

Navigating Climate Risks in the Livestock Sector: Environmental Resources, Production Sustainability, and Food Security in Pakistan

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Abstract

Research Originality: This study offers a comprehensive empirical analysis of temperature, heat stress, and flood shocks, alongside environmental and socioeconomic factors, to analyze livestock production dynamics, sustainability, and food security in Pakistan.

Research Objectives: The study investigates the short- and long-run effects of climate stressors and adaptive resource factors on livestock output, linking production to sustainable food systems and food security.

Research Method: Annual time-series data from 1980 to 2022 were analyzed for Pakistan's livestock sector. The Autoregressive Distributed Lag model and bounds-testing approach were applied to estimate both short- and long-run relationships.

Empirical Results: Rising temperatures and heat stress significantly reduce livestock output, while floods cause short-run disruptions by damaging grazing systems and feed supply. Water availability, forest cover, and cropped land positively influence production. The error-correction coefficient indicates that approximately 68% of short-term disequilibrium adjusts toward long-run equilibrium annually.

Implications: These findings highlight the need for climate-resilient livestock management, including heat-stress mitigation, flood preparedness, water and land-use management, and crop-livestock integration, supporting Sustainable Development Goals 2 (Zero Hunger) and 13 (Climate Action) by enhancing food security and strengthening rural livelihoods in Pakistan.

Keywords:

cattle productivity; thermal stress; flood shocks; auto-regressive distributed lag model; sustainable agriculture

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INTRODUCTION

For many years, Pakistan has been persistently facing food insecurity and intensifying climate risks, with the livestock sector at the core. Agriculture accounts for almost 37% of the labor force and contributes approximately 23-24% to Pakistan's Gross Domestic Product (GDP) (Usman et al., 2023). Current national assessments estimate that roughly one-third of households in the country remain food insecure, and a considerable segment faces severe food insecurity (GOP, 2024). Climate change risk to food security refers to disruptions in food systems caused by crop and livestock losses and breakdowns in food supply chain management (Mirzabaev et al., 2023). This is associated with global warming, drought, flooding, rainfall variability, and weather extremes, particularly affecting populations exposed to food insecurity due to social marginalization, resource constraints, and poor or no access to nutritious food (O'Neill et al., 2022). Production from both large and small ruminants is strongly linked to food security, as it is a primary source of meat and milk (FAO, 2018). Climate change is widely acknowledged as a significant threat to global food systems (IPCC, 2022; FAO, 2023). At the household level, raising livestock has also been associated with a 20% rise in potential caloric nutrition (Frelat et al., 2016). Hence, due to Climate change, it fails to meet sufficient calorie and protein requirements, leading to poor nutrition, the leading cause of food insecurity (Arif et al., 2022).

Pakistan is a lower-middle-income country where livestock plays a significant role in rural livelihoods and the country's food security. It is a very climate-sensitive sector, where heat stress and temperature extremes, as well as floods, may affect production and animal-source food security. Climate change affects livestock production directly and indirectly, and livestock production is highly sensitive to it. These risks underscore the urgent need for climate adaptation policies to safeguard livestock systems and ensure resilience, in alignment with SDG 13. The direct effects of elevated temperatures and heat stress include effects on animal health, production, and reproduction. Decreases in milk and meat production due to extreme temperatures directly threaten the availability of animal-derived foods, thereby linking livestock productivity to Sustainable Development Goal 2 (Zero Hunger). Indirect effects include reduced feed and water availability, pastureland degradation, and increased disease risk, all of which affect livestock systems and sustainable production. Mitigating these problems through sustainable resource management improves climate resilience in accordance with SDG 13.

Sustainable livestock production includes practices that aim to meet the need for animal-sourced food while reducing environmental degradation. This helps the agri-food system preserve natural resources and enhance the economy, adding value to a climate-sustainable and resilient future. Additionally, it increases production, reduces costs, and improves market competition (Anuta et al., 2025). However, the sector remains highly vulnerable to climate change (FAO, 2023). Heat stress, floods, and high temperatures are leading factors hindering sustainable production and altering the supply-and-demand balance of animal-based food sources, thereby impacting food security (Taye et al., 2025).

The World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) projected that, due to global warming, livestock are increasingly exposed to higher temperatures, especially during summer, for longer periods (Habeeb et al., 2023). Nonetheless, high temperatures are driving global demand for the livestock industry and its products (Escarcha et al., 2018). Climate extremes have made cattle more vulnerable, as water access is limited and water shortages are more frequent (Mihiretu et al., 2019). Due to animal output and less frequent rainfall, fodder and forage growth are impeded, and grazing is reduced (Rojas-Downing et al., 2017). Rising temperatures mainly cause intense heat stress, constraining production. High temperatures and heat stress are associated with infectious diseases, viral spread, and many other illnesses in animals (Thornton et al., 2022). Climate change disrupts traditional livestock systems through direct and indirect effects, resulting in poor pasture growth, water scarcity, and reduced feed quality (Okoronkwo et al., 2024). Floods cause devastation through limited access to clean water, malnutrition, loss of farmland, contamination of water and soil, which washes away the land's fertility, and psychological stress on livestock, all of which threaten food security and reduce the availability of animal-based foods (Manzoor et al., 2022).

Pakistan, situated in South Asia, has experienced an extreme rise in mean annual temperature, fluctuating seasons, variations in precipitation and snowfall, and a high frequency of glacier melt and urban flooding, which undermine the country's livelihoods and food security (Shahid & Adnan, 2021). The historical and future impacts of climate change have created a mismatch between livestock production and food security, resulting in lower meat and milk production, instability in reproduction and fertility rates, and reduced utilization of farm inputs. These artificial and natural ecological hazards pose a risk of extreme poverty, making people more vulnerable and worsening their well-being (Ajani & Van der Geest, 2021).

Pakistan has long been adversely affected by climate change, with limited capacity to implement mitigation strategies and inadequate farm-level infrastructure. The International Climate Index 2026 ranked Pakistan as the fifteenth most vulnerable country because of frequent, unpredictable weather and climate patterns (Germanwatch, 2025), which are weakening development and economic growth. Likewise, the country's economy remains highly exposed to future pressures posed by climate change. Future projections indicate that by the end of 2050, the country's temperature will increase by 2-3°C (Abid et al., 2016; Dehlavi et al., 2015).

Despite growing research on climate change and agricultural productivity, key gaps remain. In particular, how livestock production in Pakistan responds to temperature, heat stress, and flood shocks remains poorly understood. Most current research focuses on rainfall variability, drought, crop production, or farmers' adaptation. They do not closely consider the impacts of temperature, heat stress, and flood shocks on livestock production. In addition, environmental and adaptation factors, such as water availability, forest area, cropland area, and inflation, have not been adequately accounted for in livestock production models. The novelty of this study lies in the simultaneous analysis of both the temperature and heat stress impacts and the flood shocks using the ARDL

approach and the incorporation of environmental and adaptive resource factors in the impacts on livestock sustainability and food security in the context of SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

Therefore, this study assesses the impacts of climate stressors and environmental and adaptive resource factors on livestock production in Pakistan in the short and long run. It delivers policy-relevant evidence to help adapt livestock management to climate change and achieve sustainable food security (SDG 2 & 13). These gaps are important because livestock productivity is directly linked to the livelihoods of the rural poor, animal-sourced foods, and national food security.

METHODS

This study uses annual time-series data to examine how climate change affects Pakistan's cattle production. The dependent variable is livestock production, and the main climate-related explanatory variables are annual mean temperature, heat stress, and flood frequency. To account for environmental and economic effects on cattle output, control variables such as water availability, forest area, cultivated land, and inflation are also included. Depending on the availability of reliable and consistent data for each selected variable, the dataset spans the years 1980 to 2022. Data are sourced from the Pakistan Economic Survey, World Development Indicators, and the Climate Change Knowledge Portal. The study utilizes the Autoregressive Distributed Lag (ARDL) method to assess both short-run and long-run correlations. The ARDL model is suitable as it facilitates the estimation of correlations among variables integrated at varying orders, specifically I (0) and I (1), but not beyond these levels. The model estimates long-term coefficients alongside short-term dynamics via an error-correction mechanism (ECM), which quantifies the rate of adjustment toward equilibrium.

This study employed an adapted model, informed by various studies, to estimate the specific effects of climate change on livestock production in Pakistan. The model was used by Atchadé & Nougbodé (2024), Dossa et al. (2023), Ismail et al. (2025), Kabubo-Mariara (2009), and Khurshid et al. (2023b)

$$\text{LnLSP}_t = \beta_0 + \beta_1 \text{LnAMT}_t + \beta_2 \text{LnINFL}_t + \beta_3 \text{LnWAV}_t + \beta_4 \text{LnHTS}_t + \beta_5 \text{LnTFA}_t + \beta_6 \text{LnCRA}_t + \beta_7 \text{FLD}_t + \mu_t \quad (1)$$

t represents a time series, μ stand for the error term. The coefficients are represented by $\beta_{1,2,3,4,5,6 \text{ and } 7}$.

The ARDL approach has recently become more widely used in empirical studies to explore the relationship between climate change and agricultural factors across several countries (Acaravci & Ozturk, 2010; Hashmi et al., 2021). ARDL thus seems appropriate for econometric models that combine level and variable data (e.g., annual mean temperature, inflation, water availability, heat stress, forest area, and cropped area).

Model 1 in ARDL and ARDL-bound arrangement:

$$\text{LSP}_t = \beta_0 + \beta_1 \sum_{j=1}^K \text{LSP}_{t-1} + \beta_2 \sum_{j=1}^K \text{AMT}_{t-1} + \beta_3 \sum_{j=1}^K \text{INFL}_{t-1} + \beta_4 \sum_{j=1}^K \text{WAV}_{t-1} + \beta_5 \sum_{j=1}^K \Delta \text{HTS}_{t-1} + \beta_6 \sum_{j=1}^K \Delta \text{TFA}_{t-1} + \beta_7 \sum_{j=1}^K \Delta \text{CRA}_{t-1} + \beta_8 \sum_{j=1}^K \Delta \text{FLD}_{t-1} + \mu_t \quad (2)$$

$$\Delta \text{LSP}_t = \beta_0 + \sum_{j=1}^K \beta_1 \text{LSP}_{t-1} + \sum_{j=1}^K \beta_2 \text{AMT}_{t-1} + \sum_{j=1}^K \beta_3 \text{INFL}_{t-1} + \sum_{j=1}^K \beta_4 \text{WAV}_{t-1} + \sum_{j=1}^K \beta_5 \text{HTS}_{t-1} + \sum_{j=1}^K \beta_6 \text{TFA}_{t-1} + \sum_{j=1}^K \beta_7 \text{CRA}_{t-1} + \sum_{j=1}^K \beta_8 \text{FLD}_{t-1} + \gamma_1 \text{AMT}_{t-1} + \gamma_2 \text{INFL}_{t-1} + \gamma_3 \text{WAV}_{t-1} + \gamma_4 \text{HTS}_{t-1} + \gamma_5 \text{TFA}_{t-1} + \gamma_6 \text{CRA}_{t-1} + \gamma_7 \text{FLD}_{t-1} + \mu_t \quad (3)$$

Table 1. Expected Relationship and Data Source

Variables & Symbols Names	Description & Data Sources	Expected Relationship
Dependent Variable		
Livestock Production (LSP)	Ln of total livestock production (Million Rupees)	
Independent Variables		
Annual Mean Temperature (AMT)	Ln of annual mean temperature(°C), (CCP)	Positive /Negative (+/-)
Heat Stress (HTS)	Ln of heat stress (WDI)	Negative (-)
Flood Occurrence (FLD) ¹	Flood occurrence is coded as a dummy variable: 1 if a flood occurred in a given year, 0 otherwise.	Positive /Negative (+/-)
Cropped Area (CRA)	Ln cropped area (million hectares), (WDI)	Positive (+)
Total Forest Area (TFA)	Ln forest area (million hectares), (WDI)	Positive (+)
Water Availability (WAV)	Ln water availability (million-acre-feet), (WDI)	Positive (+)
Inflation Rate (INFL)	Rate of inflation (consumer price index), (WDI)	Positive /Negative (+/-)

Sources: Data is compiled from various sources, ESP= Economic Survey of Pakistan, CCP =Climate Change Knowledge Portal, WDI=World Development Indicators

Table 1 presents the study variables, their definitions, expected signs, and data sources. Livestock production (LSP), expressed in logarithmic form of total livestock output, is the dependent variable. The explanatory variables comprise climatic, environmental, and macroeconomic factors. Annual mean temperature (AMT) and heat stress (HTS) are climatic stressors, with HTS expected to negatively affect livestock production, while temperature may have a non-linear or ambiguous impact depending on adaptive capacity. Flood occurrence (FLD), specified as a binary variable, is anticipated to have mixed effects due to short-run production disruptions and potential longer-term resource benefits.

Environmental variables, including cropped area (CRA), forest area (TFA), and water availability (WAV), are expected to positively influence livestock production through

¹ Historical flood events in Pakistan occurred in 1950, 1955, 1956, 1957, 1959, 1973, 1975, 1976, 1977, 1978, 19981, 1983, 1984, 1988, 1992, 1994, 1995, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2019, 2020, and 2022, 2025.

improved feed availability, grazing resources, and ecological support. Inflation (INFL) is treated as a macroeconomic control variable with an indeterminate effect, given its dual influence on production costs and overall economic conditions. Data are sourced from the World Development Indicators (WDI) and the Climate Change Portal (CCP).

RESULTS AND DISCUSSIONS

Table 2 presents the descriptive statistics. The findings show that livestock production, total forest area, and cropped area are in a similar range, but the standard deviation (Std. Dev.) of the cropped area is larger. The high Std. Dev of the cropped area indicates greater volatility than in the forest area. The mean of the dependent variable, livestock production, is 29.288, while the Std. Dev is 10.068. Among the climate proxies, heat stress has the highest mean (135.393), while the annual mean temperature (AMT) has the lowest Std. Dev.

Table 2. Descriptive Statistics

	LSP	WAV	INFL	HTS	TFA	CRA	FLD	AMT
Mean	29.288	98.618	162.041	135.393	173.904	178.074	0.6279	104.756
Median	30.116	96.766	160.856	158.650	183.57	179.945	1	104.677
Maximum	49.919	136.459	343.627	187.039	225.399	255.090	1	109.502
Minimum	11	96.421	42.844	62.066	97.909	93.224	0	99.507
Std. Dev.	10.068	6.077	58.252	42.946	39.912	48.675	0.489	2.739
Observations	43	43	43	43	43	43	43	43

Sources: Data is compiled from various sources, PES = Pakistan Economic Survey, CCP=Climate Change knowledge Portal, WDI=World Development Indicators

Table 3. Unit Root Test (ADF & PP)

Variables	ADF		PP		Decisions of Stationarity
	Level	1 st diff.	Level	1 st diff.	
LSP	-1.435	-3.798***	-1.717	-6.577***	I (0)/I(1)
FLD	-3.181***	-3.181***	-3.293***	-10.038***	I (0)/I(1)
AMT	-1.085	-1.085***	-3.167***	-15.394***	I(1)
WAV	-0.952	-0.805	0.170***	0.805	I (0)/I(1)
INFL	-4.448***	-4.448***	-3.278***	-7.278***	I (0)/I(1)
TFA	-2.444	-6.420***	-2.058	-6.423***	I(1)
CRA	-0.790	-5.425***	-0.814	-5.428***	I(1)
HTS	-1.065	-6.358***	-1.065	-6.365***	I (0)/I(1)

Source: Author's calculation. The Bartlett-Kernel method was used for ADF, and PP*, PP **, and PP *** are statistically significant at the 10%, 1%, and 5% levels, respectively.

To assess the order of integration and to justify the applicability of the ARDL bound method, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) are applied to the variables presented in Table 3. The variables are of order I(0) and I(1), or a combination of both, and none of the variables is integrated of a higher order. Hence,

based on these results, the study can now apply the ARDL technique to test long-run cointegration. We conduct the bound ARDL tests to examine whether cointegration exists among the variables. Table 4 presents the results. The F-statistic in the table is 31.99, which exceeds the critical value at the 5% significance level. As a result, we reject the null hypothesis of no cointegration and support the alternative hypothesis.

The study finds that rising temperatures, heat stress, and floods significantly reduce livestock production, while water availability, forest area, and cropland enhance livestock resilience. The empirical results indicate that climate-related stressors significantly affect livestock production in Pakistan. AMT, HTS, and FLD negatively affect livestock output, indicating that climate change poses both long-run and short-run risks to the livestock sector. In the long run, higher temperatures reduce livestock production, while heat stress weakens animal productivity by lowering feed intake, reproductive performance, milk yield, and meat output. Floods primarily cause short-run disruptions by damaging grazing areas, reducing feed availability, increasing animal mortality, and disrupting rural livestock systems. Natural resources and land-use conditions, however, positively affect livestock production, with water availability, forest area, and cropland all playing key roles in enhancing livestock resilience.

Table 4. Results of the ARDL Bound Test

Model LSP=f (AMT, HTS, FLD, TFA, CRA, WAV, INFL)						
ARDL Bound Test: F-statistics: 31.999***						
Critical Value Bounds						
Test-Statistic	Value					
T-statistics	-10.080	10%	5%	1%		
Sample Size	Lower Bound I (0)	Upper Bound I (1)	Lower Bound I(0)	Upper Bound I (1)	Lower Bound I (0)	Upper Bound I (1)
40	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
45	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
Asymptotic	1.750	2.870	2.040	3.240	2.660	4.050
t-Statistics						
Asymptotic	-1.620	-3.700	-1.950	-4.040	-2.580	-4.670
* I (0) and I (1) are respectively the stationary and non-stationary bounds.						

Sources: Results are obtained from, PES= Pakistan Economic Survey, CCP=Climate Change knowledge Portal, WDI=World Development Indicators

The empirical findings in Table 5 show that higher temperatures and heat stress reduce livestock production in Pakistan, while floods have negative short-term effects by damaging grazing lands and reducing feed availability. These results are consistent with global evidence that rising temperatures harm livestock health and productivity (Anuța, Wang & Kinay, 2025) and with modeling studies showing that heat stress significantly reduces animal performance (Delpont & Van Niekerk, 2026). The ARDL results indicate

that heat stress significantly lowers livestock production in both the short and long term, while water availability, forest areas, and cropland have positive effects (Gulalai & Nazir, 2025). Similar evidence shows that heat stress reduces cattle productivity, particularly milk yield and weight gain, in both extensive and intensive production systems (Hasan et al., 2025). Climate change also disrupts livestock physiological balance and health, increasing vulnerability to heat stress. The negative effects of floods are consistent with evidence from Pakistan showing significant short-term losses in livestock production and the need for stronger adaptation. Although these findings differ from studies reporting negative effects of water availability, forest, and cropland on livestock output (Fitton et al., 2019; Gutai et al., 2025), they support research emphasizing the importance of adequate natural resources and effective adaptive management under climate stress (Govoni et al., 2024; Bonilla-Cedrez et al., 2023).

Table 5. The Empirical Results in Long Run and Short Run

Selected model ARDL (1,0,0,0,1,1), based on Akaike Criteria					
Long Run Coefficients			Short Run Coefficients		
Variables	Coefficients	T-statistics	Variables	Coefficients	T-statistics
AMT	-0.432***	-3.851	D(TFA)	0.108***	5.634
INFL	0.090***	6.345	D(CRA)	0.019	0.523
WAV	0.121*	1.150	FLD	-0.251*	0.605
HTS	-0.043***	-2.217	COINTEQ*	-0.689***	-16.309
TFA	0.097***	4.758			
CRA	0.139***	8.454			
Adjusted R-squared	0.952				
Diagnostic tests (LM version)	0.098(0.906)				
Breusch-Godfrey test	0.891(0.352)				
Functional Form					

Source: Data is compiled from various sources: PES = Pakistan Economic Survey, CCP = Climate Change Knowledge Portal, WDI = World Development Indicators. Flood is a static variable. *, **, and *** are statistically significant at 10%, 5% and 1%, respectively.

The error-correction term indicates that livestock production tends to return to its long-run equilibrium after a short-run shock. However, continued exposure to climate stress can have lasting negative effects on productivity and food security. Thornton et al. (2022) found that rising temperatures are likely to reduce cattle production in climate-sensitive areas. Liu et al. (2024) and Hasan et al. (2025) reported similar findings, observing lower cattle productivity under heat stress. Das et al. (2016) and Habeeb et al. (2023) also showed that heat stress reduces feed intake, milk production, and fertility, making livestock less productive. Land and natural resources are important for maintaining livestock productivity. When properly managed, forest areas provide shade, forage, water, and grazing opportunities. Cropped areas after harvest can provide hay and straw, support rotational grazing, reduce feeding costs, and improve food security. Floods, meanwhile, affect livestock both directly and indirectly. Direct effects include animal deaths, forage destruction, and water contamination, while indirect effects include the

spread of infectious diseases. Rasool et al. (2020) found that floods cause major economic losses for livestock farmers, damage grazing lands, and increase livestock mortality. Floods also reduce cattle production and threaten food security (Atanga & Tankpa, 2021). Ngarava et al. (2021) reported that floods disrupt feed availability and grazing activities, creating short-term declines in livestock production.

Mirzabaev et al. (2023) emphasize that extreme climate events, particularly floods, pose serious risks to food systems and communities that depend on cattle. This supports our finding that floods have immediate and disruptive effects on animal productivity. Water availability is positively related to livestock production, highlighting its importance for animal health and productivity. Water supports digestion, thermoregulation, and milk production, especially under high temperatures. Weindl et al. (2017) emphasize the importance of water for maintaining livestock productivity during climate shocks, while Govoni et al. (2024) demonstrate that adequate water availability is essential for sustainable cattle systems. Forested areas can also strengthen livestock resilience by providing shade, improving local microclimates, and supporting grazing systems. Solomon et al. (2023) show that forest ecosystems support biodiversity and sustainable livestock production, while Das et al. (2016) highlight their role in improving resilience to climate shocks. Cultivated areas are positively related to animal productivity because they provide fodder. Tulu et al. (2023) found that agricultural by-products and improved feeding practices can increase animal productivity. Similarly, Nikzaad and Nusrathali (2023) show that integrating crop and livestock systems improves resource efficiency and productivity.

The results indicate that land use and natural resources are important for maintaining cattle productivity under climate variability. The positive effect of inflation may reflect higher nominal profits for livestock producers, as higher by-product prices can encourage farmers to increase production. However, inflation can also reduce output by increasing input costs (Omele et al., 2023). Therefore, the positive relationship found in this study may reflect specific government pricing incentives rather than greater economic efficiency. The error-correction term shows that about 68% of short-run deviations are corrected within one year, indicating that livestock production tends to return toward its long-run equilibrium after shocks (Pesaran et al., 2001). However, this adjustment does not eliminate the long-term risks of climate change. Continued exposure to high temperatures and heat stress can reduce cattle productivity (Thornton et al., 2022; Liu et al., 2024), while floods can directly disrupt livestock systems (Rasool et al., 2020; Atanga & Tankpa, 2021; Ngarava et al., 2021). The positive effects of water availability and land use are consistent with Weindl et al. (2017), Govoni et al. (2024), and Tulu et al. (2023). The mixed evidence on inflation suggests that its effects depend strongly on the economic and policy context.

CONCLUSION

This study demonstrates that climate-related stressors significantly affect livestock production in Pakistan. Rising temperatures and heat stress reduce livestock output

in the long run, while floods create short-run disruptions by damaging grazing areas, reducing feed availability, and increasing livestock vulnerability. In contrast, environmental resources such as water availability, forest area, and cropped land positively influence livestock productivity, partially offsetting the negative effects of climate stressors. The ARDL error correction mechanism suggests that the system will move back toward long-run equilibrium after short-term shocks; however, repeated climate shocks can erode the system's ability to adjust, making it more prone to long-run equilibrium instability.

The results suggest policy measures to improve livestock climate resilience. Strengthening households' adaptation capacities, such as better housing, shading, ventilation, and farmer training, along with an early warning system, emergency feedstocks, and veterinary assistance, is crucial for preparedness for floods. Incorporating livestock policies into sustainable natural resource management, including water use, forest conservation, fodder development, and crop-livestock integration (CLI), can enhance productivity and resilience. These strategies directly contribute to SDG 2 (Zero Hunger) and SDG 13 (Climate Action), and aim to safeguard livestock productivity, support rural livelihoods, and promote food security in the face of climate change.

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