frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 30 November 2022
DOI 10.3389/fenvs.2022.1049187

OPEN ACCESS

EDITED BY
Ying Jing,
Zhejiang University, China

REVIEWED BY
Wende Li,
Lanzhou Jiaotong University, China
Quanjing Wang,
Zhengzhou University, China

*CORRESPONDENCE
Yanwen Wang,
wensomone@163.com
Shuwang Yang,
yswang998@163.com

SPECIALTY SECTION
This article was submitted to Land Use Dynamics,
a section of the journal
Frontiers in Environmental Science

RECEIVED 20 September 2022
ACCEPTED 24 October 2022
PUBLISHED 30 November 2022

CITATION
Yang J, Wang Y, Zhang H, Su Y, Wu X, Yan S and Yang S (2022), Impact of socio-economic and environmental factors on livestock production in Kyrgyzstan.
Front. Environ. Sci. 10:1049187.
doi: 10.3389/fenvs.2022.1049187

Impact of socio-economic and environmental factors on livestock production in Kyrgyzstan

Jiamiao Yang[1,2], Yanwen Wang[1,2]*, Hao Zhang[1,2], Yuming Su[3], Xiaoyang Wu[1], Shuqi Yan[4] and Shuwang Yang[1,2]*

[1]School of Economics and Management, China University of Geosciences, Wuhan, China, [2]Research Center of Resource and Environmental Economics, China University of Geosciences, Wuhan, China, [3]School of Resource and Environmental Sciences, Wuhan University, Wuhan, China, [4]School of Interpreting and Translation Studies, Guangdong University of Foreign Studies, Guangzhou, China

Livestock husbandry is a key indicator of economic development, environmental protection, and food security in the world, which is vulnerable to environmental changes and economic shocks. In our study on Kyrgyzstan, we quantified the effects of socio-economic and environmental factors on the dynamics of livestock sales, self-consumption, and inventory from 2006 to 2020 using a two-period livestock production model and spatial panel model. The results showed that from 2006 to 2020, more than 50% livestock were stocked annually, which means that herders in Kyrgyzstan preferred to preserve their animals as assets to deal with unknown risks. Additionally, to gain greater profit, Kyrgyz herdsmen would expand or downsize their livestock business, tailor self-consumption, and manage inventory based on the livestock market price, loan on livestock, non-herding income, and its current stock. Our study found that the development of animal husbandry in seven oblasts of Kyrgyzstan had spatial spillover effects, which indicated that the dynamics of the animal husbandry market and environment not only affected the scale of local animal husbandry but also had an important impact on adjacent oblasts. Our research contributes to ensuring the income for herdsmen and the sustainable development of animal husbandry, thereby promoting high-quality economic development in developing countries with animal husbandry as a pillar industry.

KEYWORDS

livestock husbandry, Kyrgyzstan, herders, grasslands, spatial spillover effects

1 Introduction

Livestock is an important component of global agriculture and economy, and it plays a vital role in improving food security, promoting adjustment of the agricultural structure, and realizing comprehensive utilization of resources (Han et al., 2020; Wei and Zhen, 2020). With continuous population growth and increased demand for living, the global production of meat was predicted to increase from 229 million tons in 1999 to 465 million tons in 2050, which was a huge challenge for livestock production (FAO, 2006; Gerber and Steinfeld, 2008). To improve the livelihoods of people and promote sustainable social, economic, and environmental development in the world, the United Nations formally adopted the Sustainable Development Goals (SDGs) in 2015 (WHO, 2015; Arora and Mishra, 2019; Rosati and Faria, 2019). This proposal encouraged member countries to jointly explore the sustainable and efficient animal husbandry production system to provide nutritional food for residents, which could contribute to SDG1 (no poverty), SDG2 (zero hunger), SDG3 (good health and well-being), SDG12 (responsible consumption and production), and SDG17 (partnerships for the goals) (Breeman et al., 2015; Varijakshapanicker et al., 2019; Mehrabi et al., 2020). To reach the growing demand for livestock in the coming decades, a sustainable balance between domestic products and imports must be maintained. This provided an opportunity for countries to export livestock products, livestock equipment, and breeding technology to expand the scale of livestock in countries with appropriate land resources (Gerosa and Skoet, 2012; Lan et al., 2021). Although the temporal and spatial details of grazing practices were quite different among countries, the combination of mobile animal husbandry and low-investment crop cultivation was still the main mode of production in developing countries with animal husbandry as the economic pillar (Koocheki and Gliessman, 2005). Developing with the experiences of environmental changes and natural disasters, nomadic animal husbandry was a long-term cultural choice for herdsman families (Zhang et al., 2007). For nomadic society, livestock was the foundation for herders' living, which provided food, housing construction materials, and transportation, as well other goods and services by exchange (Kerven et al., 2011; Sagynbekova, 2017; Xu et al., 2019; Haghiyan et al., 2022). However, under modern pressures, such as population growth, in-country migration, rapid urbanization, increasing demand for livestock products, land use change, and climate change, it seemed to pose a severe challenge for the sustainability of husbandry production (Tessema et al., 2014; Abay and Jensen, 2020; Raji et al., 2022; Wafula et al., 2022).

As arable land was scarce and grasslands covered about 56% of the total land in an arid climate, pastoralism became the main economic pillar in Kyrgyzstan, which made a significant contribution to the nation's economy with livestock production accounting for over 19.33% of the national GDP (NSCKR, 2020). Being well-known for the ridges and isolated valleys of the Tian Shan Mountains, Kyrgyzstan has a tradition of high spatial mobility, and nomadic civilization has become a part of the cultural symbol of Kyrgyzstan (Ludi, 2003). Local nomadic herders usually graze in mountain pastures in summer, but low temperatures in winter and unpredictable climate disasters force them to graze in lower altitudes (Borchardt et al., 2011). During Soviet times, formerly autonomous grazing was replaced by state-owned farms (sovkhozes) and collective farms (kolkhozes); thus, herders were forced to form collectives and settle, and the quantity of livestock increased drastically (Hoppe et al., 2018). The collapse of the Soviet Union led to the dissolution of the livestock markets and production-supporting services and resulted in a reduction in livestock quantity by nearly 60% in Kyrgyzstan (Iñiguez, 2004; Agadjanian and Gorina, 2019). Due to state-owned farms dismantling, many collectives broke up into individual households for lacking investment capital and comprehensive agricultural knowledge, which further led to a decrease in livestock productivity (Hauck et al., 2016). Additionally, with increasing unemployment, rural households had to focus on private subsistence agriculture. To meet the market demands for meat, dairy production, and livestock services, the livestock numbers began to increase again in 2000 (de la Martiniere, 2012), and animal husbandry was still an important source of income at the household level in Kyrgyzstan.

Due to relatively weak adaptability, high production environment risk, and low elasticity, livestock is one of the most vulnerable industries to climate and society fluctuations (Megersa et al., 2014). To avoid potential shocks on the sustainable development of husbandry, recent studies have been attempting to explore the patterns of livestock dynamics through theoretical models and field surveys. Tessema et al. (2014) reviewed and quantified global studies on the sustainable development of animal husbandry over the past decades and confirmed the sustainability of animal husbandry systems, which relied on herders' adaptability to unpredictable environments, grazing mobility, and institutional support. Grounded on a household survey of herders in southern Ethiopia, a study showed that adjusting the composition of herds was a vital adaptive strategy to cope with climate change and poor pasture conditions (Megersa et al., 2014). In volatile environments, interactions among biophysical, economic, and institutional factors promoted livestock migration for better feed resources. According to satellite imagery and interviews with herders of Kazakhstan, Robinson et al. (2016) indicated that the effects of economic and institutional factors on livestock migration and distribution were increasing. Combining the equilibrium replacement model of livestock products with the inventory relation, Ge and Kinnucan (2018) found that good weather conditions would reduce the number of goats but raise the number of cattle and sheep. In the market, higher prices had negative impact on the cattle inventory, while higher feed costs had positive impact on the stock of cattle and sheep in the Inner Mongolia Autonomous Region of China. Based on spatial autocorrelation analysis, standard deviation ellipse, and the spatial Durbin model (SDM), Han et al. (2020) found that there were significant positive spatial autocorrelation characteristics in China's husbandry industry. The result revealed that high-productivity land for grazing, people's income and living standard, and mechanization level could promote the development of animal husbandry in China.

Since the influencing factors of livestock dynamics and their interaction are complex, many researches have begun to assess and quantify internal mechanisms and impacts. Climate change, especially heat stress, could directly affect the metabolism and nutrient absorption of livestock, indirectly affect food intake, immune system, and feed supply, and ultimately affect livestock production (Baumgard et al., 2012). Wolfenson and Roth (2019) found that hot summer conditions could hinder the reproduction of cows, leading to a significant decline in worldwide pregnancy rates. In addition to climate factors, some scholars found that socio-economic factors also had the impact on the livestock scale. Based on the socio-economic and livestock quantity data over the past 40 years in Xilinguole of China, Jiang et al. (2019) revealed that the land use policy was negatively correlated with the change in livestock numbers, and the larger population of herders had significant and positive effects on the quantity of sheep and goats. Liang et al. (2021) found that population distribution would directly affect the quantity and structure of livestock consumption, and the total livestock consumption in Kazakhstan increased gradually from north to south. Xu et al. (2019) pointed out that Mongolian herdsmen would adjust their herd size according to market factors such as current and expected prices, alternative food prices, and debts. Although previous studies had focused on livestock dynamic analysis in general, few research studies had quantified the impact by integrated factors on the livestock scale, especially in the Central Asia arid region.

The main aims of this paper are to 1) assess the dynamic patterns of the livestock scale in Kyrgyzstan from 2006 to 2020; 2) quantify the impact of socio-economic and environmental factors on the scale of livestock; and 3) explore sustainable strategies for the high-quality development of animal husbandry and income security for herdsmen. To achieve the research objectives, we referred to the two-period livestock production model to determine the potential factors affecting the livestock scale. Then, we used the spatial panel model to quantify the spatial effects of different factors on the scale of livestock. Finally, we discussed the potential impact on livestock by different influencing factors. This study not only quantified the influencing mechanism of the animal husbandry scale in Kyrgyzstan but also explored effective paths for the sustainable development of local animal husbandry and income security for herdsmen. Our results could provide an important practical experience for high-quality economic development of countries in arid regions with animal husbandry as the economic pillar.

2 Materials and methods

2.1 Study area

Kyrgyzstan, a landlocked mountainous country of Central Asia located in the Tian Shan Mountains and Pamir-Alay mountain range, is bordered by Kazakhstan to the north, China to the east, and bounded by Uzbekistan and Tajikistan to the south and west (Figure 1A). The land area of Kyrgyzstan is about 199,951 km^2, including seven oblasts (provinces) and two municipalities. With 94% of the territory lying above 1,000 m, grasslands are the main land cover type (Figure 1B). Taking up 56% of the land, grasslands are one of the most vital natural resources of Kyrgyzstan (Wang et al., 2020). Due to uneven seasonal precipitation, the average annual precipitation in Kyrgyzstan is only 200–800 mm, making it a typically arid country (Liang et al., 2021). July and August are the hottest months of the year. In winter, the temperatures are the lowest in mountain valleys and depressions due to the terrain (Beer et al., 2008).

Kyrgyzstan is a low-income country with 6.59 million people. The per capita gross national income is about 1,170 USD, and more than 63% of residents live in rural areas (World Bank, 2020). Linking Eurasia and the Middle East, Kyrgyzstan is located in a key position for international trade with economies like Russia, the United Kingdom, and China. During the Soviet Union period, the main agricultural economic activities of Kyrgyzstan were controlled by state farms, which were the important livestock and agricultural suppliers of the Soviet Union. After Kyrgyzstan gained its independence in 1991, the planned economy transformed into a market economy, the state farms were demolished, and land and livestock were privatized (Dabrowski et al., 1995).

2.2 Data resources

In this study, environmental and socio-economic data in each oblast level from 2006 to 2020 were collected. Socio-economic data including GDP, population, income, livestock number (cattle, cows, sheep, goats, and horses) were obtained from the National Statistical Committee of the Kyrgyz Republic (NSCKR, http://www.stat.kg/en/). The agricultural loan data for herds were obtained from the Food and Agriculture Organization of the United Nations (FAOSTAT, https://www.fao.org/faostat/en/#home). Compared with other indexes displaying the static cover conditions of grasslands, net primary productivity (NPP) can dynamically reflect the condition of grassland production for livestock feeding in a certain period. To calculate the grassland NPP value of Kyrgyzstan from 2006 to 2020, the 1-km spatial resolution global MODIS NPP product MOD17A3 was acquired from the NASA MODIS Land Science Team website (https://modis.gsfc.nasa.gov/). The temperature and precipitation data were obtained from the NASA MODIS Land Science Team website (https://modis.gsfc.nasa.gov/), and the land cover data were obtained from the MODIS Terra–Aqua Combined Land Cover product MCD12Q1 (https://modisland.gsfc.nasa.gov/landcover.html).

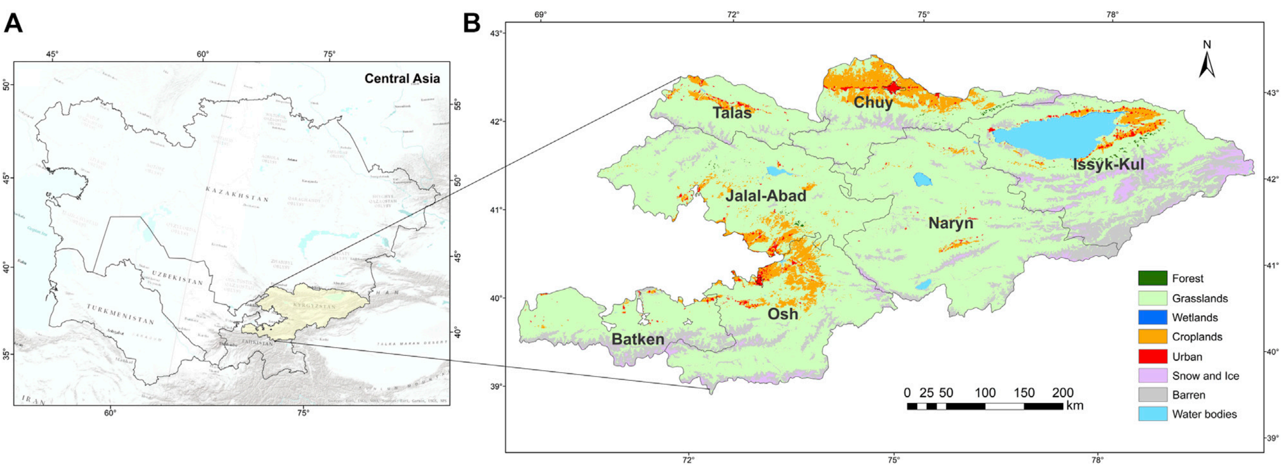

FIGURE 1
Location of the study area **(A)** and the distribution of the different land cover types in Kyrgyzstan **(B)**. The terrain map of this study region was from ESRI, USGS, and NOAA. Land cover data were obtained from the MODIS Terra–Aqua Combined Land Cover product MCD12Q1 (https://modisland.gsfc.nasa.gov/landcover.html).

2.3 Methods

To explore the dynamics of livestock production and driving factors in Kyrgyzstan from 2006 to 2020 under the changing socio-economic and environmental conditions, we first standardized and analyzed the environmental and socio-economic data and investigated the migration trajectory of the spatial gravity center of animal husbandry. Second, we used the two-period livestock production model to describe the livestock production cycle in Kyrgyzstan and introduced herders' preferences as part of the mechanism of livestock production to indicate the characteristics of livestock production dynamics. Finally, based on the calculation of global Moran's index and a series of tests for spatial model selection, we applied the spatial econometric model and panel data to quantify the driving factors of livestock production dynamics in Kyrgyzstan (Supplementary Figure S1).

2.3.1 Statistical processing

In this study, we selected an oblast scale to detect dynamic livestock sales, self-consumption, and inventory based on the environment and socio-economic data. In order to directly compare the data of past decades, all the monetary data in the socio-economic category were converted to the 2006 constant dollar using the consumer price index (CPI), which could eliminate the impact of inflation:

$$Real\ price = nominal\ price/CPI\,. \tag{1}$$

As different animals would have different sale prices and costs, large animals like horses and cattle were standardized to a national sheep unit in a way that one large animal equaled four sheep (Wang et al., 2020). In addition, we used logarithms to standardize the data with different dimensions.

In order to obtain the annual data of precipitation and temperature, we interpolated the original monthly data, then generated the grating image, and used the linear regression analysis based on the least square method. All the environmental data were processed using ArcGIS V10.3. We further carried out descriptive statistics based on the environment and socio-economic data using STATA 16, and the brief statistical description of each variable is given in Supplementary Table S1, which would be employed in the livestock production model to quantify the driving factors of livestock production in Kyrgyzstan.

2.3.2 Spatial gravity center of animal husbandry

Based on the geometric center of each oblast, we described the migration trajectory of livestock husbandry by calculating the weighted average center of gravity:

$$\bar{X}_t = \sum_{i=1}^{N} \frac{Z_{it} X_i}{\sum_{i=1}^{N} Z_{it}},\ \bar{Y}_t = \sum_{i=1}^{N} \frac{Z_{it} Y_i}{\sum_{i=1}^{N} Z_{it}}, \tag{2}$$

where X_i and Y_i are the longitude and latitude of the geometric center of the *ith* oblast, respectively. Z_{it} represents the quantity of the livestock sold, consumed, or stocked by the *ith* oblast in the *tth* year and N is the number of oblasts in Kyrgyzstan. Therefore, $(\bar{X}_t, \bar{Y}_t)$ could intuitively reflect the change path of national livestock sales, self-consumption, and inventory layout.

2.3.3 Two-period livestock production model

The livestock scale not only responded to the current environment and socio-economic conditions but was also strongly associated with herders' preferences on the production cycle, which could affect the herders' livestock scale (Rae and Zhang, 2009; Swanepoel et al., 2010). To simplify the production cycle of livestock, we used the two-period livestock production model (Xu et al., 2019) to quantify the dynamics of livestock and its influencing factors from 2006 to 2020 in each oblast of Kyrgyzstan. The original two-stage model was used to solve the problems of resource consumption and stock in agricultural production systems like fisheries and forestry (Packalen et al., 2009; Munavar et al., 2016). This two-period livestock production model (Xu et al., 2019) took herders' preferences of consuming or saving livestock as part of the mechanism of livestock dynamics and then categorized the production cycle into two periods: "present" and "future." In the present period, herders usually made decisions on livestock sales and self-consumption according to past market information and expectations for future markets. Then, the remaining livestock would become the initial stock for the second period, and Xu et al. (2019) postulated that herders would sell and consume the rest of the livestock at the end of the second period. Based on the assumption, the conceptual model is as follows:

$$U = (1-\alpha)\left[u(c_1) + \beta \cdot u(c_2)\right] + \alpha\left[g(x_{12}) + \beta \cdot g(x_{22})\right], \quad (3)$$

where U is the utility of a herder and α is a parameter that measures the relative utility weight between sale and self-consumption. c_1, c_2 denote the consumption of the present and future, respectively, and β is the time preference rate of a herder. $u(x)$ and $g(x)$ are the utility function of sale and self-consumption, respectively, x_{12} is the quantity of herder's self-consumption in the first period, and x_{22} is the quantity of herder's self-consumption in the second period.

The price of livestock production was the most vital signal for herders to adjust their livestock scale (Bakucs et al., 2014), and the variation in the interest rate was an important form to embody the risk of livestock production (Meuwissen et al., 2001). To simulate the scenarios of the livestock market, Xu et al. (2019) brought the price and interest rate into the two-period livestock production model, which could reflect the fluctuation of the market condition. Economic production is essentially the product of the interaction of social resources, which is confirmed through the calculation and analysis of Eq. 3. Xu et al. (2019) detected that the dynamic changes of livestock would be influenced by socio-economic variables (household education, income, and livestock price) and environmental variables (annual precipitation and temperature).

The two-period production model has been widely used in the estimation of agricultural production efficiency, especially in arid and semi-arid areas with scarce production resources, single economic activities, and fragile environmental conditions. These regions need to constantly balance the consumption and inventory

TABLE 1 Specific description of the variables in this study.

Variable	Meaning	Unit
Preci	Annual precipitation	mm
Temp	Annual temperature	°C
NPP	Net primary productivity of grassland in each oblast	gCm^{-2} yr^{-1}
Q_{sale}	Quantity of livestock sold by herders	Per head
$Q_{self\text{-}consumption}$	Quantity of livestock consumed by herders	Per head
Q_t	Quantity of livestock inventory at the end of this year	Per head
Q_{t-1}	Quantity of livestock inventory at the end of the previous year	Per head
P_t	Livestock price of this year	Dollar/head
P_{t+1}	Livestock price of the next year	Dollar/head
m_t	Non-herding income of this year	Dollar
m_{t-1}	Non-herding income of the previous year	Dollar
Edu	Number of people graduating from high schools	Thousand Capita
Rural	Number of rural populations	Thousand Capita
Husgrp	Output of animal husbandry in each oblast	Dollar
Lorate	Ratio of loan to income (it reflects the difficulty for borrowing; a higher ratio means loans are easier to borrow)	—
Rurate	Ratio of rural residents to total population in each oblast	—
a_0, b_0, and c_0	Constant term	—
a_1~a_7	Correlation coefficients in Eq. 4	—
b_1~b_6	Correlation coefficients in Eq. 5	—
c_1~c_{11}	Correlation coefficients in Eq. 6	—
ε_0, f_0, and e_0	Random error term	—

10.3389/fenvs.2022.1049187

of resources to maximize the output (Kimhi, 2006; Asfaw et al., 2010; Ma et al., 2018). Therefore, we ran three regressions to quantify the influencing factors of livestock change in Kyrgyzstan:

$$ln(Q_{Sale}) = a_0 + a_1 \cdot ln(P_t) + a_2 \cdot ln(P_{t+1}) + a_3 \cdot Lorate + a_4 \cdot ln(m_t) + a_5 \cdot ln(m_{t-1}) + a_6 \cdot ln(Q_t) + a_7 \cdot ln(Rural) + \varepsilon_0, \quad (4)$$

$$ln(Q_{self-consumption}) = b_0 + b_1 \cdot ln(P_t) + b_2 \cdot ln(P_{t+1}) + b_3 \cdot Lorate + b_4 \cdot ln(m_t) + b_5 \cdot ln(m_{t-1}) + b_6 \cdot ln(Q_t) + f_0, \quad (5)$$

$$ln(Q_t) = c_0 + c_1 \cdot ln(P_t) + c_2 \cdot ln(P_{t+1}) + c_3 \cdot Lorate + c_4 \cdot ln(Q_{t-1}) + c_5 \cdot ln(m_t) + c_6 \cdot ln(Preci) + c_7 \cdot Temp + c_8 \cdot ln(NPP) + c_9 \cdot Rurate + c_{10} \cdot ln(Husgrp) + c_{11} \cdot Edu + e_0. \quad (6)$$

All the aforementioned variables and their description are as follows (Table 1):

2.3.4 Spatial regression analysis

In order to explore the spatial correlation characteristics of the livestock scale in seven oblasts of Kyrgyzstan, we used the spatial regression model to quantify the driving factors based on global Moran's I analysis.

Compared with the normal linear regression model, the spatial regression model can accurately identify the spatial effects in a dataset (Anselin, 2003; Tirkaso and Hailu, 2022). Common spatial econometric models contain three basic forms, namely, the spatial lag model (SLM), spatial error model (SEM), and spatial Durbin model (LeSage and Pace, 2010). The specific descriptions of these models are given in Supplementary Material. Through a series of tests like the Lagrange multiplier (LM) test, likelihood ratio (LR) test, and Wald test, we took seven oblasts of Kyrgyzstan as spatial analysis units and selected the SLM and SDM to explore the dynamics of the animal husbandry number and its spatial effects on Kyrgyzstan from 2006 to 2020.

3 Results

3.1 Variation in livestock sales, self-consumption, and inventory

From 2006 to 2020, livestock sales of Kyrgyzstan increased overall, and a two-fold increase in obvious fluctuations appeared during this time. As shown in Figure 2A, the scale of national sales surged in 2006 and reached the first peak of 5.59 million heads in 2007. After the first peak, the national sales plummeted to an all-time low with 4.63 million heads in 2009 and then recovered and displayed a "U-shaped" curve. Since 2011, more

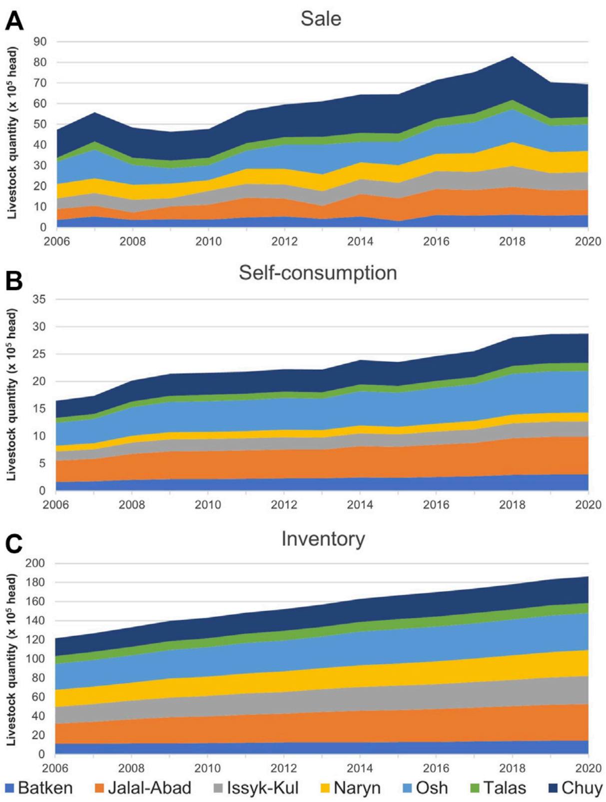

FIGURE 2
Variation in livestock quantity in each oblast of Kyrgyzstan from 2006 to 2020: **(A)** livestock quantity of sales; **(B)** livestock quantity of herders' self-consumption; and **(C)** livestock quantity of inventory.

than 5 million heads of livestock have been sold each year, and sales got the second peak of 8.29 million heads in 2018. It is obvious that Chuy Oblast had the largest actual covered area as shown in Figure 2A, which shows that Chuy Oblast sold the most livestock in Kyrgyzstan. The data series of livestock sales for Issyk-Kul, Naryn, and Chuy Oblast were relatively stable. By contrast, Batken, Jalal-Abad, Osh, and Talas Oblast had significant changes in covered areas, which means that the proportion of livestock sales in these oblasts was changed. Among these oblasts, Jalal-Abad Oblast had the largest annual growth rate of livestock sales with 9.66%, and its covered area kept increasing.

Figure 2B shows that the dynamic change of national livestock self-consumption could be divided into three periods (i.e., 2006–2007, 2008–2018, and 2019–2020). After a slight increase in 2007, livestock consumption in the country scale increased by over 16% in 2008. Since then, more than 2 million heads of livestock have been consumed annually by Kyrgyz nationals. From 2008 to 2018, the national livestock consumption grew steadily. After 2018, the livestock self-

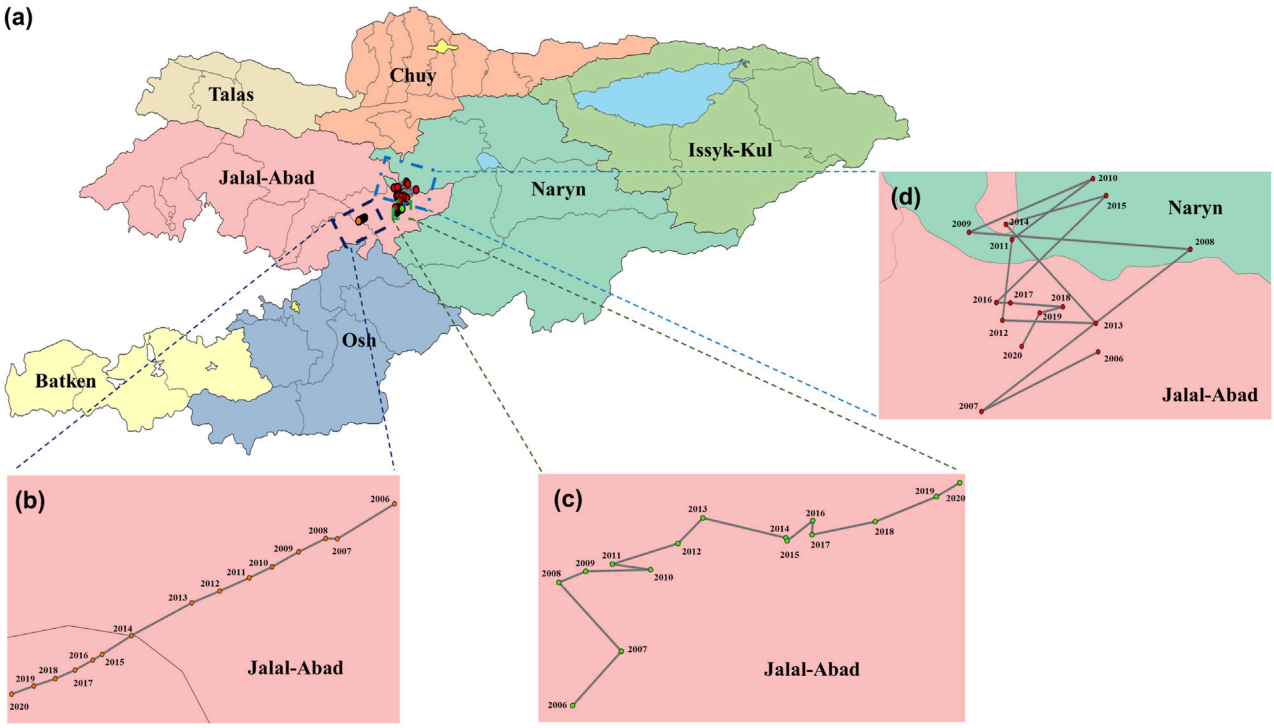

FIGURE 3
Dynamic changes in the distribution and evolution of the livestock scale in Kyrgyzstan from 2006 to 2020: **(A)** spatial distribution of the center of gravity for animal husbandry; **(B)** moving track of the center of gravity for livestock self-consumption; **(C)** moving track of the center of gravity for livestock inventory; and **(D)** moving track of the center of gravity for livestock sale.

consumption remained stable, which was contrary to the trend in sales. The consumption of livestock was mainly concentrated in Osh, Jalal-Abad, and Chuy Oblast, and the cumulative proportion of livestock consumed in these oblasts was more than 66%.

Different from the variation in livestock sales and self-consumption, the livestock inventory maintained a steady upward trend, with the number increasing over 50% in the past decade (Figure 2C). At the same time, the quantity of the livestock inventory was much larger than that of sales and self-consumption. In 2020, there were 18,622,750 heads of livestock stocked in Kyrgyzstan, while the livestock sales were only 6,940,200 heads, and herder families consumed 2,874,370 heads. The amount of inventory reached nearly 2 times of the sum of sales and self-consumption.

3.2 The shifting center of gravity for the livestock scale

Figure 3 and Table 2 show the shifting center of gravity, moving distance and direction of livestock sales, self-consumption, and inventory between 2006 and 2020 in Kyrgyzstan. It is obvious that the annual moving distance of livestock sales was much longer than self-consumption and inventory, and the center of gravity for livestock scales mainly occurred in Jalal-Abad and Naryn Oblast.

The moving track of the center of gravity for livestock self-consumption (Figure 3B) shows that the center continued to shift from northeast to southwest between 2006 and 2020. On the contrary, the center of livestock inventory has been moving to the northeast (Figure 3C). Though the shifting route looks relatively chaotic, it is not hard to find that the livestock sale center of Kyrgyzstan was spiraling northwestward (Figure 3D). Also, the center of gravity for livestock sales moved dramatically in 2008, 2009, and 2016, respectively.

3.3 Variation in different livestock stock

From 2006 to 2020, the quantity of cattle, cows, sheep and goats, and horses had a stable increase (Figure 4). Among the aforementioned livestock, cattle increased by 3 million heads, which was the largest. Although the number of sheep and goats increased more than horses, the variation in sheep and goats showed a convex curve, indicating a slowdown in growth from 4.42% in 2006 to 0.24% in 2020. On the contrary, the trend of horse numbers showed a concave curve, and the growth rate increased from 0.70% in 2006 to 3.27% in 2020.

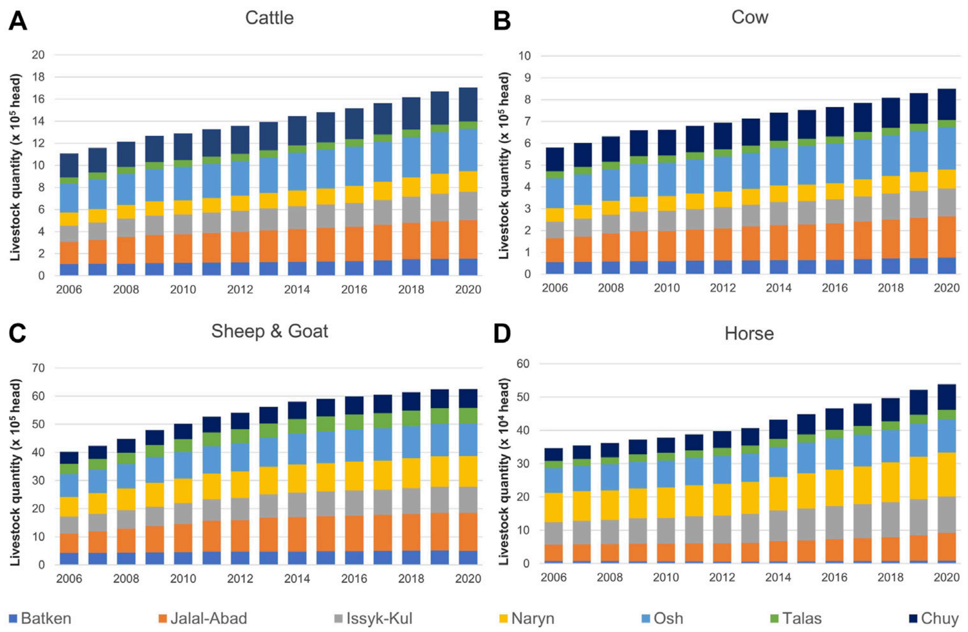

FIGURE 4
Dynamic changes in different livestock stock in each oblast of Kyrgyzstan from 2006 to 2020: **(A)** annual stock numbers of cattle; **(B)** annual stock numbers of cows; **(C)** annual stock numbers of sheep and goats; and **(D)** annual stock numbers of horses.

At the oblast level, Jalal-Abad Oblast had the highest increase in the livestock scale from 2006 to 2020, with the quantity of sheep and goats, cows, cattle, and horses increased by 95.01%, 73.82%, 74.74%, and 69.87%, respectively. For cattle and cows, Osh and Jalal-Abad Oblast showed an increase of more than 42% of the whole country, and the proportion was dynamically increasing (Figures 4A,B). The largest quantity of horses occurred in Naryn Oblast, with the proportion to the total horse number reached about 25%. At the same time, Issyk-Kul and Chuy Oblast greatly expanded the horse scale, where the quantity increased by 69.87% and 97.20%, respectively, and Batken Oblast showed the smallest increase in horse numbers with 3.56% (Figure 4D).

3.4 Results of spatial regression analysis of livestock quantity

According to the estimation of global Moran's I from 2006 to 2020, the results all showed a significant positive correlation at the 1% level, which indicates that there is a significant spatial correlation among the livestock scale in the seven oblasts of Kyrgyzstan (Supplementary Table S2). To avoid overfitting, we examined the variance inflation factors (VIFs) of each explanatory variable and dependent variable. The result showed that there was no multicollinearity problem between the variables (Supplementary Tables S3–S5). To select an appropriate spatial model to detect the driving factors of livestock production dynamics in Kyrgyzstan, we applied a series of tests including LM, LR, and the Wald test. The results given in Supplementary Table S6 show that the spatial lag model could be used to quantify the driving factors of livestock sales and self-consumption, and the spatial Durbin model suited better for analyzing the dynamics of livestock inventory and its influencing factors.

3.4.1 The driving factors of livestock sales

As shown in Table 3, the livestock price, the ratio of loan to income, non-herding income, livestock inventory, and rural population all exerted significant impact on livestock sales. The livestock sales were mainly affected by the ratio of loan to income and livestock price herders expected for the next year; in particular, the livestock prices of the present and next years could have opposite effects on sales. Though the effects of the present livestock price were not significant, the increase in the present price may lead to a reduction in livestock sales. For the price expected for the next year, each 1% price increase would promote livestock sales by 2.987 units. As a key indicator which would influence livestock sales, a higher ratio of loan to income could encourage local herders to sell more livestock, which has significantly negative spatial spillover effects on livestock sale markets in adjacent oblasts.

10.3389/fenvs.2022.1049187

TABLE 2 Center of gravity for livestock scale in Kyrgyzstan from 2006 to 2020.

Year	Sale				Self-consumption				Inventory			
	Longitude	Latitude	Distance (mile)	Direction	Longitude	Latitude	Distance (mile)	Direction	Longitude	Latitude	Distance (mile)	Direction
2006	74.17	41.48	—	—	73.66	41.33	—	—	74.05	41.37	—	—
2007	74.03	41.42	8.45	Southwest	73.64	41.32	0.71	Southwest	74.06	41.38	0.72	Northeast
2008	74.28	41.58	17.31	Northeast	73.64	41.32	0.12	Northwest	74.05	41.39	0.92	Northwest
2009	74.01	41.60	14.02	Northwest	73.64	41.32	0.32	Southwest	74.05	41.39	0.26	Northeast
2010	74.16	41.65	8.65	Northeast	73.63	41.32	0.32	Southwest	74.06	41.39	0.55	Northeast
2011	74.06	41.59	6.62	Southwest	73.63	41.31	0.27	Southwest	74.05	41.40	0.33	Northwest
2012	74.05	41.51	5.60	Southwest	73.62	41.31	0.34	Southwest	74.06	41.40	0.60	Northeast
2013	74.17	41.51	5.91	Southeast	73.62	41.31	0.32	Southwest	74.07	41.40	0.35	Northeast
2014	74.06	41.60	8.88	Northwest	73.60	41.31	0.72	Southwest	74.08	41.40	0.74	Southeast
2015	74.18	41.63	6.63	Northeast	73.60	41.30	0.37	Southwest	74.08	41.40	0.03	Southeast
2016	74.05	41.53	10.13	Southwest	73.60	41.30	0.12	Southwest	74.09	41.40	0.31	Northeast
2017	74.06	41.53	0.89	Southeast	73.59	41.30	0.22	Southwest	74.09	41.40	0.15	Southwest
2018	74.13	41.52	3.32	Southeast	73.59	41.30	0.23	Southwest	74.10	41.40	0.55	Northeast
2019	74.10	41.52	1.53	Southwest	73.58	41.30	0.24	Southwest	74.11	41.41	0.59	Northeast
2020	74.08	41.48	2.57	Southwest	73.58	41.30	0.25	Southwest	74.11	41.41	0.25	Northeast

TABLE 3 Effect of explanatory variables on livestock sales.

Variable	Main	Direct effect	Indirect effect	Total effect
Price $_t$	−1.572	−1.613	0.503	−1.110
	(1.25)	(1.36)	(0.48)	(0.93)
Price $_{t+1}$	2.987**	3.079**	−0.946*	2.133**
	(1.32)	(1.43)	(0.55)	(1.01)
Lorate	13.570***	14.830***	−4.441**	10.390***
	(4.98)	(4.94)	(1.88)	(3.89)
m $_{t-1}$	−0.100**	−0.107**	0.032**	−0.075**
	(0.04)	(0.04)	(0.02)	(0.03)
m $_t$	0.003	0.003	−0.001	0.001
	(0.04)	(0.04)	(0.01)	(0.03)
Q $_t$	0.597***	0.638***	−0.195***	0.443***
	(0.09)	(0.10)	(0.07)	(0.08)
Rural	0.270***	0.280***	−0.081**	0.199**
	(0.10)	(0.10)	(0.03)	(0.09)
R-squared	0.604			

Note: ***, **, and * represent that the statistics are significant at the 1%, 5%, and 10% levels, respectively.

3.4.2 The driving factors of livestock self-consumption

According to Table 4, all the variation in the livestock price of the next year, the ratio of loan to income, previous non-herding income, and current livestock inventory would have significant effects on herders' self-consumption. Among them, a higher ratio of loan to income was the primary signal for herders to increase their self-consumption, while the main factor restraining consumption was the higher livestock prices expected for the next year. With other conditions unchanged, every 1% increase in the ratio of loan to income would cause extra 14.620 units of livestock to be consumed. Different from the impact exerted on livestock sales, both the livestock price of the present year and next year had negative spatial spillover effects on livestock quantity for self-consumption.

3.4.3 The driving factors of livestock inventory

As shown in Table 5, the value of R-squared was 0.858, which showed that this model had good explanatory significance. It was observed that the livestock inventory in Kyrgyzstan was mainly influenced by the variation in current non-herding income, previous inventory, the number of educated people, the proportion of rural residents to regional population, and the regional output of animal husbandry. More previous inventory

TABLE 4 Effect of explanatory variables on livestock self-consumption.

Variable	Main	Direct effect	Indirect effect	Total effect
Price $_t$	−0.177	−0.140	0.041	−0.099
	(1.21)	(1.28)	(0.35)	(0.96)
Price $_{t+1}$	−5.481***	−5.729***	1.410**	−4.319***
	(1.20)	(1.27)	(0.63)	(1.09)
Lorate	14.620***	15.600***	−3.652**	11.950***
	(4.87)	(4.69)	(1.52)	(4.40)
m $_{t-1}$	0.097**	0.100**	−0.024*	0.076**
	(0.04)	(0.04)	(0.01)	(0.03)
m $_t$	0.024	0.025	−0.006	0.020
	(0.04)	(0.04)	(0.01)	(0.03)
Q $_t$	0.585***	0.613***	−0.144***	0.469***
	(0.10)	(0.09)	(0.05)	(0.12)
R-squared	0.546			

Note: ***, **, and * represent that the statistics are significant at the 1%, 5%, and 10% levels, respectively.

TABLE 5 Effect of explanatory variables on livestock inventory.

Variable	Main	Direct effect	Indirect effect	Total effect
$Price_t$	−0.037	−0.028	−0.107	−0.135
	(0.05)	(0.05)	(0.10)	(0.11)
$Price_{t+1}$	0.081	0.089*	−0.147*	−0.058
	(0.05)	(0.05)	(0.09)	(0.11)
Lorate	0.238	0.226	0.565	0.790
	(0.26)	(0.26)	(0.52)	(0.49)
Q_{t-1}	0.891***	0.906***	−0.192***	0.714***
	(0.04)	(0.04)	(0.07)	(0.09)
Temp	−0.002	−0.001	−0.014	−0.015
	(0.00)	(0.00)	(0.01)	(0.01)
Preci	0.003	0.008	−0.060**	−0.052**
	(0.01)	(0.01)	(0.03)	(0.03)
NPP	−0.020	−0.013	−0.085*	−0.099**
	(0.02)	(0.02)	(0.05)	(0.05)
m_t	−0.005**	−0.004**	−0.004	−0.008***
	(0.00)	(0.00)	(0.00)	(0.00)
Rurate	2.255***	2.026***	3.558***	5.584***
	(0.58)	(0.56)	(1.25)	(1.49)
Husgrp	−0.046**	−0.054***	0.113***	0.059
	(0.02)	(0.02)	(0.04)	(0.04)
Edu	0.003*	0.003*	0.001	0.004
	(0.00)	(0.00)	(0.00)	(0.00)
R-squared	0.858			

Note: ***, **, and * represent that the statistics are significant at the 1%, 5%, and 10% levels, respectively.

and educated people would have significant and positive spatial spillover effects on livestock inventory. Meanwhile, with other conditions unchanged, every 1% increase in the proportion of the rural population could facilitate the local livestock inventory expansion by 2.026 units and encourage the herders in adjacent oblasts to increase their livestock scale by 3.558 units.

The changes in the environment also had influences on livestock quantity. It was found that higher precipitation and grassland productivity could have significant and negative spatial spillover effects on neighboring livestock inventory. Each 1% increase in precipitation and grassland NPP could lead to an overall reduction by 0.052 and 0.099 units of livestock scale in the seven oblasts of Kyrgyzstan, respectively.

4 Discussion

This study quantified the dynamics of livestock scale and then assessed the effects of environmental and socio-economic factors on livestock sale, self-consumption, and inventory. Results showed that the quantity of livestock in Kyrgyzstan increased overall from 2006 to 2020 (Figure 4), and there were different patterns among the livestock distribution and variations in different oblasts (Figures 3, 4). Based on the spatial regression analysis, we found that multiple variables had effects on livestock quantity (Tables 3–5). All the livestock sales, self-consumption, and inventory were significantly influenced by the variation in livestock price, the ratio of loan to income, and non-herding income at different levels. The higher proportion of rural residents to regional population would have significant and positive impact on self-consumption and inventory, respectively. In addition to the socio-economic factors, the fluctuation of precipitation and grassland NPP also affected the number of livestock inventory.

4.1 The effects of environmental and socio-economic factors on livestock quantity

Our regression analysis showed that a higher non-herding income could encourage herders to consume more livestock, and the higher ratio of loan to income would also promote local herders to sell and consume more livestock (Tables 4, 5). In Kyrgyzstan, most households made a living with employment income, savings and loan, social grants, and income from animal husbandry (Wang et al., 2016; Sagynbekova, 2017). The direct contribution of livestock to the total income of household families was limited, and many people diversified their income by international or internal labor migration (Schoch et al., 2010; Pica-Ciamarra et al., 2015). Previous studies reported that non-herding income accounted for about 38% of the total household income in the rural areas of developing countries (Ragie et al., 2020). Regional economic development provided non-agricultural employment opportunities for farmers and promoted the off-farm income for farmers. This caused strong and direct shock on animal husbandry, and even the negative effects were shown on adjacent areas (Wang et al., 2016). Meanwhile, due to more non-agricultural employment opportunities emerging and higher non-herding income increasing, pastoralists might gradually reduce their livestock scale. Kyrgyzstan's economy and people's living standards were changed greatly after the collapse of the Soviet Union, and Kyrgyzstan was classified as a lower-middle income country by the World Bank (World Bank, 2016). In order to improve people's living and production standards, microfinance was introduced in Kyrgyzstan as a poverty reduction tool. Lacking funds and technology to achieve self-sufficiency in production, the majority of Kyrgyz pastoralists would be more inclined to allocate most of the loans to scale up livestock production and compress production cycles to gain more profits (Ksoll et al., 2016; Angioloni et al., 2018). Herders also tend to purchase more food or consume more livestock to enhance living standards when they receive extra loans (Aldashev, 2019). Therefore, a higher ratio of loan to income may support Kyrgyz herders to sell and consume more livestock.

Market price was one of the most important signals that affect herders' choices for adjusting the livestock scale. Rucker et al. (1984) indicated that the change of the present price could have opposite effects on producers' decisions, bringing about herders' different responses to the market situation (Pica-Ciamarra et al., 2015). Higher market price could encourage producers to sell more livestock immediately to deal with important expenditures like living or medical costs (Megersa et al., 2014). On the other hand, producers would expect a more satisfactory price in the future and expand their stock for higher speculative profit (Ge and Kinnucan, 2018; Xu et al., 2019). Lacking more attractive and optional investment opportunities, livestock were often taken as main assets and buffer stocks in Kyrgyzstan (Munavar et al., 2016). However, only the wealthier large-herd owners could take risks and regard livestock inventory as investment for a longer term, while most livestock production came from small herders, who were more vulnerable to climate and economic fluctuation in Kyrgyzstan (de la Martiniere, 2012; Sabyrbekov, 2019). Munavar et al. (2016) defined herders with large livestock and no grazing services as large-herd owners, and small herders were those who offered grazing services to obtain seasonal income (Steimann, 2012). For small herders, pressure for longer-term feed costs and climate uncertainty would weaken their profitability (Brookfield, 1991; Biglari et al., 2019). The 2008 global financial crisis caused the surge of energy and food prices in Kyrgyzstan (Ruziev and Majidov, 2013). The attractive prices promoted herders to reduce livestock sales for saving capital to deal with uncertainty and wait for better sale opportunities. This was consistent with Figure 2A. As long as the livestock price reaches herders' anticipation, they prefer to sell more livestock.

Research results showed that more precipitation and higher grassland NPP could lead herders to reduce their livestock number in neighboring oblasts. The livestock scale was vulnerable to feed production, which depended on climate and environmental conditions (Jaber et al., 2016; Karimi et al., 2018). Insufficient precipitation, shortage of water resources, and poor water infrastructure would reduce grassland productivity, which directly affects the feed price and impacts the cost of animal husbandry and its size (Sagynbekova, 2017; Chen et al., 2020; Umuhoza et al., 2021; Kadupitiya et al., 2022). Pastures with more precipitation benefit for grassland productivity in Kyrgyzstan (Wang et al., 2020), which could offer abundant and high-quality feed for livestock and greatly promote the development of animal husbandry. In addition to the climate factors, human activities could also contribute to the recovery of grassland productivity. To ensure the sustainability of pastures, the Kyrgyzstan government established a series of policies and laws for pasture management after the country gained independence. As a result, more than 40% of grasslands recovered significantly under the joint efforts of the government and local people from 2000 to 2014 (Wang et al., 2020). The grassland restoration caused by anthropogenic activities mainly occurred in Osh, Naryn, Issyk-Kul, and southern Jalal-Abad Oblasts, which would attract more herders to migrate and graze in these regions. It is found that the center of gravity for livestock inventory in Kyrgyzstan shifted from southern Jalal-Abad to the northeast of Kyrgyzstan (Figure 3C).

As shown in Table 5, higher grassland NPP and more precipitation in pastures had significant spatial spillover effects, which might attract herders to migrate and graze from other regions (Opiyo et al., 2011). Lacking sufficient funds and anti-risk ability for long-distance migration, small herdsmen often grazed in pastures near villages, even if the feed resources were inadequate (Rahimon, 2012; Steimann, 2012). With the gradual improvement and stringency of policies of pasture management, small herders with little access to high-quality resources will be increasingly restricted (Crewett, 2012). In contrast, wealthier herders generally possessed significant power, sufficient funds, and livestock management expertise to migrate and privileges to graze on more productive pastures (Sagynbekova, 2017; Kasymov and Thiel, 2019).

4.2 Implication policy

The livestock system is extremely complex and influenced by different factors. To achieve sustainable development of animal husbandry, Kyrgyzstan needs innovative combinations of system, policy, and technology. First, it is vital for the government to develop more flexible financial policies to directly ease the cost pressure on pastoralist families. In many countries, microfinance is regarded as an important approach to increase the flow of capital (Hossain, 1988; Hartarska and Nadolnyak, 2008; Kabir et al., 2017), which is an effective short-term method to help herdsmen overcome climate disasters such as drought or snowstorms, and has been advocated by governments and international organizations (Turner and Williams, 2002; Ouma et al., 2011; Addison and Brown, 2014). Meanwhile, the government could steer domestic investment and foreign capital in animal husbandry by reducing the tax rate of animal husbandry and increasing production subsidies for animal husbandry enterprises (Upton, 2004; Dovie et al., 2006; Zeleke et al., 2021). Second, national and local managers need to explore a new animal husbandry production system, which could improve the adaptability and reproductive efficiency of livestock under fluctuated environments. This system includes the techniques of feed and nutrition, genetics and breeding, disease prevention, and environmental management and then adopts different technical combinations for different production systems (Zhao et al., 2018; Enahoro et al., 2019). Third, pasture management should be transformed from unidirectional to multiple forms and make herders become the common managers. Providing alternative and cognitive frameworks, as well as appealing for actions, could be a more effective way to enhance herders' self-concept and produce positive outcomes (Cohen, 2001; Korman, 2012). For example, pasture managers could provide local herders with jobs like paid environmental monitors and data collectors, so herders can obtain extra income and be encouraged to co-create pasture conservation initiatives (Levine et al., 2017). Furthermore, it is worthwhile to explore the policies of livestock international trade, which conduces to promoting national economic development. The local livestock industry could be supported by raising import taxes, which could help to protect the market for domestic livestock production and ensure an income for local herdsmen (Jaber et al., 2016). For livestock export, developed countries follow strict food safety and quality standards to meet the international health standards. The Kyrgyzstan government should ensure the production and export of animal husbandry by actively complying with various health measures and actively exploring the market potential of importing countries with huge demand for livestock products (Kumar, 2010).

4.3 Innovation and contribution

Some previous studies have indicated that social economic factors played a dominant role in husbandry development of arid and semi-arid areas (Ge and Kinnucan, 2018; Xu et al., 2019; Wei and Zhen, 2020). The results provided more diversified practical proof for the dynamics of livestock scale and introduced a more flexible environmental index to strengthen the assessment of environmental effects on livestock quantity in Kyrgyzstan. This study also offered a new perspective for research studies on livestock change in arid and semi-arid areas and proposed significant measures for developing husbandry economy under the context of high quality and sustainable development of the national economy for developing countries. The approach we used was widely applicable in identifying the impact of climate change and socio-economic changes on the dynamics of livestock in arid and semi-arid areas and determined the spatial effects of socio-economic factors and environmental factors. This research not only provided new evidence for the efficient development of animal husbandry in Kyrgyzstan under environmental policies and financial regulation but also proposed a theoretical and practical basis for other Central Asian countries to maintain husbandry and national economy sustainability.

4.4 Limitation and uncertainty

In this study, the two-period livestock production model divided the operation of the livestock market into two stages, introduced the herdsmen's speculative behavior as a weight to the model, and revealed the specific influencing factors of livestock quantity change (Xu et al., 2019). However, this model algorithm has not been verified by a wide range of cases yet, and its control variables may be incomplete. In addition to the variables mentioned in this study, four other variables (i.e., abundance of feed resources, proportion of productive land area, the improvement of agricultural productivity, and mechanization level) had direct and positive effects on the grass-feeding livestock breeding industry (Wang et al., 2016), but the urbanization level and climatic changes had obvious negative effects (Peng et al., 2005; Munavar et al., 2016). Therefore, the accuracy of our model and variable selection may have a certain degree of limitation.

The analysis of livestock variation was also limited by data uncertainties as the dataset did not reflect the specific condition of the household unit. The livestock sales, self-consumption, and inventory could be significantly influenced by the household size and livestock structure (Xu et al., 2019; Wei and Zhen, 2020). In this study, the variables were based on provincial statistics, which represented the provincial average condition. Although the official data could objectively reflect the real condition of husbandry in the seven oblasts of Kyrgyzstan, the household data based on a field survey were deficient, which could not reflect the production capacity and income levels of different families and pastures. Future studies should focus on accessing and quantifying how the environmental and financial policies have affected the development of husbandry in Kyrgyzstan. This is a very promising direction for future policy approaches, especially in light of the multiple pressures anticipated from agricultural investment under China's Belt and Road Initiative.

5 Conclusion

We used the two-period livestock production model and spatial panel econometric model to estimate the dynamics of livestock quantity change and its influencing factors from 2006 to 2020 in Kyrgyzstan. Our results showed that the quantity of livestock increased overall, and the quantity of livestock for inventory was far more than sales and self-consumption. In addition, market price, non-herding income, and current livestock inventory were the dominant socio-economic factors contributing to dynamic changes in livestock sales, self-consumption, and inventory, and the higher proportion of rural residents and education level could support herders to expand their livestock scale. The results provided an effective way to not only guarantee the herders' livelihood and realize the sustainable development of animal husbandry but also promote high-quality economic development for Kyrgyzstan. In a broader sense, our findings have greatly advanced the understanding of sustainable development of a grassland ecosystem and animal husbandry economy in arid and semi-arid regions.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author contributions

JY and YW designed the study and planned the analysis; JY prepared the basic data; JY, HZ, and XW conducted the data analysis; JY drafted the manuscript; YW, JY, YS, SY, and SY revised the manuscript. All authors contributed critically to the drafts and approved the final version of the manuscript.

Funding

This work was supported by the National Natural Science Foundation of China (grant number 72074198).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1049187/full#supplementary-material

References

Abay, K. A., and Jensen, N. D. (2020). Access to markets, weather risk, and livestock production decisions: Evidence from Ethiopia. *Agric. Econ.* 51, 577–593. doi:10.1111/agec.12573

Addison, J., and Brown, C. (2014). A multi-scaled analysis of the effect of climate, commodity prices and risk on the livelihoods of Mongolian pastoralists. *J. Arid Environ.* 109, 54–64. doi:10.1016/j.jaridenv.2014.05.010

Agadjanian, V., and Gorina, E. (2019). Economic swings, political instability and migration in Kyrgyzstan. *Eur. J. Popul.* 35, 285–304. doi:10.1007/s10680-018-9482-4

Aldashev, A. (2019). Social norms, status spending and household debt: Evidence from Kyrgyzstan. Available at: https://mpra.ub.uni-muenchen.de/id/eprint/91363.

Angioloni, S., Kudabaev, Z., Ames, G. C. W., and Wetzstein, M. (2018). Household allocation of microfinance credit in Kyrgyzstan. *Post-Communist Econ.* 30, 78–98. doi:10.1080/14631377.2017.1361691

Anselin, L. (2003). Spatial externalities, spatial multipliers, and spatial econometrics. *Int. regional Sci. Rev.* 26, 153–166. doi:10.1177/0160017602250972

Arora, N. K., and Mishra, I. (2019). United nations sustainable development goals 2030 and environmental sustainability: Race against time. *Environ. Sustain.* 2, 339–342. doi:10.1007/s42398-019-00092-y

Asfaw, S., Mithofer, D., and Waibel, H. (2010). Agrifood supply chain, private-sector standards, and farmers' health: Evidence from Kenya. *Agric. Econ.* 41, 251–263. doi:10.1111/j.1574-0862.2010.00443.x

Bakucs, Z., Falkowski, J., and Ferto, I. (2014). Does market structure influence price transmission in the agro-food sector? A meta-analysis perspective. *J. Agric. Econ.* 65, 1–25. doi:10.1111/1477-9552.12042

Baumgard, L. H., Rhoads, R. P., Rhoads, M. L., Gabler, N. K., Ross, J. W., Keating, A. F., et al. (2012). "Impact of climate change on livestock production," in *Environmental stress and amelioration in livestock production* (Berlin, Heidelberg: Springer).

Beer, R., Kaiser, F., Schmidt, K., Ammann, B., Carraro, G., Grisa, E., et al. (2008). Vegetation history of the walnut forests in Kyrgyzstan (central Asia): Natural or anthropogenic origin? *Quat. Sci. Rev.* 27, 621–632. doi:10.1016/j.quascirev.2007.11.012

Biglari, T., Maleksaeidi, H., Eskandari, F., and Jalali, M. (2019). Livestock insurance as a mechanism for household resilience of livestock herders to climate change: Evidence from Iran. *Land Use Policy* 87, 104043. doi:10.1016/j.landusepol.2019.104043

Borchardt, P., Schickhoff, U., Scheitweiler, S., and Kulikov, M. (2011). Mountain pastures and grasslands in the SW Tien Shan, Kyrgyzstan — floristic patterns, environmental gradients, phytogeography, and grazing impact. *J. Mt. Sci.* 8, 363–373. doi:10.1007/s11629-011-2121-8

Breeman, G., Dijkman, J., and Termeer, C. (2015). Enhancing food security through a multi-stakeholder process: The global agenda for sustainable livestock. *Food Sec.* 7, 425–435. doi:10.1007/s12571-015-0430-4

Brookfield, D. (1991). Structural relationships in UK store livestock markets. *J. Agric. Econ.* 42, 11–20. doi:10.1111/j.1477-9552.1991.tb00328.x

Chen, T., Tang, G., Yuan, Y., Guo, H., Xu, Z., Jiang, G., et al. (2020). Unraveling the relative impacts of climate change and human activities on grassland productivity in Central Asia over last three decades. *Sci. Total Environ.* 743, 140649. doi:10.1016/j.scitotenv.2020.140649

Cohen, S. (2001). *States of denial: Knowing about atrocities and suffering*. New York, United States: John Wiley & Sons, 177–183.

Crewett, W. (2012). Improving the sustainability of pasture use in Kyrgyzstan. *Mt. Res. Dev.* 32, 267–274. doi:10.1659/mrd-journal-d-11-00128.1

Dabrowski, M., Jermakowicz, W., Pańków, J., Kloc, K., and Antczak, R. (1995). Economic reforms in Kyrgyzstan. *Communist Econ. Econ. Transformation* 7, 269–297. doi:10.1080/14631379508427825

de la Martiniere, R. (2012). Rural livelihood trajectories around a "bull market" in Kyrgyzstan studying agropastoral change at the household level through farming system modeling. *Mt. Res. Dev.* 32, 337–344. doi:10.1659/mrd-journal-d-11-00098.1

Dovie, D. B. K., Shackleton, C. M., and Witkowski, E. T. F. (2006). Valuation of communal area livestock benefits, rural livelihoods and related policy issues. *Land Use Policy* 23, 260–271. doi:10.1016/j.landusepol.2004.08.004

Enahoro, D., Mason-D'Croz, D., Mul, M., Rich, K. M., Robinson, T. P., Thornton, P., et al. (2019). Supporting sustainable expansion of livestock production in South Asia and Sub-Saharan Africa: Scenario analysis of investment options. *Glob. Food Secur.* 20, 114–121. doi:10.1016/j.gfs.2019.01.001

FAO (2006). *World agriculture: Towards 2030/2050, interim report*. Rome, Italy: FAO.

Ge, W., and Kinnucan, H. (2018). Dynamic analysis of the livestock inventory in Inner Mongolia. *China Agric. Econ. Rev.* 10, 498–515. doi:10.1108/caer-02-2017-0015

Gerber, P. J., and Steinfeld, H. (2008). "Worldwide growth of animal production and environmental consequences," in *Trace elements in animal production systems*. Editors P. Schlegel, S. Durosoy, and A. W. Jongbloed (Wageningen, Netherlands: Wageningen Academic), 21–32.

Gerosa, S., and Skoet, J. (2012). Milk availability: Trends in production and demand and medium-term outlook. *Agrifood Econ.* ESA Working Papers. doi:10.22004/ag.econ.289000

Haghiyan, I., Mofidi-Chelan, M., Azadi, H., Nejatiyanpour, E., Motamedi, J., Sheidai-Karkaj, E., et al. (2022). Evaluating economic and ecological management to determine the economic size of pastoral units for different climatic zones in the northeast of Iran. *J. Environ. Manag.* 301, 113766. doi:10.1016/j.jenvman.2021.113766

Han, C. J., Wang, G. G., Zhang, Y. X., Song, L. L., and Zhu, L. Z. (2020). Analysis of the temporal and spatial evolution characteristics and influencing factors of China's herbivorous animal husbandry industry. *Plos One* 15, e0237827. doi:10.1371/journal.pone.0237827

Hartarska, V., and Nadolnyak, D. (2008). An impact analysis of microfinance in Bosnia and Herzegovina. *World Dev.* 36, 2605–2619. doi:10.1016/j.worlddev.2008.01.015

Hauck, M., Artykbaeva, G. T., Zozulya, T. N., and Dulamsuren, C. (2016). Pastoral livestock husbandry and rural livelihoods in the forest-steppe of east Kazakhstan. *J. Arid Environ.* 133, 102–111. doi:10.1016/j.jaridenv.2016.05.009

Hoppe, F., Schickhoff, U., and Oldeland, J. (2018). Plant species diversity of pastures in the Naryn Oblast (Kyrgyzstan). *DIE ERDE-Journal Geogr. Soc. Berlin* 149, 214–226. doi:10.12854/erde-2018-384

Hossain, M. (1988). *Credit for alleviation of rural poverty: The Grameen Bank in Bangladesh*. Washington, D.C., USA: Intl Food Policy Res Inst. 65.

Iñiguez, L. (2004). Goats in resource-poor systems in the dry environments of west Asia, central Asia and the inter-andean valleys. *Small Ruminant Res.* 51, 137–144. doi:10.1016/j.smallrumres.2003.08.014

Jaber, L. S., Diehl, K. E., and Hamadeh, S. K. (2016). Livestock and food security in the arab region: Policy framework. *Food Sec.* 8, 899–908. doi:10.1007/s12571-016-0608-4

Jiang, Y., Zhang, Q., Niu, J., and Wu, J. (2019). Pastoral population growth and land use policy has significantly impacted livestock structure in inner Mongolia-A case study in the xilinhot region. *Sustainability* 11, 7208. doi:10.3390/su11247208

Kabir, M. J., Alauddin, M., and Crimp, S. (2017). Farm-level adaptation to climate change in Western Bangladesh: An analysis of adaptation dynamics, profitability and risks. *Land Use Policy* 64, 212–224. doi:10.1016/j.landusepol.2017.02.026

Kadupitiya, H. K., Madushan, R. N. D., Gunawardhane, D., Sirisena, D., Rathnayake, U., Dissanayaka, D., et al. (2022). Mapping productivity-related spatial characteristics in rice-based cropping systems in Sri Lanka. *J. Geovis. Spat. Anal.* 6, 26. doi:10.1007/s41651-022-00122-0

Kang, Y. Q., Zhao, T., and Yang, Y. Y. (2016). Environmental kuznets curve for CO2 emissions in China: A spatial panel data approach. *Ecol. Indic.* 63, 231–239. doi:10.1016/j.ecolind.2015.12.011

Karimi, V., Karami, E., and Keshavarz, M. (2018). Vulnerability and adaptation of livestock producers to climate variability and change. *Rangel. Ecol. Manag.* 71, 175–184. doi:10.1016/j.rama.2017.09.006

Kasymov, U., and Thiel, A. (2019). Understanding the role of power in changes to pastoral institutions in Kyrgyzstan. *Int. J. Commons* 13, 931–948. doi:10.5334/ijc.870

Kerven, C., Steimann, B., Ashley, L., Dear, C., and Rahim, I. (2011). *Pastoralism and farming in central asia's mountains: A research review*. Bishkek, Kyrgyzstan: University of Central Asia. MSRC background paper. 1.

Kimhi, A. (2006). Plot size and maize productivity in Zambia: Is there an inverse relationship? *Agric. Econ.* 35, 1–9. doi:10.1111/j.1574-0862.2006.00133.x

Koocheki, A., and Gliessman, S. R. (2005). Pastoral nomadism, a sustainable system for grazing land management in arid areas. *J. Sustain. Agric.* 25, 113–131. doi:10.1300/j064v25n04_09

Korman, A. K. (2012). "Self-enhancement and self-protection: Toward a theory of work motivation," in *Work motivation in the context of a globalizing economy* (United Kingdom: Psychology Press), 127–136.

Ksoll, C., Lilleør, H. B., Lønborg, J. H., and Rasmussen, O. D. (2016). Impact of village savings and loan associations: Evidence from a cluster randomized trial. *J. Dev. Econ.* 120, 70–85. doi:10.1016/j.jdeveco.2015.12.003

Kumar, A. (2010). Exports of livestock products from India: Performance, competitiveness and determinants. *Agric. Econ. Res. Rev.* 23, 57–68. doi:10.22004/ag.econ.92095

Lan, X., Zhang, Q., Xue, H. L., Liang, H. G., Wang, B. J., and Wang, W. J. (2021). Linking sustainable livelihoods with sustainable grassland use and conservation: A case study from rural households in a semi-arid grassland area, China. *Land Use Policy* 101, 105186. doi:10.1016/j.landusepol.2020.105186

LeSage, J. P., and Pace, R. K. (2010). "Spatial econometric models," in *Handbook of applied spatial analysis* (Berlin, Heidelberg: Springer), 355–376.

Levine, J., Isaeva, A., Eddy, I., Foggin, M., Gergel, S., Hagerman, S., et al. (2017). A cognitive approach to the post-soviet central asian pasture puzzle: New data from Kyrgyzstan. *Reg. Environ. Change* 17, 941–947. doi:10.1007/s10113-017-1122-8

Liang, L., Zhang, F., and Qin, K. (2021). Assessing the vulnerability of agricultural systems to drought in Kyrgyzstan. *Water* 13, 3117. doi:10.3390/w13213117

Ludi, E. (2003). Sustainable pasture management in Kyrgyzstan and Tajikistan: Development needs and recommendations. *Mt. Res. Dev.* 23, 119–123. doi:10.1659/0276-4741(2003)023[0119:spmika]2.0.co;2

Ma, W. L., Renwick, A., and Grafton, Q. (2018). Farm machinery use, off-farm employment and farm performance in China. *Aust. J. Agric. Resour. Econ.* 62, 279–298. doi:10.1111/1467-8489.12249

Megersa, B., Markemann, A., Angassa, A., Ogutu, J. O., Piepho, H. P., and Valle Zárate, A. (2014). Livestock diversification: An adaptive strategy to climate and rangeland ecosystem changes in southern Ethiopia. *Hum. Ecol.* 42, 509–520. doi:10.1007/s10745-014-9668-2

Mehrabi, Z., Gill, M., Wijk, M. V., Herrero, M., and Ramankutty, N. (2020). Livestock policy for sustainable development. *Nat. Food* 1, 160–165. doi:10.1038/s43016-020-0042-9

Meuwissen, M. P. M., Huirne, R. B. M., and Hardaker, J. B. (2001). Risk and risk management: An empirical analysis of Dutch livestock farmers. *Livest. Prod. Sci.* 69, 43–53. doi:10.1016/s0301-6226(00)00247-5

Munavar, Z., Nicole, W. M., and Dietrich, D. (2016). Farmers' decision-making and land use changes in Kyrgyz agropastoral systems. *Mt. Res. Dev.* 36, 506–517. doi:10.1659/mrd-journal-d-16-00030.1

NSCKR (2020). National statistical committee of the Kyrgyz republic. Available at: http://www.stat.kg/en/.

Opiyo, F. E., Mureithi, S. M., and Ngugi, R. K. (2011). The influence of water availability on pastoralist's resource use in Mwingi and Kitui districts in Kenya. *J. Hum. Ecol.* 35, 43–52. doi:10.1080/09709274.2011.11906389

Ouma, R., Mude, A., and Van De Steeg, J. (2011). Dealing with climate-related risks: Some pioneering ideas for enhanced pastoral risk management in africa. *Exp. Agric.* 47, 375–393. doi:10.1017/s0014479710000888

Packalen, P., Suvanto, A., and Maltamo, M. (2009). A two stage method to estimate species-specific growing stock. *Photogramm. Eng. remote Sens.* 75, 1451–1460. doi:10.14358/pers.75.12.1451

Peng, X., Marchant, M. A., Qin, X. D., and Zhuang, J. (2005). Chinese consumers' preferences for livestock products. *Int. Food Agribus. Manag. Rev.* 8, 62–76. doi:10.22004/ag.econ.8134

Pica-Ciamarra, U., Tasciotti, L., Otte, J., and Zezza, A. (2015). Livestock in the household economy: Cross-country evidence from microeconomic data. *Dev. Policy Rev.* 33, 61–81. doi:10.1111/dpr.12092

Rae, A. N., and Zhang, X. (2009). China's booming livestock industry: Household income, specialization, and exit. *Agric. Econ.* 40, 603–616. doi:10.1111/j.1574-0862.2009.00402.x

Ragie, F. H., Olivier, D. W., Hunter, L. M., Erasmus, B. F. N., Vogel, C., Collinson, M., et al. (2020). A portfolio perspective of rural livelihoods in Bushbuckridge, South Africa. *S. Afr. J. Sci.* 116, 98–105. doi:10.17159/sajs.2020/7522

Rahimon, R. M. (2012). "Evolution of land use in pastoral culture in Central Asia with special reference to Kyrgyzstan and Kazakhstan," in *Rangeland stewardship in central Asia* (Dordrecht: Springer).

Raji, S. A., Odunuga, S., and Fasona, M. (2022). Spatially explicit scenario analysis of habitat quality in a tropical semi-arid zone: Case study of the sokoto-rima basin. *J. Geovis. Spat. Anal.* 6, 11. doi:10.1007/s41651-022-00106-0

Robinson, S., Kerven, C., Behnke, R., Kushenov, K., and Milner-Gulland, E. J. (2016). The changing role of bio-physical and socio-economic drivers in determining livestock distributions: A historical perspective from Kazakhstan. *Agric. Syst.* 143, 169–182. doi:10.1016/j.agsy.2015.12.018

Rosati, F., and Faria, L. G. (2019). Addressing the SDGs in sustainability reports: The relationship with institutional factors. *J. Clean. Prod.* 215, 1312–1326. doi:10.1016/j.jclepro.2018.12.107

Rucker, R. R., Burt, O. R., and LaFrance, J. T. (1984). An econometric model of cattle inventories. *Am. J. Agric. Econ.* 66, 131–144. doi:10.2307/1241030

Ruziev, K., and Majidov, T. (2013). Differing effects of the global financial crisis on the central asian countries: Kazakhstan, the Kyrgyz republic and Uzbekistan. *Europe-Asia Stud.* 65, 682–716. doi:10.1080/09668136.2013.766044

Sabyrbekov, R. (2019). Income diversification strategies among pastoralists in Central Asia: Findings from Kyrgyzstan. *Pastoralism* 9, 14. doi:10.1186/s13570-019-0152-x

Sagynbekova, L. (2017). Environment, rural livelihoods, and labor migration: A case study in Central Kyrgyzstan. *Mt. Res. Dev.* 37, 456–463. doi:10.1659/mrd-journal-d-17-00029.1

Schoch, N., Steimann, B., and Thieme, S. (2010). Migration and animal husbandry: Competing or complementary livelihood strategies. Evidence from Kyrgyzstan. *Nat. Resour. Forum* 34, 211–221. doi:10.1111/j.1477-8947.2010.01306.x

Steimann, B. (2012). "Conflicting strategies for contested resources: Pastoralists' responses to uncertainty in post-socialist rural Kyrgyzstan," in *Pastoral practices in high Asia* (Dordrecht: Springer).

Swanepoel, F., Stroebel, A., and Moyo, S. (2010). *The role of livestock in developing communities: Enhancing multifunctionality*. Johannesburg, South Africa: UJ Press.

Tessema, W. K., Ingenbleek, P. T. M., and van Trijp, H. C. M. (2014). Pastoralism, sustainability, and marketing. A review. *Agron. Sustain. Dev.* 34, 75–92. doi:10.1007/s13593-013-0167-4

Tirkaso, W., and Hailu, A. (2022). Does neighborhood matter? Spatial proximity and farmers' technical efficiency. *Agric. Econ.* 53, 374–386. doi:10.1111/agec.12702

Turner, M. D., and Williams, T. O. (2002). Livestock market dynamics and local vulnerabilities in the sahel. *World Dev.* 30, 683–705. doi:10.1016/s0305-750x(01)00133-4

Umuhoza, J., Jiapaer, G., Yin, H., Mind'je, R., Gasirabo, A., Nzabarinda, V., et al. (2021). The analysis of grassland carrying capacity and its impact factors in typical mountain areas in Central Asia-A case of Kyrgyzstan and Tajikistan. *Ecol. Indic.* 131, 108129. doi:10.1016/j.ecolind.2021.108129

Upton, M. (2004). The role of livestock in economic development and poverty reduction, PPLPI Working Paper No. 10.

Varijakshapanicker, P., Mckune, S., Miller, L., Hendrickx, S., Balehegn, M., Dahl, G. E., et al. (2019). Sustainable livestock systems to improve human health, nutrition, and economic status. *Anim. Front.* 9, 39–50. doi:10.1093/af/vfz041

Wafula, W. M., Wasonga, O. V., Koech, O. K., and Kibet, S. (2022). Factors influencing migration and settlement of pastoralists in Nairobi City, Kenya. *Pastoralism* 12, 2. doi:10.1186/s13570-021-00204-6

Wang, G. G., Wang, M. L., Wang, J. M., Yang, C., and Liu, Y. F. (2016). Characteristics and influencing factors of grass-feeding livestock breeding in China: An economic geographical perspective. *J. Geogr. Sci.* 26, 501–512. doi:10.1007/s11442-016-1282-3

Wang, Y., Yue, H., Peng, Q., He, C., Hong, S., and Bryan, B. A. (2020). Recent responses of grassland net primary productivity to climatic and anthropogenic factors in Kyrgyzstan. *Land Degrad. Dev.* 31, 2490–2506. doi:10.1002/ldr.3623

Wei, Y., and Zhen, L. (2020). The dynamics of livestock and its influencing factors on the Mongolian Plateau. *Environ. Dev.* 34, 100518. doi:10.1016/j.envdev.2020.100518

WHO (2015). *Health in 2015: From MDGs, millennium development goals to SDGs, sustainable development goals*. Geneva: WHO Press.

Wolfenson, D., and Roth, Z. (2019). Impact of heat stress on cow reproduction and fertility. *Anim. Front.* 9, 32–38. doi:10.1093/af/vfy027

World Bank (2016). Country and lending group. Available at: https://data.worldbank.org/about/country-and-lending-groups#Lower_middle_income (Accessed March 10, 2022).

World Bank (2020). Data worldbank. Available at: https://data.worldbank.org/country/kyrgyz-republic?view=chart (Accessed March 10, 2022).

Xu, Y., Zhang, Y., Chen, J., and John, R. (2019). Livestock dynamics under changing economy and climate in Mongolia. *Land Use Policy* 88, 104120. doi:10.1016/j.landusepol.2019.104120

Zeleke, F., Kassie, G. T., Haji, J., and Legesse, B. (2021). Would market sheds improve market participation and earnings of small ruminant keepers? Evidence from Ethiopia. *J. Agric. Econ.* 72, 470–485. doi:10.1111/1477-9552.12411

Zhang, M. A., Borjigin, E., and Zhang, H. (2007). Mongolian nomadic culture and ecological culture: On the ecological reconstruction in the agro-pastoral mosaic zone in Northern China. *Ecol. Econ.* 62, 19–26. doi:10.1016/j.ecolecon.2006.11.005

Zhao, X., Zhao, L., Li, Q., Chen, H., Zhou, H., Xu, S., et al. (2018). Using balance of seasonal herbage supply and demand to inform sustainable grassland management on the Qinghai-Tibetan Plateau. *Front. Agric. Sci. Eng.* 5, 1–8. doi:10.15302/j-fase-2018203