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Estimating the Nexus between Climate Change and Livestock Production in Pakistan

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Abstract

This study estimated the impact of annual mean rainfall, heat stress, water availability, inflation, floods, crop and forest area on livestock production in Pakistan using time series data from 1980 to 2022. Autoregressive distributed lag (ARDL) method was employed and it was found that annual mean rainfall, heat stress, water availability, total forest and cropped areas have both long- and short-run impacts on livestock production. Among all the variables, water availability increased livestock production by 4.62%, and mean annual rainfall increased livestock production by 0.17%. In contrast, heat stress reduced livestock production by 14% in the long run and 0.19% in the short run. The short-run analysis demonstrated that floods had a devastating impact on livestock production, reducing it by 0.79%. This study recommends the need for practical and adaptive measures for resilient livestock breeds, improved rangelands, flood management, clean water access, and better varieties of crops to be used as fodder and forage for the livestock to enhance production. The government should priorities policies that support livestock production, and the development of flood mitigation infrastructure, ease access to credit, and early warning systems are important. To curb the negative impacts of climate change and improve livestock production in the long run, understanding the relationship is important. If it is not clear and scientifically proven, the measures will achieve less significance in attaining the required level of production.

Keywords: ARDL, Rainfall, Heat Stress, Floods, Livestock, Climate Change

JEL Classification: Q10, Q12, Q18, Q54, Q56, C32

1. Introduction

In the present century, climate change is no longer a myth, and it can be avoided. Climate change is an existential threat to humanity, ecosystems and biodiversity (Amoak et al., 2022) and one of the formidable challenges on the planet for the livestock sector across the world. Livestock, which refers to animals that are domesticated for several uses, are valuable resources for the agrarian and manufacturing economies (Nketsang et al., 2025). Pakistan is highly exposed to climate change and faces significant challenges in its livestock sector (Hashmi et al., 2021). Agriculture is the foremost sector globally, ensuring food, fiber, energy and income to the increasing human population. Due to the increase in food demand in the 21st century, the global food systems face several backlashes caused by climate change (Onyeneke et al., 2024). Climate change is a worldwide subject with no exception to Pakistan (Shahzad & Amjad, 2022). Thus, climate extreme events are considered to pose danger to the livestock sector, undermine its gross value addition to the gross domestic product (GDP), and threaten household food security. Sustainable livestock output production assists in alleviating poverty, guaranteeing food security, and encouraging agricultural development.

The unpredictability caused by climate change creates a massive risk to the natural and human ecosystem, which poses a threat to both developing and advanced countries (Ankrah Twumasi & Jiang, 2021). Pakistan is grappling with the heavy impacts of climate change, such as disastrous floods, droughts, and ever-changing weather patterns, leading to unfavorable livelihood conditions (Abid et al., 2016; Barón et al., 2022). Floods usually cause a shortage of clean water, a shortage of crop production and fodder, and financial constraints to manage livestock (Anitha et al., 2023). This dominant aspect of climate change in the form of heat stress caused a financial burden, hence, a loss to the livestock producers due to the decline in milk yield and its different milk components, as well as the quality and quantity of meat production and deterioration of animal health and reproductive efficiency (Sejian et al., 2016). The gross value addition of livestock production makes a substantial share in the economy, but due to the rising temperatures and extreme weather events like heavy storms and floods, it has reduced pasture availability, increasing vector-borne diseases like ticks and flies, along with damage to the water resources (Eckstein et al., 2021).

In Pakistan, the rainfall intensity and duration of annual rainfall have decreased owing to deforestation or land degradation. Many parts of the country are getting with no more than 250 (mm) rainfall per annum, which requires more improvement in farming and infrastructure for irrigation, including water channels, canals, and dams for water storage (Syed et al., 2022).Climate changes and its adverse effects are drastically felt on the livestock sector, as it is one of the largest subsectors of the agricultural sector (Hussain & Rehman, 2022). In addition, the country contributes less than 1 % of the greenhouse gases (GHGs) in the atmosphere, but is still vulnerable to the adverse effects of global warming (Syed et al., 2022). Climate change is enormous for the poor and agricultural communities, because they have meager adaptive capacities and limited means of production (Fahad & Wang, 2018). Climate distress affects livestock in four different ways, i.e., it brings changes in livestock feed grain, quality of grassland, and forage crop production. (Giridhar & Samireddypalle, 2015).Similarly, the direct effects are associated with the health, growth, and the level of reproduction of the animals (Ferreira et al., 2023). Among all the factors, such as high temperature, erratic rainfall, and droughts, heat stress has the most significant impact.

The livestock sector helps in the eradication of poverty and, in the form of gross value addition, enhances it by 5.5 trillion in 2023. The livestock sector of Pakistan included animals such as sheep, goats, cows, buffaloes, horses, camels, mules, and oxen, as stated in the Economic Survey of Pakistan (2024-2025). Pakistan recorded an increase of 0.56% growth in the livestock sector, with the growth of 4.72% in contrast to the previous year, 4.38% despite several challenges. This sector also contributes 60.84% to agriculture and 14.63% to the annual GDP of Pakistan. In the country, less than 75% of cattle are provided with essential nutrients. However, 60% of livestock lack digestible crude protein. If forage is managed in the country, approximately 50% of livestock productivity may be enhanced (Ashraf et al., 2020). Pakistan is ranked as the fifth largest milk producer, with an estimated 67 million tons of gross annual production. The rising livestock population of the country makes $950 (USD) million in the export of leather, making it the fourth largest leather apparel exporter. Dairy production, especially meat and milk production, can worsen now and in the future (Abbas, 2022).

Livestock is a critical part of Pakistan's GDP, helping to sustain rural livelihoods and reduce food insecurity. However, climate change is becoming more evident due to rising temperatures, rainfall variability, floods, heat stress, and changing access to crops and water, which cause significant losses to livestock health, productivity, and survival. Climatic changes not only disrupt water availability but also damage crop fodder, leading to increased disease prevalence and mortality rates among livestock. Despite its importance, the impacts of climate change variables on livestock production in Pakistan remain poorly measured and understood.

Therefore, the present study will help the existing literature by contributing as follows: First, the study includes livestock production as the dependent variable and adds climate change proxies, such as temperature and heat stress, along with other environmental variables in the regression analysis. This approach will provide an all-inclusive understanding of the relationship between these determinants. Secondly, using the autoregressive dependent lag econometric technique, this study employed a very long dataset of 42 years which has not yet been explored for livestock production in the context of Pakistan. Finally, given the role of livestock production, it is important to reevaluate the indirect effects of climate change on crops, forests, water, and animal yield. Our study aims to reduce this gap by directly examining the impact of climate change on livestock production in Pakistan. This study will help the Ministry of Climate Change and the Directorates of Livestock and Dairy Development with essential insights for the present and future.

The remaining part of the paper is structured as follows: the next section presents a literature review. Section 3 presents the empirical results, and section 4 details the data and methodology used in the study. The results and discussions are included in Section 4. Finally, the conclusions and policy implications are provided in section 5.

2. Literature Review

Extensive research has been undertaken at the national and international levels to understand the impact of climate change on livestock production. However, there remains a conclusive gap in the evidence on how rainfall, flood, and heat stress, along with other climate variables, affect livestock production in Pakistan. Researchers outlined various variables that affect livestock production, such as floods, lack of water, poor quality of intake of forage and fodder, high temperature, and droughts. The decline in livestock output is due to low rainfall, leading to droughts that have a massive impact on livestock production and husbandry-based livelihoods in southern Ethiopia. Livestock keepers have been dependent on the cattle in their herds for generations. Due to frequent drought, the death rate of cattle and sheep has increased in EthiopiaWako et al. (2017). Similarly, the declining trends of rainfall and alarming increase in the prolonged drought have affected livestock communities in eastern Africa and all over the globe (Osborn et al., 2018). The reduction in rainfall has caused more prolonged and frequent droughts, which have made livestock vulnerable in Tanzania (Leweri et al., 2021b).

Changes in the pattern of rainfall distribution may cause forage and water shortages that indirectly instigate changes in feed crop yields and grasslands (Kerr et al., 2022). The study of (Kassa et al., 2024) found that changes in the frequency and duration of rainfall affect the quality of forage, influencing the sustainability of livestock rangelands. Therefore, understanding this relationship helps in the formulation of adaptive management strategies for resilient livestock production under changing climatic conditions (Kassa et al., 2024; Sloat et al., 2018). In the same way, Emediegwu and Ubabukoh (2023) found that a marginal rise in the annual rainfall caused a 2.1% increase in beef production.

In contrast, Lacetera (2019) showed that variation in the level of precipitation negatively affects the quality of feed and spreads contagious animal diseases that decrease their welfare. Less rainfall seriously decreased fertility, high market prices, and poor pasture and rangelands for animals grazing that have to roam long distances and have access to pasture and fresh water, with a greater financial burden on the livestock owner to arrange feed for high-quality of milk and meat (Kargbo et al., 2023).Territorial distribution and access to green grassland and clean water are due to rainfall. Shortages of feed and water reduce livestock production and performance in the form of slow growth rates and poor reproductive performance in mature animal (Aklilu et al., 2013; Kargbo et al., 2023; Pal et al., 2024). Delayed rainfall causes a sharp decline in the population of livestock and vice versa, whereas reduced rainfall leads to population decline (Nketsang et al., 2025).

Mansoor et al. (2021) found that rainfall plays a significant role in the production of meat, milk, wool, and the weight of animals across the globe, including Pakistan. Prior studies of Hasan et al. (2024) and (Orquera-Arguero et al., 2022) has shown that rainfall is a primary determinant of feed for cattle growth. The interaction between rainfall and cattle growth provides valuable insights for refining management practices for extensive beef production. Similarly, Ateba Boyomo et al. (2024) assessed that rainfall improved growth of pasture, resulting in better crop yields and increase water availability in lakes, ponds, and rivers which directly increased the production of milk, meat, wool and other by products of animals. Likewise, Ngarava et al. (2021) examined that floods impact small ruminants such as sheep and goats. Due to heavy floods, the number of livestock deaths increased frequently.

Extensive empirical literature is available on the impact of climate change on Pakistan's agricultural sector (Awan & Yaseen, 2017; Hashmi et al., 2021; Hussain & Bangash, 2017; Syed et al., 2022; Usman et al., 2023) that examine the productivity of the agricultural sector, such as crops and food security, in Pakistan. However, this study will be different from previous studies as it will examine the extent to which mean annual rainfall, water availability, and heat stress, which are the direct effects of climate change on livestock, negatively affect livestock production in Pakistan from 1980 to 2022 through a long-run and short-run analysis.

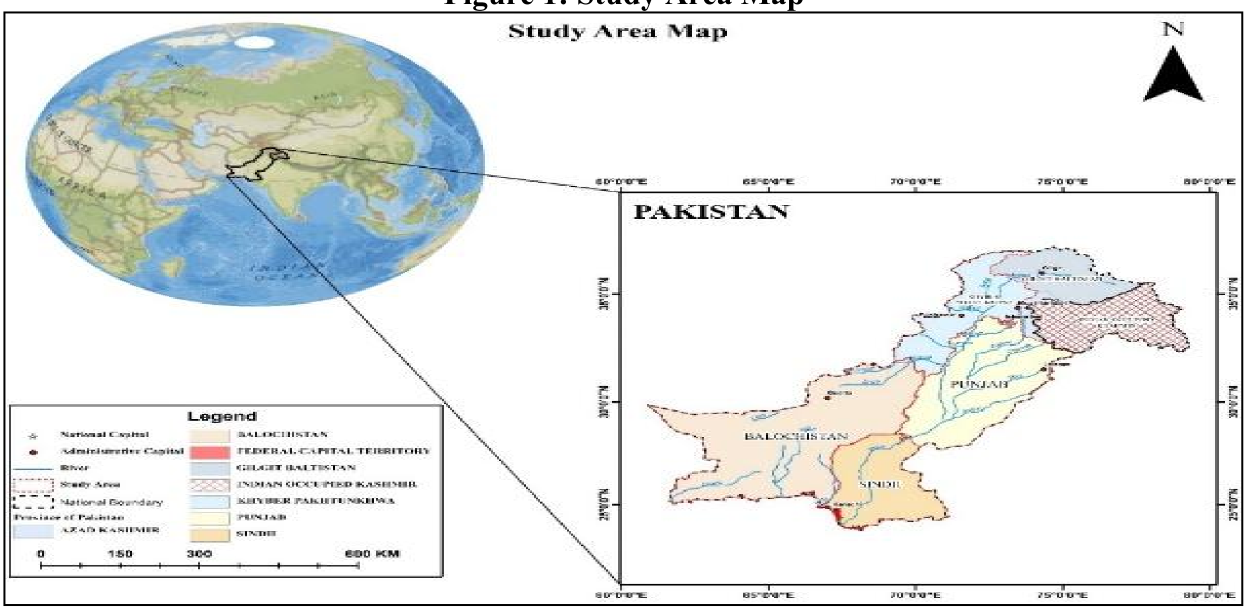
Table 1: Summary of Literature Review Regarding Climate Change and Livestock Production

Studies	Countries & Sample	Methodology	Variables
Onyeneke et al. (2023)	Nigeria (1971–2018)	ARDL	Cattle production, precipitation, mean temperature, ecological footprint, carbon footprint, grazing land, cattle livestock, agricultural land, cattle share
Khurshid et al. (2023)	Pakistan (1980-2021)	NARDL	Livestock production, temperature, precipitation, exchange rate, CO2 emissions, credit to livestock
Dey (2023)	Bangladesh (1971 - 2020)	FMOLS	Livestock production, greenhouse gas emission, floods, maximum and minimum temperatures, and precipitation
Ayanlade and Ojebisi (2019)	Guinea (1984- 2017)	CDI	Livestock production, temperature, rainfall, wind, humidity, droughts, floods, cyclones, and others
Ateba et al. (2024)	SSA (2000 - 2021).	Fixed Effect	Livestock production, temperature, precipitation, water availability, maize price, forest loss, population,
Feng et al. (2021)	China 959 herders	Hsiao's two-step	Net livestock production, temperature, precipitation, and extreme weather events
Leweri et al. (2021a)	East Africa Primary data	logit model	Livestock production, precipitation, length of rainy days, floods, droughts, and rangelands
Ali (2018)	Pakistan, (700 livestock keepers)	Multivariate probit	Livestock owned, age, experience, gender, family size, married, education, land assets, fodder area, fodder storage, climate change experiences

3. Methodology

3.1 Study Area

Figure 1: Study Area Map



The study was conducted in Pakistan. A country that lies between latitudes 24°– 37° N and longitudes 60°–77° E and is surrounded by various agroclimatic zones. The climate of the country varies from arid to semi-arid in most regions, with variations in rainfall and temperature. These differences in climate affects livestock production patterns, making Pakistan a suitable case for estimating the impacts of climate change on the livestock production.

3.2 Data and Variables

Description of the variables along with their symbols, data sources and unit of measurement is given in table below (Table 2):

Table 2 : Variables and Data Source		
Symbols	**Description & Unit of measurement**	**Data Sources**
Dependent Variable		
$LnLP_t$	Natural log of total livestock production in a year (Million Rupees)	Pakistan Economic Survey
Independent Variables		
$LnPPT_t$	Natural log of annual mean precipitation (mm)	CCP
$LnHT_t$	Natural log of heat stress	WDI
$DFLD_t$	Dummy variables assuming values of one when flood =1 and zero when flood = 0.	FFC
LnCA	Natural log of cropped area (mh)	WDI
$LnFA_t$	Natural log of forest area (mh)	WDI
$LnWA_t$	Natural log of water availability (million-acre-feet)	WDI
$LnIR_t$	Natural log of inflation rate (consumer price index, %)	WDI

Note: mh=million hectares, WDI= World Development Indicator, FFC = Federal Flood Commission, CCP = Climate Change Knowledge Portal

4. Econometric Model

4.1 Model Specification

The relationship between LP, PPT, IR, WT, HT, FA, CA and FLD was studied. The study employed the autoregressive dependent lag (ARDL) for Pakistan over the period of 1980-2022. The study will apply the ARDL-bound testing approach model introduced by (Pesaran et al., 2001) and (Pesaran & Shin, 1998). Recently, the ARDL methodology has mainly been applied in empirical studies to explore and analyze the relationship between the impact of climate change on agriculture in many countries (Hashmi et al., 2021).

$$LP_t=f(PPT, IR, WT, HT, FA, CA, FLD) \quad (1)$$

Whereas, LP_t stands for livestock production: PPT_t represent mean annual precipitation, IR_t is rate inflation (change in the consumer price index); WT_t is water availability; HT_t is heat stress; FA_t is the total forest area; CA_t the cropped area and FLD_t indicates flood a dummy variable. The parameters $\alpha_{1....7}$ is the slope coefficients, β_0 is the scalar, t is the time period and μ_t is white noise.

After the specification of equation (1), a linear relationship between the study variables is given in equation (2)

$$LP_t=\alpha+PPT_t+IR_t+WT_t+HT_t+FA_t+CA_t+FLD_t+\mu_t \quad (2)$$

After applying the linear relationship, the equation is transformed into log-linear form, and the log is applied to the equation to obtain equation (3)

$$lnLP_t=\beta_0+\beta_1 lnPPT_t+\beta_2 lnIR_t+\beta_3 lnWT_t+\beta_4 lnHTS_t+\beta_5 lnFA_t+\beta_6 lnCA_t+\beta_7 lnFLD_t+\mu_t \quad (3)$$

The equation (3) variables hold the same meaning as those of equations (1&2). This signifies the logarithmic form, while t discusses the time and μ is the random error term. The regressor of the coefficients is depicted by $\beta_{1,2,3,4,5,6,7}$.

4.2 Stationarity test

To verify the applicability of ARDL bound methods, three tests were used to assess the order of integration for the variables presented in Table 6. Table 6 clearly shows that all variables are of order I (0), I (1), or a combination of both, and none are integrated of more than I (1). Based on these results, the study will employ the ARDL technique. Since all variables are integrated of I (0) and I (1), the bound testing approach is used to determine whether the variables are cointegrated. The t-statistics form the basis for the results from the ADF, PP, and KPSS unit root tests, as shown in equations (4 and 5) below.

$$\Delta X_t=\omega_0+\omega_1 X_{t-1}+\sum_{j-k}^{p} d_j \Delta X_{t-1}+\varepsilon_1 \quad (4)$$

In the above equation (4) Δ means the initial difference operator, ω_0 depicts constant, X_t is for time series: p is the optimal lag for the dependent variable ε_1 stands for the error term.

4.3 ARDL Bound Testing Method

The ARDL method was introduced by the (Pesaran & Shin, 1998) to investigate the long-run relationship between the LP, PPT, IR, WT, HT, FA, CA and FLD . The formula for the equation is in equation 5.

$$\Delta lnLP_t = \beta_0 + \sum_{i=1}^{k}\beta_1 \Delta ln\ PPT_{t-1} + \sum_{i=1}^{k}\beta_2 \Delta lnIR_{t-1} + \sum_{i=1}^{k}\beta_3 \Delta lnWT_{t-1} + \sum_{i=1}^{k}\beta_4 \Delta lnHT_{t-1} + \sum_{i=1}^{k}\beta_5 \Delta lnFA_{t-1} + \sum_{i=1}^{k}\beta_6 \Delta CA_T + \sum_{i=1}^{k}\beta_7 \Delta FLD_t + \varphi_1 \Delta lnPPT_{t-1} + \varphi_2 \Delta lnINR_{t-1} + \varphi_3 \Delta lnWT_{t-1} + \varphi_4 \Delta lnHT_{t-1} + \varphi_5 \Delta lnFA_{t-1} + \varphi_6 \Delta CA_{t-1} + \varphi_7 \Delta FLD_{t-1} + \mu_t \quad (5)$$

The dummy variables capture the overall flood process in the time series (1980-2022), the first part of the equation represents the short run, while the second part shows the long run relationships. The F test examines the associations between LP, PPT, IR, WT, HT, FA, CA, and FLD in the long run. The parameters in Eq (5): β_1, $\beta_{2,}\beta_{3,}\beta_{4,}\beta_5\beta_{6,}\beta_7$ are the long-run elasticity coefficients of mean annual precipitation, inflation rate, water availability, heat stress, forest area, crops area, floods, and μ is the error term.

The ECM will be used to measure the short-run relationship among the variables using an error correction model based on the ARDL technique. The expression for ECM is given in equation (6)

$$\Delta LP_t = \alpha_0 + \sum_{j=o}^{p}\beta_j\ \Delta LP_{T-J} + \sum_{J=0}^{p}\gamma_j \Delta PPT_{t-j} + \sum_{j=0}^{p}\emptyset_j \Delta IR_{t-j} + \sum_{j=0}^{p}\xi_j \Delta WA_{t-j} + \sum_{j=0}^{p}\eta_j\ \Delta HT_{t-j} + \sum_{j=0}^{p}\varphi_j \Delta_j FA_{t-j} + \sum_{j=0}^{p}\psi_j \Delta CA_{t-j} + \sum_{j=0}^{p}\varpi_j FLD_t + \theta ECM_{t-1} + \mu_j \quad (6)$$

The coefficients β_j, γ_j, $\emptyset_j$, ξ_j, η_j, φ_j ,$\varpi_j$and ψ_j represented the short run dynamics of the variables in (eq: 6), while the coefficients of $\sigma_i(i=1,2,3,4,5,6,7)$ indicates long-term dynamics. θ represents the coefficients of the correction for disequilibrium.

5. Results and Discussions

5.1 Descriptive Statistics

Based on data processing for the selected variables, the maximum, minimum, mean, standard deviation, and Jarque-Bera values are shown in Table 3. The LP values range from 11.30 to 51.850, with a mean of 29.288. The PPT values range from 3.984 to 4.876, with a mean of 4.444. The IR variable has a mean of 5.019 and ranges between 3.757 and 5.839. The WT values span from 62.066 to 187.039, with a mean of 97.471. The FST values range from 97.909 to 225.399, with a mean of 173.904. The CA values range from 4.535 to 5.541, with a mean of 5.140. Lastly, the FLD variable has values of 0.000 and 1.000, with a mean of 0.627. The results of the Jarque-Bera normality test suggest that the parameters are normally distributed.

Table 3: Summary Statistics

Test	LP_t	PPT_t	IR_t	WT_t	HT_t	FST_t	CA_t	FLD_t
Mean	29.288	4.444	5.019	97.471	135.393	173.904	5.140	0.627
Median	30.376	4.500	5.080	96.755	158.650	183.577	5.192	1.000
Maximum	51.850	4.876	5.839	88.922	187.039	225.399	5.541	1.000
Minimum	11.307	3.984	3.757	92.870	62.066	97.909	4.535	0.000
Std. Dev	9.919	0.210	0.394	1.529	42.946	39.912	0.300	0.489
Jarque-Bera	0.492	1.534	13.347	0.092	5.508	5.186	1.897	7.307
Sum	1259.4	191.09	215.837	4191.26	5821.925	7477.88	221.05	27.000
Observartion	43	43	43	43	43	43	43	43

Source: Authors' calculations, for data sources

5.2 Correlation Matrix

The role of the correlation matrix is to provide a brief summary of the linear association among the variables, giving major insight into the pathway of this association. The correlation coefficient ranges between -1 & +1. The negative values indicated an inverse relationship, whereas the positive values indicated a positive relationship between the variables. Similarly, the off-diagonal shows the relationship between pairs of variables. The coefficient of 0 shows no relationship between the variables of the study. The diagonal elements in the matrix denote the correlation with itself, which must be equal to 1.

Table 4: Correlation Matrix

Variables	LP_t	FLD_t	PPT_t	WT_t	CA_t	HT	IR_t	FA_t
LP_t	1							
FLD_t	-0.075	1						
PPT_t	0.278	0.210	1					
WT_t	0.113	0.123	0.392	1				
CR_t	0.694	0.173	0.089	0.020	1			
HT	-0.441	-0.466	-0.202	-0.283	-0.011	1		
IR_t	0.652	0.187	0.415	0.426	0.198	0.073	1	
FA_t	0.692	-0.085	-0.057	-0.162	0.498	0.527	0.14	1

Source: Authors' calculations, for data sources

5.3 Unit Root Test Results

Before estimating the ARDL bound testing approach, it is important to check the stationarity of the data collected for estimation. To avoid the problem of spurious regression, a unit root test was performed. ADF (Dickey & Fuller, 1979) and nit root (Phillips & Perron, 1988). The variables shown in Table 6 indicate that the variables LP, FLD, PPT, IR and HT are stationary at level and first difference of the ADF, PP and KPSS. Meanwhile, WA is stationary at the level, and FA and CA are stationary at the first difference. *, ** and *** are statistically significant at different level of confidence 10%,1% and 5%, respectively.

Table 6: Results of Unit Root Testing

Variables	LP_t	FLD_t	PPT_t	WA	IR_t	FA_t	CA_t	HT
ADF I(0) /I(0)								
With constant I (0)	-1.435	-3.18***	-7.10***	-0.952	-4.448	-2.444	-0.790	-1.065
With constant I (1)	-3.798***	3.18***	7.10***	-0.952	-4.45***	-6.42***	-5.42***	-4.62***
PP I(0) /I(0)								
With constant I(0)	-1.717	3.29***	-7.10***	0.17***	-3.28***	-2.058	-0.814	-1.065
With constant I(1)	-6.577***	-10.04***	-20.9***	0.805	-7.28***	-6.42***	-5.42***	-6.36***
KPSS I(0) / I(0)								
With constant I (0)	0.393*	0.15*	0.11	0.163*	0.049***	0.287	0.782	0.199***
With constant I (1)	0.089***	0.05***	0.25	0.347	0.142*	0.059***	0.091***	0.156***
Decision	I(0)/I(1)	I(0)/I (1)	I(0)/I (1)	I (0)	I (0)/I (1)	I (1)	I (1)	I(0)/I (1)

Note: Barlett-Kernel was used for ADF, PPP and KPSS *, ** and *** are statistically significant at 10%,1% and 5% respectively.

5.4 Lag Selection Criteria

Table 7: Lag Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1207.326	NA	3.39e+16	60.766	61.104	60.888
1	-1005.225	313.255*	3.62e+13*	53.861	56.901*	54.960*
2	-940.883	73.993	5.30e+13	53.844	59.586	55.920
3	-860.616	60.200	8.37e+13	53.030*	61.475	56.084

Note: * Specifies lag order selected by the criterion. L.R: sequential modified L.R: test statistic

It is difficult and important in ARDL estimation to choose an accurate number of lags for the estimation. The Unrestricted Vector Autoregression (VAR) lag selection criterion is used for the optimal number of lags. Throughout the literature, the Akaike Information Criterion (AIC) (Akaike, 1974) and Schwarz Information

Criterion (SIC) (Schwarz, 1978) are mostly preferred. Following, (Özokcu & Özdemir, 2017; Xu & Lin, 2017), we choose AIC to be the optimal lag for the estimation of ARDL (see below Table 7). The AIC usually provides the best optimal results for lag selection as discussed by (Lütkepohl, 2006). The observed results below show that the model gives better results at lag 3 as compared to lag 1 and 2.

5.5 ARDL Bound Test

The calculated F-statistic value is 44.384, which exceeds the lower limit of 2.45 and the upper limit of 3.61 at 5%, confirming long-run association and co-integration between variables. The bound test value below the threshold rejects the null hypothesis and accepts the alternative hypothesis of co-integration.

Table 9: ARDL Bound Test Results

Test Statistic	Value					
F-statistics	44.3849					
T-statistics	-13.931	**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	2.353	3.599	2.797	4.211	3.8	5.643
45	2.327	3.541	2.764	4.123	3.79	5.411
Asymptotic	2.120	3.23	2.45	3.61	3.15	4.43
			t-Statistics			
Asymptotic	-2.570	-4.040	-2.860	-4.38	--3.43	-4.99

* I (0) and I (1) are respectively the stationary and non-stationary bounds.

5.6 Results of Long-Run & Short-Run Relationship

The variable of Table 10 in the model explains the impact of mean annual rainfall on livestock production. The coefficient value of PPT in the long-run dynamics is 0.176 and significant at the 10% level of significance. This value indicates that a 1% increase in rainfall also increases livestock production by 0.176% in the long term. Studies of (Ateba Boyomo et al., 2024), (Dellar et al., 2018), (Emediegwu & Ubabukoh, 2023) and (Okoro, 2023) found that rainfall positively impacts livestock production. Rainfall in the proper distribution is very significant for livestock production, particularly due to the growing yield and efficiency of green pastures and fodders. Rainfall increases dairy and milk production, hence indirectly increasing their productive yield. Growth of the animals is associated with the amount of rainfall, which is a key limiting factor for grasslands. This indicates that for optimal livestock production, rainfall is significant. In Pakistan, above-average rainfalls during the monsoon season in the leading livestock production regions may increase milk production, as studied by Crumpler et al. (2021).

The coefficient of the variable inflation, 0.063, is highly significant at 5%. The value of inflation depicts that a 1% increase in prices also raises livestock production by 0.063% in the long run. This value is very minimal in terms of the prevailing inflation. High prices usually benefit livestock producers. The income can incentivize the producer to reinvest in infrastructure and expand herd size. Higher prices lead to livestock management practices that can increase production levels. Likewise, inflation in agricultural products such as milk can positively influence private investment in the agricultural sector(Masoudi, 2016). In contrast, inflation has a positive and significant impact on developing countries (Aye & Odhiambo, 2021; Freebairn, 1981).The coefficient of water availability is 4.621 and significant. In the long run, a 1% increase in water availability increases livestock production by 4.621%. Among all the independent variables, water has the most significant impact on livestock production. Water availability increases milk production, enhances the growth of the animals, and increases the rate of reproduction. Water availability boosts the animal's metabolism, keeping them healthy and safe from diseases. Studies of (Habeeb et al., 2023) and (Tulu et al., 2024) also supports our results.

Water directly and indirectly impacts livestock production, which includes growing feed crops and processing their byproducts. The coefficient for the variable heat stress, at -0.144, is negative and highly significant. A 1% increase in HTS decreases livestock production by 14% over the long term. Heat stress also reduces milk production, thereby lowering the profitability of the farmer. Furthermore, the increased heat stress raised the risk of contagious diseases, leading to a higher mortality rate. This resulted in the early slaughter of weaker animals. Studies of Baile and Forbes (1974); Das et al. (2016); Mittal et al. (2019); Saka et al. (2021) are in line with our results. The coefficient for forest area is 0.128 and is significant at 5%. A 1% increase in forest area boosts livestock production by 12% in the long run. Forests offer numerous benefits for livestock, including the option for rotational or communal grazing that provides shelter, fodder, and green grasses when properly managed.

Table 10: Long Run Dynamics (1,1,0,0,1,1,1)

Variables	Coefficient	T-statistics	Prob
PPT	0.176	1.899	0.080
IR	0.0637	7.210	0.000
WA	4.621	3.401	0.001
HT	-0.144	-3.524	0.001
FA	0.128	9.342	0.000
CA	0.249	6.494	0.000
Normality Test	0.034		
	(0.982)		
Breusch-Godfrey Test	0.239		
	(0.788)		
Heteroskedasticity	1.142		
(Breusch- Pagan-Godfrey)	0.366		

*Notes: *, ** and *** are statistically significant at 10,1 and 5%, respectively.*

Study of Pandey et al. (2003) have also made similar recommendations that in developing countries, forests provide various kinds of feeds and plants that boost milk and meat production. Crops have a positive and significant effect on livestock output, with a long-term coefficient of 0.249. A 1% increase in crop production leads to a 24% increase in livestock output. Crops like legumes, root crops, forage, grains, millet, and jowar, with the addition of crop residues, are easily digestible by the animals. These crops usually provide adequate nutrition, which helps in weight gain, production, and reproduction (Mengistu et al., 2016; Shukla et al., 2019). The empirical data indicate a short-term relationship among the variables. The short-term dynamics show that WT has an insignificant connection with LP in the short run. Farmers and livestock keepers manage water through temporary storage methods, such as rainwater harvesting, as a short-term solution. Some large ruminants may also have the ability to store water inside their bodies temporarily. Heat stress also negatively impacts LP in the short run, with a 1% decrease resulting in a -0.19% change in LP. Heat stress has both significant and harmful effects on animals in both the short and long term. According to a study by Thornton et al. (2022), Heat stress can affect body weight, milk production, and fertility rates. Specifically, in the short term, animals' well-being is negatively impacted by heat stress. The effects of CA provide both short-term and long-term benefits for livestock production. A 1% increase in CA raises LP by 0.05% in the short term. Crop growth may take time, and the harvest period depends on the type of crops.

Crops serve as an immediate source of feed and are also stored as silage for animals. Flooding is seasonal and can result from glacier melting or monsoon rainfall. Floods have a negative and destructive short-term impact on livestock production, while the implications are extended for years. Unlike crops, livestock can be moved; farmers can easily relocate their animals to a nearby safe zone. PPT, used as a proxy for rainfall, has a positive and statistically significant short-term effect on livestock production. Specifically, a 1% increase in rainfall leads to a 0.196% increase in livestock yield. Rainfall availability has a massive impact on the spatial distribution on the pasture and water for cattle (Aklilu et al., 2013). The outcomes of the short-run estimates provided an error correction mechanism (ECM) that explains the cointegration relationship between variables. ECM value is negative and significant at a 5% level, depicting the disequilibrium from the shock of the previous year that covers the long run in the current year by 0.704%. The value of the ECM explains the degree of adjustment of the selected variables per year to achieve the long-run equilibrium. Clearly observed from Table 10, the ECM value specifies that the change in livestock production from the short run to the long run would be corrected by 70% yearly.

Table 11: Short Run Dynamics (1,1,0,0,1,1)

Variables	Coefficients	T-statistics	Prob
D(WA)	0.0315	0.848	0.402
D(HT)	-0.191	-8.085	0.000
D(CA)	0.049	1.977	0.055
FLD	-0.799	-0.270	0.788
D(PPT)	0.196	10.361	0.000
COINTEQ*	-0.704	19.364	0.000

Notes: *, ** and *** are statistically significant at 10,1 and 5%, respectively.

5.7. ARDL Diagnostic tests

Recursive regression residuals, including the cumulative sum (CUSUM) and cumulative sum of square (CUSUMsq) are used for model reliability, as proposed by Brown et al. (1975). If the statistical line falls inside the critical boundaries in the CUSUM at a significance level of 5%, the model shows stability. This test also examined whether the estimated coefficient of the ARDL model ensures the model's reliability, as studied by Huang et al. (2011); Ploberger and Krämer (1992); Tinoco-Zermeno et al. (2014); Westerlund (2005). The figures below (2 and 3) show that the data collected for the variables are reliable. Furthermore, additional diagnostic tests were applied to confirm the ARDL model reliability, with acceptable outcomes. These diagnostic tests include the Breusch-Godfrey serial correlation LM test and the heteroskedasticity test depicted in Table 10.

Figure 2 CUSUM

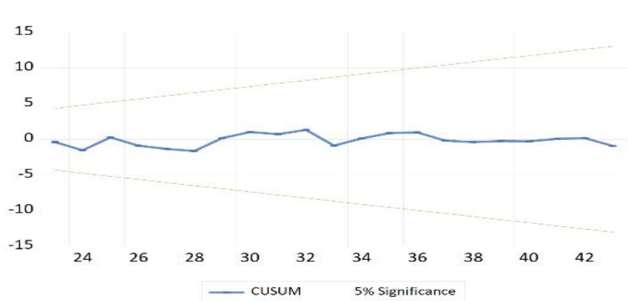


Figure 3 CUSUM SQR

Sources: Authors' own computations for cumulative sum (CUSUM) and cumulative sum of square (CUM SQR)

6. Conclusion and Policy Implications

Climate change threatens livestock production because natural pastures, on which most livestock owners depend for feeding their animals, are deteriorating in quality and quantity. In this study, we examined the relationships between livestock production and factors such as annual mean precipitation, floods, heat stress, water availability, crop area, and forest area in Pakistan from 1980 to 2022. We conducted ADF, PP, and KPSS unit root tests on all selected variables before applying the Autoregressive Distributed Lag (ARDL) bounds test to analyze both short-term and long-term correlations. The results indicated that precipitation has a significant positive impact in the long run, along with a short-term relationship.

Rainfall plays a vital role in livestock production by ensuring water availability, which promotes the growth of fodder and grasslands. This supports milk production and yields other livestock byproducts like wool from sheep. Adequate rainfall enhances the growth of grasses and plants in grazing areas, providing nutritious feed for animals and maintaining rangeland quality. Additionally, rainfall helps reduce heat stress by protecting the environment and prevents the spread of certain diseases by washing away pathogens. It also aids manure decomposition, which boosts soil fertility for fodder crops and reforestation. Overall, rainfall is essential for maintaining livestock health, productivity, and the economic stability of farming communities, both directly and indirectly influencing livestock production. The impact of floods on livestock has a negative but insignificant relationship in the short term, as floods can lead to animal deaths and the spread of diseases.

The above study emphasizes the need to provide an overall opportunity to design forward-looking policies, such as identifying suitable breeds and genetics, drought-resistant feeds, and incorporating adaptation and mitigation into national and provincial climate and livestock policies. Stabilizing prices is crucial for livestock production to boost dairy and meat output. Additionally, access to clean water resources, early warning systems, and raising awareness among farmers about climate change should be made mandatory. To ensure sustainable livestock production, indigenous practices must be promoted. This will help livestock farmers avoid environmental degradation, improve accessibility, and gain experience, leading to increased production and, ultimately, boosting the nation's GDP.

However, this study has certain limitations. It is a purely macro-level analysis that cannot highlight the micro-level impacts of climate change on livestock production. Future studies in the country should focus on district or provincial levels. This study was limited to annual mean precipitation, heat stress, and floods. Similar research should incorporate additional climate change proxies, such as CO2 and annual mean temperature, to better understand their effects on livestock production. Furthermore, techniques like wavelet econometrics could be applied for more in-depth analysis of the relationship between climate change and livestock production.

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