPV are largely species-specific, mixed herding does lead to cross-infection as both viruses share similar transmission routes and symptoms (Clemmons *et al.* 2021). Across the capripoxvirus family, vaccination remains the most effective mitigation strategy.

### Lumpy Skin Disease

LSD is a vector-borne transboundary viral disease of cattle (Akther *et al.* 2023) caused by the LSD virus (LSDV). Despite not replicating within arthropods and not being a true arbovirus, its transmission by biting insects, including *Culicoides* midges, *Stomoxys* flies, and various tick species (Bianchini *et al.* 2023) means that vector control strategies applied to arboviral diseases are effective in limiting transmission. The first officially recorded outbreak of LSD in Kazakhstan occurred in 2016 (Issimov *et al.* 2020), at a livestock facility in Makasch, Atyrau, located close to the Volga River delta and the Russian border near Astrakhan. This outbreak resulted in 459 confirmed cases among cattle, with 34 deaths and culling of 425 animals out of a susceptible population of 3,557.

Molecular analysis of vector samples collected during the outbreak confirmed the presence of LSDV in ticks and horseflies. Atyrau's relatively low share of the national herd, estimated at approximately 2% in 2016, with a cattle density of approximately 1.4 head per km<sup>2</sup>, alongside limited ecological niches for insect vectors may reduce potential viral spread into Kazakhstan. Additionally, the isolation of the strain LSDV KZ-Kostanay-2018 suggests further undocumented circulation of the virus within Kazakhstan (Kutumbetov *et al.* 2025). However, this strain was not accompanied by official outbreak notification to WAHIS, underscoring potential gaps in national reporting systems. As climate shifts contribute to vector species habitat translocation, LSD may spread into previously unaffected northern and central regions along the Batys and Atyrau border with Russia, where higher cattle densities, a naïve population, and limited vector control infrastructure may amplify epidemic potential. Integrated strategies of entomological monitoring, PCR-based screening of vectors and livestock, and WOAHA-aligned outbreak reporting protocols (Lee *et al.* 2024) are critical to maintain regional biosecurity.

### **Sheep and goat pox**

Sheep pox and goat pox are both endemic capripoxvirus infections in Kazakhstan (Clemmons *et al.* 2021), occurring sporadically across regions with high concentrations of small ruminants. In 2019, the most notable outbreaks were recorded in Atyrau and Mangystau, both of which lie along Kazakhstan's border with Russia and the Caspian Basin. In Atyrau, the outbreak occurred in the settlement of Suyindik, located near the Volga River and the Russian border. A total of 260 sheep were affected in this outbreak, all of which died from a susceptible population of 13,486 animals. While cross-border incursion is possible, the adjacent Russian territory to Atyrau, specifically the lower Volga delta, is focused on crop agriculture. As such, the sparse distribution of small ruminants may contribute to the limited number of reported sheep/goat pox events on the Russian side. Only one outbreak was recorded in 2023 in Artel', Enotaevskiy Rayon, Astrakhan (1 case, 118 susceptible), suggesting that outbreaks in this region may be self-limiting. The second significant outbreak in 2019 occurred in Kyzylozen, Mangystau, resulting in 45 sheep cases, all of which were fatal, from a susceptible population of 1,178 animals. Though smaller in scale, this outbreak is notable due to the broader environmental and structural land changes observed in Mangystau over the preceding decade. Between 2010 and 2023, land-cover data from MODIS (MCD12Q1) indicate a marked shift in the region's landscape, with an estimated 50% loss in grazing-compatible land types (discussed later). Viable rangeland loss imposes stress on livestock systems, leading to increased animal densities and heightened disease susceptibility in remaining productive zones. Whether these ecological stressors have contributed to disease emergence or intensity of the 2019 outbreak remains unverified, though this warrants further investigation.

### **Highly pathogenic avian influenza**

Highly pathogenic avian influenza (HPAI) is a disease deadly to domestic poultry with significant zoonotic potential. It is a recurrent challenge to poultry production in Kazakhstan, particularly in the northern regions of Soltustik Kazakhstan, Kostanay, and Akmola. These regions collectively account for an estimated 44% of the national poultry population (Kazakhstan Bureau of National Statistics, 2024). The frequency of HPAI cases in these northern regions is further influenced by proximity to Russia, where across the border, a notably higher incidence of HPAI was documented in recent years. The discrepancy in reported cases suggests an under-reporting of HPAI within Kazakhstan, possibly linked to limited diagnostic reach, insufficient field reporting, or variations in surveillance capacity. 2020 was particularly notable for the scale and distribution of HPAI cases in both poultry and wild bird populations. A major outbreak occurred near Koldi, Almaty, situated just outside the metropolitan boundaries of Almaty City. This outbreak was among the most severe recorded nationally, with 67,057 cases reported, 67,957 animals confirmed infected, and a total of 534,827 birds culled as part of containment efforts. In Soltustik Kazakhstan, two outbreaks were also recorded. The first, in Yakor' (near Petropavl), 581 poultry cases were reported, all resulting in death with 5,981 birds culled. The second event in Suchorabovka led to 355 deaths and the culling of 2,303 birds from a susceptible population of 17,549. One component to controlling HPAI spread is the WOAHA mandated HPAI reporting for non-poultry species (WOAHA 2017). Migrating birds passing through or nesting in Kazakhstan form wildlife reservoirs that include long-range migratory waterfowl such as ducks, geese, and swans. Investigations also identified the Corvidae family, including crows and ravens, as susceptible species and potential vectors (Alexander 2000; Shriner & Root 2020). The inclusion of non-poultry species surveillance highlights the zoonotic and environmental dimensions of HPAI epidemiology, particularly given the potential for spillover and viral reassortment events between wild and domestic animal populations (Bellido-Martín *et al.* 2025). As climate conditions influence waterbody permanence, migration routes and insect vector

ecology change, leading to unpredictable variations in HPAI affected regions (Prosser *et al.* 2023). This is particularly serious for Kazakhstan given the potential impact of HPAI on the dairy industry (Owusu & Sanad 2025) as HPAI is increasingly occurring in previously unreported animal hosts (Plaza *et al.* 2024), demonstrating its zoonotic risk. To combat the risk posed by HPAI, veterinary coordination across Kazakhstan's northern regions of Soltustik Kazakhstan, Pavlodar, and Abay in conjunction with nearby Russian regions reporting frequent outbreaks, alongside monitoring migratory species in southern Karagandy, northern Almaty, and north Zhetisu in the Balkhash-Alakol basin, may offer a means to improve early warning systems and harmonise control protocols.

### **Anthrax**

Anthrax is a persistent zoonotic threat within Kazakhstan, with sporadic outbreaks reported annually across diverse ecological zones (Kracalik *et al.* 2012; Abdrakhmanov *et al.* 2020). Caused by *Bacillus anthracis*, it predominantly affects ruminants including cattle, sheep, and goats, but also impacts equines and other species exposed to contaminated soils (Hugh-Jones & Blackburn 2009). Kazakhstan's broad rangeland ecology, coupled with the historical presence of anthrax burial sites and widespread distribution of susceptible livestock, creates a baseline risk for reemergence in multiple regions. While typically reported at low levels, 2021 marked an unusual increase in number and spread of anthrax cases, affecting three distinct regions: Soltustik Kazakhstan, Kostanay, and Turkistan. In Soltustik, northern Kazakhstan, an outbreak was reported in Gorkoe village (Akzharskiy district), where six confirmed cattle cases died. In response, 1,655 cattle and 15 horses were vaccinated to contain further transmission. The Kostanay 2021 outbreak occurred on the Altai farm (Denisovskiy district) and resulted in overall 18 cattle dead, 6 cattle culled, 629 cattle vaccinated, alongside 17 horses dead, 1 horse culled, and 87 horses vaccinated, with 408 sheep vaccinated. This loss can cripple the smaller farmers that form a large section of Kazakhstan's livestock industry. These northern outbreaks reflect the disease's endemicity and importance of preventive vaccination in regions with high livestock densities and prior case histories. A third, geographically distinct outbreak occurred in Southern Kazakhstan, within Turkistan, near Nesterovka, just south of Shymkent. This event involved 21 confirmed cattle cases with 29 deaths, and triggered a substantial response with 238 cattle, 288 horses, as well as 1,250 sheep and goats vaccinated. The incident highlights the risk of anthrax in warmer, more arid zones, particularly where water availability, grazing intensity, and soil disruption (e.g., during seasonal migration or tillage) may contribute to spore exposure. Though regional WAHIS reported data for anthrax across Central Asia remains sparse, there are confirmed outbreaks reported within a 200 km radius of Kazakhstan's borders. Sporadic cases reported in Kyrgyzstan indicate a persistent transboundary risk, potentially driven by cross-border herd movements, trade in contaminated animal products, and improper disposal of infected carcasses. These events underscore the need for extensive cooperative cross-border reporting between Kazakhstan and Kyrgyzstan to improve regional biosurveillance. Building on existing spatial analyses that identify persistent anthrax risk zones in Kazakhstan using soil, climate, and geographical features (Kracalik *et al.* 2012; Abdrakhmanov *et al.* 2020), enhanced monitoring is necessary for historically affected areas, livestock corridors, and spore-prone ecologies such as seasonal pastures and floodplains. Overlaying these risk maps with livestock density and movement data will support effective surveillance and targeted vaccination campaigns and facilitate cross-border initiatives with Kyrgyzstan.

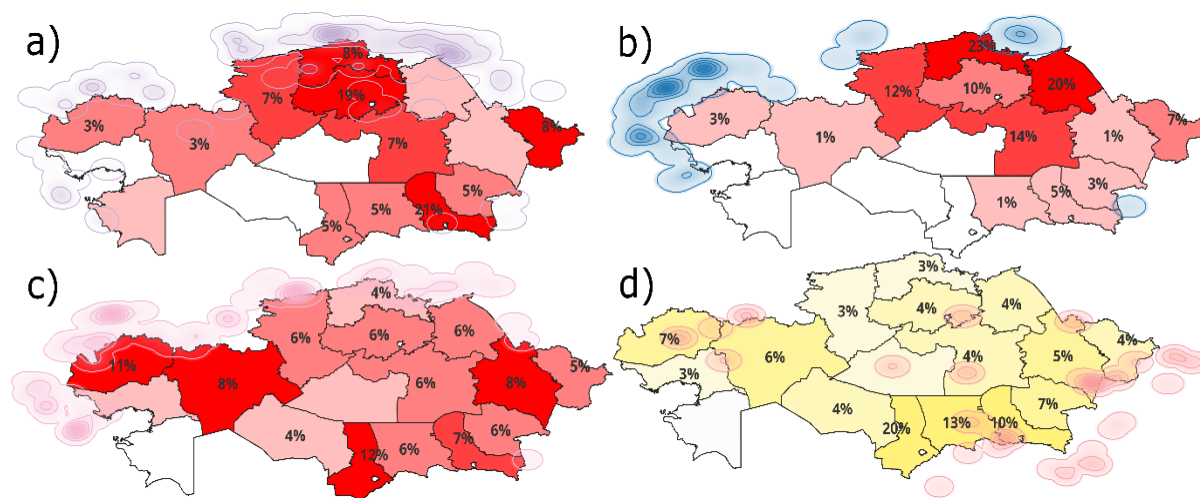
### **Infectious Bovine Rhinotracheitis and Infectious Pustular Vulvovaginitis**

Infectious bovine rhinotracheitis/infectious pustular vulvovaginitis (IBR/IPV) is a clinically and economically significant viral disease complex caused by bovine herpesvirus type 1 (BoHV-1; Muylkens *et al.* 2007; Engdawork & Aklilu 2024). Its relevance in Kazakhstan is its impact on herd fertility and productivity, particularly in the dairy sector (Bulatov *et al.* 2025). The virus, transmitted via latent carriers, spreads undetected in herds lacking robust surveillance or vaccination programs. Clinical signs range from respiratory distress to reproductive disorders, including reduced conception rates, abortions, and neonatal mortality. In regions with weak biosecurity protocols and poor immunization coverage, the disease may substantially reduce calving rates, forcing producers to import replacement stock, compounding biosecurity vulnerabilities through increased transboundary animal movements. IBR/IPV outbreaks in 2022 were concentrated in Soltustik Kazakhstan, Pavlodar, and Akmola, collectively representing around 14% of the national cattle herd. In Priezernoye village (Soltustik Kazakhstan), 11 cases were reported among cattle, with 9 deaths out of 124 susceptible animals. In Zhetekshi (Pavlodar), 10 cases were confirmed among 832 susceptible cattle, while Yerkinshilik in Akmola reported 46 cases, 3 deaths, and a total susceptible population of 10,276. These regions are critical to the national livestock sector in terms of

herd size and industrial dairy production. Soltustik Kazakhstan produces approximately 16% of Kazakhstan's industrial milk supply, while Turkistan, located in the south, contributes the highest share of household dairy production at 22% (Kazakhstan Bureau of National Statistics 2025). Given the dual impact of IBR/IPV on reproduction and lactation, these regions are particularly sensitive to outbreaks, both in terms of food security and economic returns. No concurrent outbreaks were reported in neighboring countries during this period may suggest that the 2022 events were the result of endemic virus circulation rather than cross-border incursions. This raises concerns about latent viral persistence and internal transmission pathways. In regions such as Mangystau and Kyzylorda, calving rates are significantly lower than other regions, a trend coinciding with their substantial pastoral area losses of 50% and 4% respectively, from 2010 to 2023. While direct causation is not established, reduced grazing land may increase stocking densities and stress, in turn influencing disease susceptibility and reproductive efficiency. The following year, 2023, saw further IBR/IPV activity in the central regions. In Koskolj (Ulytau), 53 cases were reported among 317 susceptible cattle, all of which were subsequently vaccinated. In Karatobe (Kyzylorda), two cases were identified among 56 susceptible animals, while another two were reported in Nagi Ilyasova village (Kyzylorda), again followed by immediate vaccination. A final cluster occurred in Terensay (Aktobe), with six confirmed cases among 52 susceptible animals. The seasonal timing of these outbreaks, typically in early spring, coincides with calving, a period of heightened vulnerability. Recommended control measures include targeted vaccination campaigns during April-May, improved calving supervision, and increased diagnostic testing in dairy-producing regions and with elevated cross-border trade. These outbreaks highlight the economic burden of IBR/IPV on reproductive performance and milk production, as well as the need for more consistent data collection on fertility parameters and vaccination efficacy. Given the disease's silent transmission dynamics and lack of comprehensive reporting from neighboring Central Asian states, there is a strong case for Kazakhstan to lead in establishing regional reproductive health surveillance networks and coordinated calving-season immunization strategies.

### Potential WAHIS blind spots

As Kazakhstan strengthens its biosurveillance infrastructure, the integration of regional outbreak data remains critical for identifying transboundary threats and informing targeted prevention strategies. As previously stated, the WAHIS data relies upon self-reporting, with the associated drawbacks for countries with limited economic and biosurveillance capabilities. To address this, reports from adjacent areas in neighboring countries may indicate potential risks. To explore this, events for selected diseases reported within a 200 km buffer zone surrounding Kazakhstan were evaluated as indicators of epizootic risks/under-reporting (see Supplementary Table S4). Fig. 1 presents spatial overlays of four major transboundary diseases, highly pathogenic avian influenza (HPAI, Fig. 1a), African swine fever (ASF, Fig. 1b), lumpy skin disease (LSD, Fig. 1c), and foot-and-mouth disease (FMD, Fig. 1d), as recorded in the WAHIS database. These are shown in conjunction with the proportional distribution of susceptible livestock populations within Kazakhstan as of 2024, highlighting risk exposure and surveillance prioritization.



**Fig. 1.** a) HPAI events from the WAHIS database in Kazakhstan and within 200 km with the proportional distribution of 2024 poultry within Kazakhstan, b) ASF events with the regional distribution of pigs in Kazakhstan c) LSD events reported and 2024 cattle distribution, d) FMD events alongside the proportion of total susceptible animals (cattle, sheep, pigs, goats).

Illustrated in Fig. 1a are reported HPAI outbreaks alongside the regional distribution of Kazakhstan's poultry industry. HPAI outbreaks were recorded in North Kazakhstan, Akmola, and Pavlodar, regions containing the country's largest poultry populations (10-20% of national totals). However, a large concentration of HPAI outbreaks were reported across Kazakhstan's northern border in western Russia, indicating persistent transboundary pressure. While few cases were reported in the southern or western regions, the substantial poultry production from Soltüstik Kazakhstan through Akmola, Karaganda, and Almaty form a north-south corridor. This corridor of industrial production coupled with the migratory avian species of Lake Balkhash poses a potential disease progression pathway. Given the economic threat HPAI poses to both poultry and dairy sectors, and its zoonotic potential, enhanced surveillance along this corridor is warranted to mitigate risk to animal and public health. ASF outbreaks within a 200 km region of Kazakhstan are noted in Fig. 1b with Kazakhstan's swine population distribution. While no outbreaks were reported within Kazakhstan, clusters were reported by Russia in the Volgograd and Saratov regions to the west of Kazakhstan and Omsk region to the north. Due to cultural aspects, the greater demand for pork products in Northern Kazakhstan supports a larger swine industry there, whereas in the southern regions of Kazakhstan there is a higher demand for goat and sheep products. While the largest reported clusters of ASF are near the western region of Kazakhstan which has a low portion of the industry and is likely self-limiting, there are smaller clusters adjacent to Kostanay, North Kazakhstan, and Pavlodar. These northern regions are also home to the greatest portion of the swine livestock industry with potential transboundary disease transmission and under-reporting risking a large portion of Kazakhstan's industry. Greater cooperation between Russia and Kazakhstan within these regions coupled with greater internal biosurveillance is necessary for the protection of Kazakhstan's swine industry. The distribution of LSD cases reported adjacent to Kazakhstan and the cattle density within Kazakhstan as of 2024 is shown in Fig. 1b. LSD, a vector-borne disease transmitted by biting insects, can severely impact dairy production (Tuppurainen *et al.* 2018). There are frequent reports of LSD outside Kazakhstan, adjacent the west and northern regions of Kazakhstan, with a concentration around the Volga River basin and Caspian region, reflecting the environmental conditions of an insect-borne disease. Despite this, LSD outbreak reports for events occurring within Kazakhstan are sparse. The proximity of high-risk regions in Russia's Astrakhan region raises concerns that Kazakhstan's low reported incidence may reflect under-reporting rather than true absence. Regions such as Soltüstik Kazakhstan, Akmola, and Pavlodar, along with the border-adjacent regions of Kostanay, Aktobe, and Batys, may represent under-surveilled zones, vulnerable to vector incursions and silent transmission cycles. As climate change may influence insect vector distributions, there may be increased risk to regions such as Batys Kazakhstan and Aktobe, together accounting for nearly 20% of the national cattle population. To protect the cattle industry, these regions should be prioritized for entomological surveillance and early response planning. Subsequently, Fig. 1d overlays FMD events with the combined distribution of major susceptible species (cattle, sheep, goats, pigs). External outbreaks were concentrated to the south and southeast Kazakhstan, corresponding with endemic zones in Kyrgyzstan, Afghanistan, Pakistan, and parts of Western China. Internal event reports were limited to the southern regions, regions also with the highest proportions of susceptible livestock. While the northern region of Kazakhstan does not require FMD vaccination, this is not the case for the southern areas. Particularly rigorous and continued efforts are necessary, including shared biosurveillance and control strategies with China, Kyrgyzstan, and Uzbekistan to eliminate the critical threat FMD has for each of these countries livestock industries. Overall, these spatial overlays reveal important patterns of alignment and mismatch between livestock densities and disease emergence. One apparent omission is the occurrence of equine influenza, with no reported outbreaks in Kazakhstan according to WAHIS. A surprising outcome given the national herd was approximately 3.8 million head. This highlights the necessity for biosurveillance and control strategies that account for the transboundary nature of diseases, and the significant impact they can have on economies relying on agrarian industries.

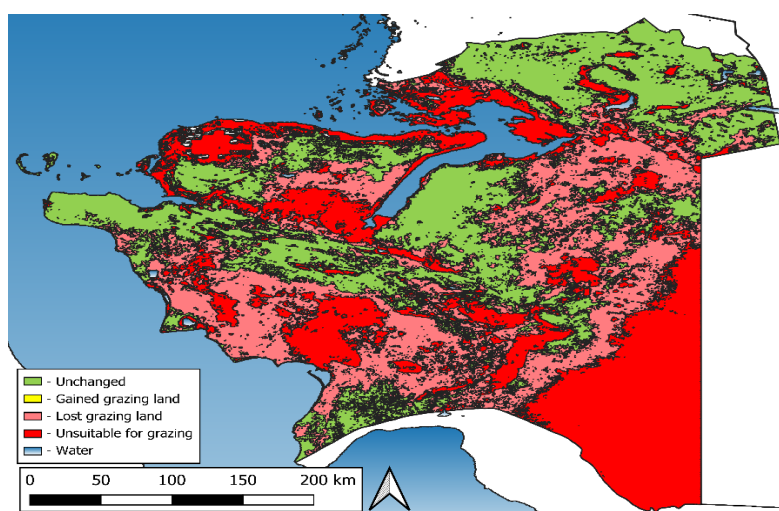
### **MODIS data and climate change**

While the WAHIS database is invaluable in assisting biosecurity and veterinary policy, a one health approach ties in the wholistic impact of environment, economy, as well as disease pathogens to provide a complete picture. A valuable addition to this is the NASA MODIS land-cover evaluation data. Insights into patterns of climate change and land-cover trends can guide policies not directly aimed at veterinary outcomes, yet improve livestock conditions, and thus economic security. To achieve this, land-cover changes between 2010 and 2023 were evaluated, assigning land types 30 (Natural herbaceous), 35 (Natural herbaceous/Cropland mosaics), and 40 (Shrublands) as productive grazing land. Other land types were considered non-productive in the context of

livestock uses. Coupling this MODIS land-cover data with livestock and productivity data from the Kazakhstan Bureau of Statistics highlights correlations that support evidence-based strategy development and improved health and economic outcomes for the region.

### Land change in Kazakhstan

Anthropogenic climate change is an undeniable challenge for agricultural industries. Increasing weather extremes, changing weather patterns, temperature, humidity, soil moisture, animal migration, and disease vector distribution, contribute to emergence and re-emergence of transboundary livestock diseases (Tulemissova *et al.* 2021; Baker *et al.* 2022; Kenesovna Zhanerke Ussenova *et al.* 2025), including respiratory and intestinal infections in young animals and reproductive pathologies in productive livestock caused by bacterial and viral agents such as salmonellosis, leptospirosis, chlamydia, and listeriosis. These threats necessitate enhanced surveillance, predictive immunoprophylactic modeling, and adaptive immunization strategies to ensure resilience in the face of changing epizootic pressures. Of all Kazakhstan's regions, Mangystau has undergone the greatest degree of change from 2010 to 2023 (Fig. 2.).



**Fig. 2.** Changes in Mangystau grazing land from 2010 to 2023. For full map of Kazakhstan land changes see Supplementary Fig. S1.

Mangystau's primary industry involves oil and gas reserves and, perhaps reflecting its limited agricultural importance, has undergone the greatest change in available grazing land area. Between 2010 and 2023, Mangystau lost almost 50% of its viable grazing land (Tables 2 and 3). According to the NASA MODIS MCD12Q1-061 data, in 2010, Mangystau had 101,962 km<sup>2</sup> of natural herbaceous land (LCCS2 type 30), optimal for natural pasture. By 2023 this original area was reduced by more than half with 50,702 km<sup>2</sup> of the previous natural herbaceous land becoming barren (LCCS2 type 1), and 2,885 km<sup>2</sup> converting to shrubland (LCCS2 type 40). Although the extensive grazing land losses observed in Mangystau may have limited national significance due to the region's low contribution to Kazakhstan's livestock sector, the same cannot be said for regions with more substantial ruminant populations. Reduced grazing land availability and quality disproportionately affect smallholders and household producers, who are directly dependent on natural pasture fertility and productivity (Morton 2007). Whereas large-scale agricultural enterprises have means to mitigate reduced forage availability with supplemental feed and concentrated rations. This structural vulnerability underscores the broader socioeconomic risks associated with climate-induced declines in grazing suitability.

### Impacts of climate and cattle productivity

Climate change susceptibility can be observed in differences in productivity outcomes between large enterprise farms and smaller landholders, including household producers. Land-cover change from 2010 to 2023, derived from MODIS data, is compared with livestock productivity indicators reported in 2024 to assess the vulnerability of livestock operations to changing land conditions. Although the current MODIS data set is only up until 2023, and productivity indicators are available only for 2024, this temporal difference is considered minor, as land cover reflects longer-term trends while the most recent productivity indicators are likely to provide the most reliable values. Among the available indicators, milk yield and calving rates are selected as they reflect herd nutrition and disease status (Table 3.). Data from Kazakhstan's Bureau of Statistics provide regional breakdowns of these

metrics, with some information further disaggregated by industry. When combined with MODIS land-cover changes, this data set allows for the identification of several notable patterns.

**Table 2.** Mangystau Land Changes (km<sup>2</sup>, 2010 to 2023).

2010 Classifications (km <sup>2</sup> )		2023 Classifications						
		30	40	1	20	2	9	3
30	(101,962)	48,365	2,885	50,702	3	7	-	-
40	(504)	0	451	53	-	-	-	-
1	(50,833)	167	1	50,586	-	75	2	2
20	(11)	11	-	-	-	-	-	-
2	(316)	1	-	234	-	80	-	1
9	(64)	-	-	-	-	-	64	-
3	(8,591)	2	-	4	0	0	0	8,585
2023 Total:		48,546	3,337	101,579	3	162	66	8,588

Grazing land classifications: (30) Nat. Herbaceous, (40) Shrublands.

Non-grazing land classifications: (1) Barren, (20) Open Forests, (2) Perm. Snow/Ice, (9) Urban/Built-up, (3) Water.

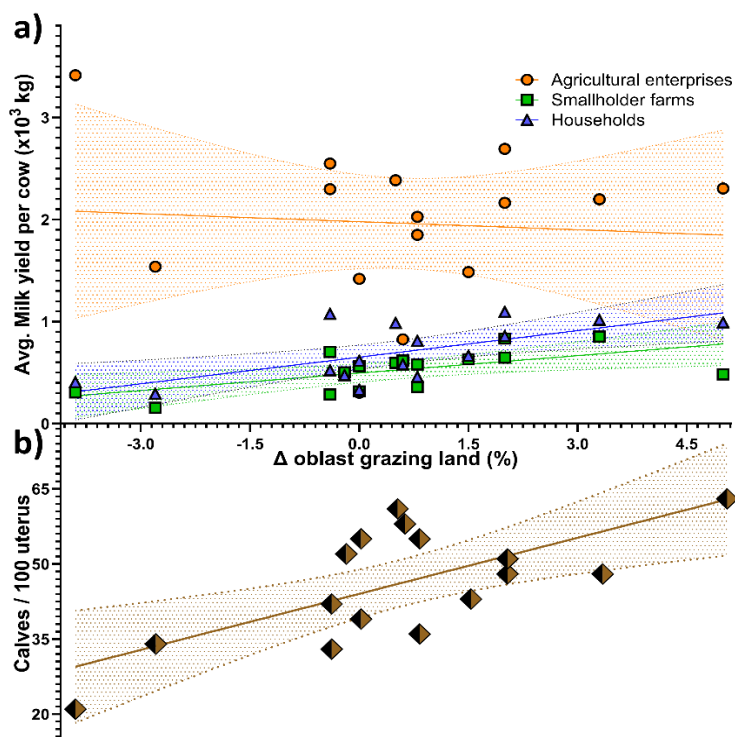
**Table 3.** Grazing area changes from 2010 to 2023 compared with 2024 productivity.

Region	Δ Obl. (%)	Δ Nat. (%)	Av. Milk yield (kg/year/cow)			calves (/100 uterus)
			AE	SHF	HH	
Mangystau	-49.6%	-2.19%	-	-	-	-
Kyzylorda	-3.9%	-0.25%	3414	306	407	21
Atyrau	-2.8%	-0.13%	1538	156	293	34
Aktobe	-0.4%	-0.04%	2549	286	523	33
Kostanay	-0.4%	-0.03%	2297	703	1075	42
Ulytau	-0.2%	-0.02%	-	502	474	52
Abay	0.0%	0.00%	1419	562	617	55
Batys Kazakhstan	0.0%	0.00%	303	316	333	39
Pavlodar	0.5%	0.02%	2385	596	986	61
Shygys Kazakhstan	0.8%	0.03%	2026	359	459	55
Turkistan	0.8%	0.04%	1850	581	811	36
Karagandy	0.6%	0.06%	826	619	581	58
Zhetisu	2.0%	0.08%	2163	647	857	48
Zhambyl	1.5%	0.09%	1485	632	665	43
Akmola	2.0%	0.09%	2692	833	1096	51
Almaty	3.3%	0.13%	2198	852	1017	48
Soltustik Kazakhstan	5.0%	0.13%	2304	483	992	63

AE = Agricultural enterprises, SHF = Smallholder farms, HH = Household farms.

Grazing land availability was assessed using MODIS MCD12Q1-061 with the FAO LCCS2 classification using the land-cover classes 30 (Natural Herbaceous), 35 (Herbaceous/Cropland Mosaics), and 40 (Shrublands), as a proxy for grazing suitability. While this classification provides a coarse-grained, land-cover-based estimate of potential pasture, it does not directly quantify forage biomass or grazing capacity and does not reflect short-term seasonal variability, within-class heterogeneity, or degradation within nominally suitable classes. Nevertheless, this proxy indicates regional disparities: the north and southeast of Kazakhstan have seen increases in these grazing land classes (Soltustik Kazakhstan: +5.0%, Almaty region: +3.3%, Akmola: +2.0%), but these gains were offset by losses in the west (Mangystau: -49.6%, Kyzylorda: -3.9%, Atyrau: -2.8%). Overall, this translates to an estimated 2% net reduction in grazing-suitable land between 2010 and 2023. While seemingly modest, this figure assumes equal productivity across land classes, which is not the case. Class 30 (Natural Herbaceous) is significantly more productive and accessible for grazers than Class 40 (Shrublands), suggesting that land-cover

transitions may obscure a more substantial decline in effective grazing capacity. Comparing the productivity indicators disaggregated by industry against land changes yielded the following.



**Fig. 3.** Correlating changes in grazing land area with the agricultural productivity indices of a) milk production for agricultural enterprises (orange circle), smallholders (green square), and household farms (blue triangle) and b) calving rate (brown diamond). Shaded section indicates 95% confidence intervals with fitted linear relationships.

Normality was satisfied ( $\alpha = 0.05$ , Supplementary Table S5) for all variables except for household milk yield, which yielded a borderline response. For household milk yield, the positive association with grazing land change was confirmed by Spearman's rank correlation ( $\rho = 0.63$ ,  $p = 0.010$ ), consistent with the Pearson correlation. Fig. 3 shows the relationship between grazing land changes and milk yield. Pearson correlation and linear regression analyses (Supplementary Table S6) yielded strong positive correlations between changes in region-level grazing land area (2010-2023) and 2024 average milk yield per cow for smallholder farms ( $r = 0.60$ ,  $p = 0.013$ ,  $R^2 = 0.36$ ) and household farms ( $r = 0.66$ ,  $p = 0.005$ ,  $R^2 = 0.44$ ). In contrast, large-scale agricultural enterprises (LCs) exhibited no significant association ( $r = -0.07$ ,  $p = 0.793$ ,  $R^2 = 0.005$ ). Intensive agricultural enterprise systems typically physiologically decouple high-yielding dairy cows from reproductive function due to genetic specialization, targeted feeding regimes, and centralized management practices (Windig *et al.* 2006). This buffering likely reduces their sensitivity to grazing land variability, consistent with the weak observed relationship. Conversely, cows in smallholder and household farms are more reliant on natural forage availability and pasture conditions, demonstrating a significant risk for Kazakhstan's industry and food security. Calving rate showed the strongest correlation with grazing land change ( $r = 0.69$ ,  $p = 0.003$ ,  $R^2 = 0.47$ ), likely reflecting the link between herd fertility and nutritional quality in pasture-based systems (Roche *et al.* 2009). Collectively, these results suggest that grazing-dependent production systems are more vulnerable to land degradation, with measurable impacts on productivity, reproductive outcomes, and potentially broader aspects of herd health. This is particularly important for Kazakhstan given that, in 2024, almost 90% of cattle belonged to smallholder and household farms (Kazakhstan Bureau of National statistics, 2025). To limit the significant risk that climate change may have on the vulnerable section of Kazakhstan's livestock industry, closer analysis of changes in the waterways, irrigation, bodies of water, water use, and allocation should be made to ensure the future of Kazakhstan's internal food security, and general stability within Central Asia.

## DISCUSSION

The combination of the WAHIS data, MODIS land-cover changes, and data from the Kazakhstan Bureau of Statistics give a clear indication of the challenges faces by Kazakhstan, that are likely mirrored across the Central

Asian region. These are primarily in diseases impacting herd replenishment and productivity, and small landholder vulnerability to climate variations. Between 2010 and 2023, Kazakhstan experienced an estimated 2% reduction in effective grazing land, with disproportionately severe losses observed in regions such as Mangystau (~50%) and Kyzylorda (~4%). These estimates are based on MODIS LCCS2 land-cover classifications, which offer spatial resolution only down to 500 meters and do not account for intra-category variability in vegetation quality or productivity. As a result, the true extent of functional grazing land loss, and its impact on forage availability, may be substantially underestimated. Declines in pasture productivity impact herd replenishment rates affecting smallholders and household-based producers who rely heavily on extensive grazing systems. Given that a significant proportion of Kazakhstan's livestock sector operates under smallholder management, continued shifts in precipitation patterns, water resource availability, and feedstock conditions are likely to impose increasing pressure on national livestock productivity. Accurate assessment of pasture productivity trends and surface water dynamics is therefore essential. Furthermore, these ecological shifts may influence the geographic distribution and seasonality of livestock diseases, especially vector-borne and emerging arboviral infections. In the northern and western regions of Kazakhstan, there appear fewer reported cases of HPAI, LSD, and ASF than expected based on epidemiological trends in adjacent Russian and Chinese territories. Notably, given the concentration of HPAI outbreaks immediately north of Pavlodar and Soltüstik Kazakhstan, proactive biosurveillance in these regions is critical to protect Akmola, which accounts for nearly 20% of the country's poultry production. Changing climate conditions may also impact the movement of migratory bird species, potentially enabling vectors into naïve livestock or other wildlife reservoirs. Enhanced monitoring for ASF is also essential, particularly due to the economic significance of the swine industry in Kostanay, Pavlodar, and Soltüstik Kazakhstan. LSD is also likely under-reported in the western border areas, despite confirmed cases in neighbouring regions that coincide with areas housing approximately 20% of Kazakhstan's national cattle herd. FMD outbreaks are also reported in the southwest, parts of Kyrgyzstan, and China. While the Tien Shan Mountains offer some geographical protection, the corridor between Almaty and Shymkent, adjacent to the Kyrgyz border, contains roughly 43% of all FMD-susceptible livestock in Kazakhstan. Given the porous nature of this border, strengthened bilateral cooperation between Kazakh and Kyrgyz veterinary authorities, focused on joint biosurveillance and coordinated outbreak response, would significantly enhance the region's resilience to economically disruptive FMD incursions. While the WAHIS, MODIS, and national statistics are critical for evaluating and enhancing national and regional biosecurity frameworks, it is increasingly evident that additional disease surveillance data is required. For a country with a developing biosurveillance infrastructure and limited exports like Kazakhstan, improved herd replenishment rates and biosurveillance capabilities an economic development priority. Diseases impacting herd replenishment include pathogens such as *Brucella* spp., BVDV, IBR/BoHV-1, *Leptospira pomona*, *Leptospira hebdomadis*, and *Listeria monocytogenes*. Characterizing the burden of subclinical infections, reproductive inefficiencies, and herd-level immunosuppression for these diseases is essential to improve national food security. Alongside these diseases, pathogens such as *Pasteurella multocida*, *Clostridium perfringens* Type D, and *Salmonella abortus-ovis*, not currently included in WOA's list of notifiable diseases, are known to contribute to elevated mortality in young stock, abortion storms, and impaired productivity, particularly within small ruminant (Niyazbekova *et al.* 2025) and mixed-dairy production systems. Their undetected circulation may be a contributing factor to the low calving rates observed in Kyzylorda, Atyrau, and Aktobe. Developing means to include these into official reporting frameworks will improve regional capacity to anticipate and mitigate risks to herd replenishment, milk yield, and zoonotic transmission. Expanding biosurveillance priorities to include such production-limiting and zoonotically relevant diseases is thus vital for a comprehensive and preventive approach to livestock health management and epizootic preparedness.

## CONCLUSION

Integration of the WAHIS and MODIS datasets provides a valuable framework for assessing Kazakhstan's livestock health and environmental resilience within a One Health context. Analysis of the WAHIS dataset indicates that strengthening biosurveillance along the Almaty-Shymkent corridor and across the Kyrgyz border would substantially enhance national and regional biosecurity given the prevalence of transhumant and cross-border pastoralism. Complementary MODIS-derived data, coupled with Kazakhstan's national statistics, reveal that reduced grazing-land productivity disproportionately affects smallholder and household farms, which produce the majority of Kazakhstan's agricultural output. Improving herd replenishment and productivity requires strengthened detection and management of pathogens such as *Brucella* spp., BVDV, IBR/BoHV-1, *Leptospira*

*pomona*, *Leptospira hebdomadis*, and *Listeria monocytogenes*. Prioritizing surveillance and control of these diseases directly supports food security and rural livelihoods. Kazakhstan's extensive grazing base and veterinary capacity enable it to lead vital coordinated regional initiatives in biosurveillance, diagnostics, and outbreak response across Central Asia.

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#### Data availability statement

Data that support the findings of this study are available from the corresponding author upon reasonable request.

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