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Climate-Smart Adaptation Among Livestock Farmers: Determinants and Sustainability in Northwestern Pakistan

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Abstract
Climate change is increasing rainfall variability, high-temperature events, and heat stress, putting livestock productivity and the livelihoods of livestock-dependent communities at risk. Therefore, climate-resilient livestock farming is significant for enhancing food security and promoting social, environmental, and economic sustainability. The present study aims to identify the key determinants of farmers' adoption of various climate-smart livestock adaptation strategies and to assess the effectiveness of these strategies in the northwestern districts of Khyber Pakhtunkhwa, Pakistan. The research employed a quantitative cross-sectional survey of 399 livestock keepers. Six major adaptation strategies were investigated: communal grazing, rotational grazing, herd size reduction, efficient water practices, heat-tolerant breeds, and use of drought-resistant plants. The Multivariate Probit (MVP) model was employed to estimate the factors that significantly influence climate change adaptation strategies. At the same time, the Weighted Average Index (WAI) was used to rank the perceived effectiveness of these strategies. The estimated Multivariate Probit results showed that all the adaptation strategies were significantly influenced by household monthly income, the number of labourers, rainfall variability, and occupation. In contrast, a lack of livestock farming experience and limited access to climate change information increase farmers' vulnerability. Weighted Average Index results explicitly ranked herd size reduction as the most effective adaptation strategy. All six adaptation strategies significantly contribute to social, environmental, and economic sustainability; however, due to limited information and weak extension service, there are hindrances to fully benefiting the livestock farmers. The results also show that livestock farmers must prioritise and adopt an integrated approach as a key adaptation strategy towards climate anomalies. Continuing learning through capacity-building workshops and seeking help from other farmers is essential for effective climate change adaptation. The study's findings will also help policymakers develop appropriate policies and invest in adaptation strategies that enhance food security and sustainability.

Keywords: Sustainability, Climate change, Livestock farmers, Adaptation strategies, Northwestern Districts, Pakistan, Multivariate Probit model
JEL classification: Q01, Q10, Q15, Q18, Q54

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1. Introduction

Out of the 17 Sustainable Development Goals (SDGs) established by the United Nations (UN), the second goal is Zero Hunger (SDG 2). In 2024, approximately 8.2 per cent of the global population faced chronic hunger, while about 28 percent, nearly 2.3 billion people, were severely food insecure.[4]The growing threat of climate change worsens global food insecurity. Furthermore, the threat of climate change primarily impacts the livestock sector (Behmanesh et al., 2025), causing lower pasture growth, feed shortages, and heat stress, which significantly endangers its productivity and, consequently, global food security[5].

The agricultural sector, particularly livestock, crops, and fisheries, is considered the backbone of developing countries (Zafeiriou & Azam, 2017). Among all these three subsectors of agriculture, livestock production is the most vital component for the global agricultural sector, which reduces poverty and food insecurity (Shukla et al., 2019). Livestock are a source of food and provide dietary nutrients that support overall well-being and diet (Bonilla-Cedrez et al., 2023). The demand for agricultural products is also increasing tremendously (Soumya et al., 2022), and it contributes to health, economies, and cultural development, all of which are linked to the Sustainable Development Goals (SDGs). The livestock sector has a potential to contribute to SDG 8.4 (decoupling economic growth from environmental degradation), SDG 12.1 (sustainable consumption and patterns of production), SDG 13.1 (strengthening resilience and adaptive capacity), SDG 13.2 (the integration of climate change measures in national policies) and SDG 13 (promoting mechanisms for raising the capacity of effective climate change-related planning and management) by improving the resources, supporting production and consumption patterns.

Climate change in any form, such as frequent weather extremes, irregular precipitation, and high temperatures, floods, and droughts, decreases the quality of livestock production, outbursts of diseases and pests, sharp decline in forage quality and quantity (Ayal & Leal Filho, 2017) and high mortality rates is thus reducing the sustainable development of the agricultural sector (Birkmann et al., 2022; Koo et al., 2019). The effects of climate change not only reduce the livestock production but also affect the producer and consumer (Rojas-Downing et al., 2017).

[4] https://unstats.un.org
[5] https://www.who.int

That ultimately hinders the attainment of SDG 2 (zero hunger). While climate change and its risks are felt widely, they hit socioeconomic groups with inadequate means to adapt the hardest, predominantly low-income and marginalized communities (Asfaw et al., 2021).

As a country intensely susceptible to climate change, Pakistan is ranked as the 8th most vulnerable country globally (Eckstein et al., 2021). According to (United Nations Office for the Coordination of Humanitarian Affairs, 2025), almost 33 districts are at risk due to monsoon-induced floods, which account for 21% of the country's total population. Pakistan faced a challenging 2022, marked by severe droughts and floods, which wreaked havoc on the country, resulting in countless deaths and loss of livelihoods, with estimated economic losses totaling about $15.2 billion (World Bank, 2022). The country also faces an annual mean temperature rise and excessive heat stress of approximately 0.63 °C[6] (Saleem et al., 2021). Despite the ongoing growth of Pakistan's industrial sector, agriculture remains an inseparable component of the economy, contributing to poverty reduction and job creation. Livestock contributes over 60% to Pakistan's agricultural GDP. Livestock supports almost 8 million HHs, where 40% of their income is derived. Livestock also plays a positive role in the external sector. It adds 2.9% to total exports through trade in meat, animal-based products, and live animals. The efficiency of livestock production is at risk due to high temperatures and heat stress (Gulalai & Nazir, 2025) , floods, drought, and variability in rainfall (Ali & Mujahid, 2024; Bacha et al., 2021). Consequently, a large body of literature and worldwide organizations and agencies are suggesting the most resilient adaptation strategies for vulnerable (Ayal & Leal Filho, 2017).

Several policies and adaptation strategies are implemented to mitigate the effects of climate change on livestock and yield. Adaptation refers to “the adjustment of natural or human systems to respond to actual or expected climate stimuli, and their negative implications that reduce or diminish beneficial opportunities. However, active adaptation strategies are expensive for mitigation” (IPCC, 2014). HHs, groups, or individual communities are essential for encouraging the adaptation process (Simane et al., 2016). Adaptation strategies towards climate change ensure sustainability (Zenda, 2025). Thereafter, a comprehensive understanding of the household

[6] World Economic Forum, “Record-breaking heat wave strains 'limits of human survivability' in India and Pakistan,” WEF, May 9, 2022, last accessed September 4, 2022, https://www.weforum.org/agenda/2022/05/record-breaking-heatwaves-limit-human-survivability-india-pakista

determinants towards climate change is required. Essentially, adaptation strategies are considered and planned to boost livestock yield and help farming communities achieve resilience (Alemayehu et al., 2025; Godde et al., 2021; Mahato, 2014; Thomas et al., 2021). Agricultural communities must consider autonomous adaptation practices to mitigate the potential vulnerabilities posed by a changing climate (Khan et al., 2021).

Several adaptation strategies have been identified in the literature, including the use of drought-resistant plants, reducing the number of livestock categories, communal and rotational grazing, heat-tolerant breeding, and efficient water practices. (Abazinab et al., 2022; Boliko, 2019; Mulwa et al., 2017; Mwinkom et al., 2021; Naazie et al., 2024; Naess, 2013; Sharma & Ravindranath, 2019; Takele et al., 2019). Research has been conducted in different provinces, districts, and agro-pastoralist regions of Pakistan (Abbas et al., 2024; Ahmad et al., 2024; Habib et al., 2016; Hussain & Rehman, 2022; Usman et al., 2023). Earlier findings resulted that various biophysical and socioeconomic as well as demographic factors impact livestock farmers' choice of adaptation (Adaawen, 2021). Age, gender, livestock ownership, off-farm income, and access to loans are key variables (Ayal & Mamo, 2024; Chemeda et al., 2023; Debisa et al., 2025). Adaptation strategies vary by region, and area-specific studies are a vital approach. Northwest Pakistan has been ignored due to the focus on crops or mixed cropping, with insufficient information on HH choices for various adaptation strategies. Moreover, focus on a location-specific approach by identifying adaptation strategies across distinct agroecological zones in the KP region, including both lowland and highland settings. Consequently, the present research aims to explore farmers’ adaptation measures and the factors influencing them within the distinct agroecological context of the KP.

These gaps led to the aim of the current study to identify and evaluate the major adaptation strategies and the HHs level of factors shaping their choice towards adaptation. The key question addressed here is which determinants govern HHs' preferences for adaptation strategies when dealing with the climate vulnerabilities of their livestock. Despite the pivotal role of animals in Pakistan’s economy and the country's susceptibility to climate change, there is limited knowledge of the specific adaptation strategies of livestock farmers in the Northwestern region. KP is purposively selected as a study area due to various reasons. KP lies in the northwestern part of Pakistan. This region of the country is mostly vulnerable to floods, droughts, rainfall variation, and high temperature rises (Nizami et al., 2020). The study area encompasses diverse agro-climatic zones, from dry to hot and humid lowlands to forested highlands, and the majority of the HHs raise livestock and earn their livelihood from it (GOKP, Pakhtunkhwa, 2022)[7]. Third, most studies conducted in Pakistan focus on crop farming and its adaptation strategies. There remains a gap in empirical research on HH determinants and climate-smart livestock farming in KP, particularly in the wake of the heavy impacts of floods from 2010 to 2022, when climate perceptions are consistently high, and people are at risk (Bacha et al., 2021). Focusing on this province, it will address both sectoral and geographical gaps by evaluating the impacts of climate change on the most vulnerable sectors in KP and demonstrating adaptation across SDGs 2, 6, 12, and 13. This study provides sufficient knowledge to fill the gap through quantitative analysis using a cross-sectional survey, which delivers evidence-based recommendations for policymakers and practitioners. These findings will help inform evidence-based policies for achieving SDG-2 (Zero Hunger) and SDG-13 (Climate Action). Although studies have focused on the determinants of climate change adaptation strategies, sustainable livestock farming in an integrated manner remains underexplored. Thus, this study frames adaptation strategies within the pillars of sustainability, demonstrating how HH-level responses to climate change advance progress toward SDGs 2, 8, 12, and 13. Similarly, many adaptation strategies typically adopt one strategy at a time, thereby ignoring interrelated strategies, leading to bias that overlooks livestock farmers' choices. Likewise, most importantly, climate-smart agricultural and SDG-oriented research mainly focused on the role of adaptation towards environmental, social, and economic sustainability.

1.1 Theoretical Framework of the Study

Following (Debisa et al., 2025) the current study is accurately grounded on two complementary theoretical perspectives: the theory of adaptation and the theory of utility maximization. The theory of adaptation viewed the livestock farmer as a social actor whose adaptive capacity is shaped by access to resources, information, and institutions, as well as sensitivity and exposure to climate risk (Smit & Wandel, 2006). In line with this framework, age, livestock farming experiences, HHs' income, family size, gender, education, and occupation, combined with

[7] Government of Khyber Pakhtunkhwa

climate risk perception (rainfall variability, increase in temperature, and drought), are the key indicators of adaptive capacity. The socioeconomic and institutional characteristics of livestock keepers are also indicators of adaptive capacity. All six adaptation strategies: rotational grazing, communal grazing, herd size reduction, efficient water practices, using drought-resistant plants, and heat-tolerant breeds are major adaptive strategies in the face of climate change.

This study also used the theory of maximization (Fisher-Vanden et al., 2011) that provides a presence for conceptualizing climate change adaptation decisions. Utility maximization theory explains how livestock keepers compare the expected costs and benefits of each individual strategy and choose the strategy that maximizes their utility. However, in this context, the farmers are risk-averse. They compare the utility derived from adopting a strategy that can reduce losses, yield more, or improve access to resources used for livestock, with the cost associated with the adaptation strategy and the expected utility from not adopting a specific strategy. The integration of both the theory of adaptation and the theory of utility maximization assumes that adaptive capacity (who can adapt) and decision-making (how they adapt) both determine the pattern of adaptation. Thus, the use of the MVP technique is justified in the literature, as it determines each adaptation strategy and captures the correlations among strategies that arise from joint utility maximization theory. Finally, linking all the adaptation strategies to social, environmental, and economic dimensions of sustainability and to SDGs, the study attempts to find the HH decision towards the adaptation within the broader framework of resilient and sustainable livestock farming.

1.2 Adaptation strategies and their association with the socio-economic and environmental sustainability framework

Schneider and Tarawali (2021) researched that SDGs goals set by the United Nations (UN) that affect the livestock are SDGs (1, 2, 3, 5, 8, 12, 13, 15, and 17). Due climate change, adoption of climate-resilient strategies are important for sustainable livestock farming (Fushai et al., 2025).The current study is just limited to goal 2, 6,12,13 and 15.

Table 1: Adaptation Strategies and Sustainability

Adaptation Strategies adopted by Livestock farmers	Social Sustainability	Environmental Sustainability	Economic Sustainability	Linked SDGs
Rotational grazing[8]	Supports communal land	Reduce overgrazing of rangelands and pasture, and increase drought resilience.	Reduce labor cost and increase revenue	SDG 15.b & 13.b
Communal grazing	helps community networks	Better utilization of degraded pasture	Reduce the economic burden of feed and fodder	SDG 2.3& 8.4
Heat-tolerant breed	Reduce food insecurity	Adoption in harsh weather	High production of milk and meat	SDG 2.1& 12.1
Herd size Reduction	Strengthen HH stability	Lower grazing pressure and management	Stabilize the income of pastoralists	SDG 2.4, 12.2 & 13.1
Efficient water practices	Accessible HH	Conservation of water resources	Better use and management of scarce water /clean water	SDG 6.1& 13.4
Use of drought-resistant plants	A source of feed during climate-induced threats	Helps to improve soil and pasture	Forage and fodder availability	SDG 2.1 & 13.2

Source: Authors' compilation based on field survey data (2024) and SDGs

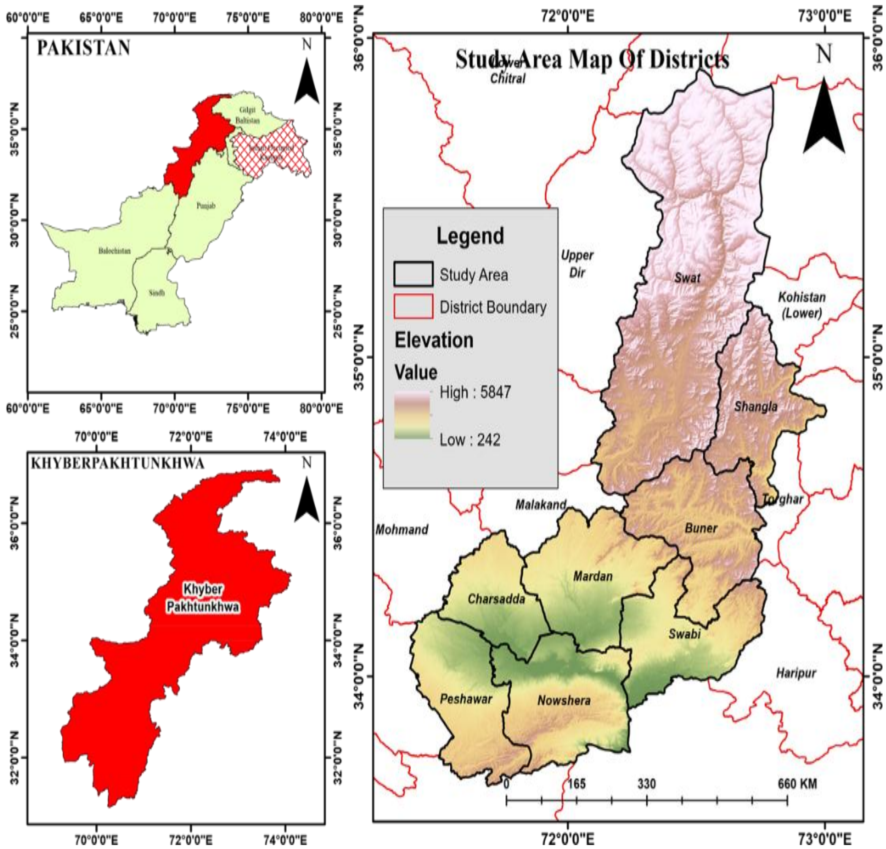
2 Material and Methods

2.1 Study area

This research was undertaken in KP, a province in Pakistan. The study area is diverse, comprising rocky, dry, and hot areas with a high rise in temperature, typically in the south (Ali et al., 2018), along with greener, cooler areas with dense forest cover in the north, as well as low-lying plains. The snow-covered mountains are most visible in winter (December – April) and experience a cool breeze in summer (May - September). KP is located in the mid-latitude region of the globe and is divided into four agro-climatic zones based on rainfall, climate, temperature, altitude, and topography (Gul et al., 2019; Nizami et al., 2020). KP is recognized as a critical province for Pakistan's agricultural sector, highlighting its importance given the interaction between climate variability and agricultural dependency (Arif & Mahsud, 2024).

[8] https://www.climatehubs.usda.gov/hubs/international/topic/rotational-grazing-climate-resilience

Figure 1: Study Area



Source: Authors own using Arc GIS

2.3 Research Design

A cross-sectional HH survey was used to collect data, focusing on livestock farmers' adaptation to a changing climate and the factors that influence their adaptation decisions. A structured, closed-ended questionnaire HH survey was administered, and primary data related to the study's objectives were collected among livestock keepers following (Dhoke et al., 2021; Marie et al., 2020; Usman et al., 2023; Zvobgo et al., 2023). The MVP model helps to examine the simultaneous adoption of more than one interconnected climate change adaptation strategy, surpassing the binary models usually applied in earlier literature(Dawid & Boka, 2025; Debisa et al., 2025). Thus, this research selects the MVP model, which is suitable for simultaneously analyzing the relationship between the independent variables and each dependent variable, while allowing for correlations among unobserved factors (Anik et al., 2021; Esfandiari et al., 2020; Purwanti et al., 2022).

2.4 Sampling Technique and Population Size

Throughout the province, significant variations and severe weather conditions occur. Owing to catastrophic events, changes in temperature, varying precipitation, shifts in weather patterns, glacial melting, and a decline in biodiversity, the people and society were severely impacted. Out of 38 districts, eight districts, Shangla, Buner, Swat, Mardan, Nowshera, Charsadda, Swabi, and Peshawar have been purposively chosen based on the sensitivity and high impact of climate extremes, such as floods, landslides, droughts, GLOF risks, and multiple hazards. These areas are densely populated with livestock, including cattle, sheep, cows, and goats (GOKP, 2023) [9] For the selected districts, data for the livestock keepers were sourced from (Pakistan Bureau of Statistics, 2021). The total number of livestock holders in the study area was 186628. Following proportional sampling, a sample size at a 95% confidence level with a 5% margin of error has been applied, and livestock keepers from vulnerable districts have been selected. (Yamane, 1973) was employed to calculate the study sample size: $n = N/1 + (N)e^2$

Where N = size of the population, n = sample size, and e = margin of error. The desired sample size is n=399. The respondents were selected randomly from the HHs. Following (Kish, 1965) respondent in each district, such as Charsadda (97), Shangla (16), Swat (37), Nowshera (24), Buner (18), Peshawar (82), Mardan (72) and Swabi (53) were selected. The background information and characteristics of livestock keepers are given in Table 2. In the study, dependent variables were communal grazing, rotational grazing, efficient water practices, heat tolerant breeds, reducing the number of livestock, and supplemental feeding with local resources were regressed against the independent variables; gender of the respondent, age, level of education, livestock farming experience, monthly income, years stayed in the area, family size, increase in temperature, variation in rainfall, drought events, labors engage and mode of climate change.

Table 1 : Variables Description

Variable	Mean	SD	Variables Descriptions
Dependent variables			
Rotational grazing	.333	.471	Categorical (Yes=1, No=0) .
Communal grazing	.526	.499	Categorical (Yes=1, No=0)
Heat-tolerant breed	.531	.499	Categorical (Yes=1, No=0)
Herd size reduction	.814	.389	Categorical (Yes=1, No=0)
Drought-resistant plants	.611	.488	Categorical (Yes=1, No=0)

[9] Livestock and Dairy Department

Efficient water practices	.428	.495	Categorical (Yes=1, No=0) .
Independent Variables			
Mode of climate change information	2.315	1.246	Categorical (1= Electronic media= Print media= Fellow framers 4=Other)
Livestock farming experience	2.471	1.375	Categorical variable (1=less than 20 years, 2=20-30 years=30-40 years, 4=More than 40 years)
Gender	1.125	.331	Categorical (1=Male, 2=Female)
Family Size	1.293	.455	Categorical (1= Joint family, 2= Nuclear family)
Age	2.776	1.30	Categorical (1= 20-30,2=30-40, 3=40-50, 4=50-60, 5=Above 60)
Number of laborers	.872	.908	Categorical (1=Less than 10, 2= 11-20, 3= Above 20)
Years stayed in the area	4.072	1.32	Categorical (1=10 years and below, 2=11-20, 3=21-30, 4=31-40, 5=Above 40 years)
Education	3.188	1.135	categorical (1=Illiterate, 2=Primary school, 3=High school, 4=Tertiary education)
Occupation	3.390	1.908	Categorical (1= Farmer, 2=Daily wager, 3= Pensioner, 4 = Businessman, 5= Government employee, 6= Private sector employee)
Increase in temperature	2.576	.689	Categorical (0: No increase, 1: Less increase, 2: Medium increase, and 3: High increase)
Variation in Rainfall	1.914	.991	Categorical (0: No increase, 1: Less increase, 2: Medium increase, and 3: High increase)
Droughts	1.601	.991	Categorical (0: No increase, 1: less increase, 2: Medium increase, and 3: High increase)
Labors engage	.872	1.009	Categorical (1: Less than 10, 2: 11-20, 3: above 20)
Total Monthly Income (Rs)	3.218	1.743	Categorical (1:11000-20000, 2: 21000-30000, 3:31000-40000, 4: Above 40000)

Source: Estimated, Survey results (2024)

3 Data Analysis Techniques

3.1 Assessing Adaptation Strategies

To analyze the effects of climate change, agriculturalists frequently employ a mix of adaptation strategies rather than rely on a single predefined method, confirming the substitutability of all substitutes (Adamseged & Kebede, 2023). The adaptation strategies farmers practice are not comparable, as their current strategies influence future adaptation decisions. The dependent variable in the present context comprises multiple binary outcomes, reflecting the non-mutually exclusive nature of the adaptation strategies preferred by the livestock keepers. MVP may overcome the limitations of other techniques by assuming mutually exclusive adaptation, enabling the simultaneous analysis of multiple strategies adopted by farmers. This technique extends research opportunities in climate change adaptation strategies by leveraging the mutually exclusive alternatives (MAI) assumption of MVP (Debisa et al., 2025). This model helps measure the observed and hidden impacts of several independent variables on dependent variables simultaneously (GC & Yeo, 2020; Kassie et al., 2013). The MVP is a powerful technique that captures the interdependencies among all the strategies employed by the livestock keepers. The technique has been broadly used in the literature for adaptation (Aidoo et al., 2021; Ali et al., 2025; Anik et al., 2021; Gemeda et al., 2023). Thus, to better examine socioeconomic variables that affect climate change adaptation strategies, MVP is appropriate (Takele et al., 2019), particularly when the farmer adopts more than one strategy, such as supplemental feeding with local resources, use of drought-resistant plants, reducing the number of livestock, preferring heat-tolerant breeds, traditional water practices, and rotational and communal grazing. Prior literature (Ali et al., 2025; GC & Yeo, 2020; Ojo & Baiyegunhi, 2018) has used it in this context. Hence, the use of MVP is accepted due to its ability to facilitate simultaneous decision-making (Ali et al., 2025). For the present study, the quantitative data were collected by surveying the livestock keepers and analyzed with the help of Stata, which has both the combination of discrete and continuous variables, as done by (Lesaffre & Molenberghs, 1991). The present study uses the equation below to evaluate the socio-economic variables that determine the choice of climate change adaptation strategies:

$$Z_i = 1 \text{ if } Y'\beta_i + \epsilon_i > 0$$
$$Z_i = 0 \text{ if } \beta_i + \epsilon_i \leq 0, i = 1,2,3,4,5, \ldots, n \quad (1)$$

In equation (2) Z_i denotes vector of predicted variables (strategies adopted by livestock keepers), Y'as a matrix of independent variables, β_i a vector of coefficients, ϵ_i is a random error term, and n is the number of factors with zero means and constant variance.

3.2 The Effectiveness of Climate Change Adaptation

To assess the significance of climate change adaptation strategies in the selected districts of KP, a list of 6 strategies was developed using a 3-point Likert scale. HH were asked to rank the six adaptation strategies, with 0 indicating not effective, 1 indicating moderately effective, and 2 indicating very effective. The rank of these climate change adaptations was evaluated using the Weighted Average Index (WAI) described in equation 3 from the earlier literature by (Masud et al., 2017; Salman et al., 2021; Williams et al., 2019).

$$WAI = \frac{\sum F_i W_i}{\sum F_i} \quad (2)$$

In this context, F = Frequency, W = Weighted individual score, I = score (0 = not effective, 1 = moderately effective, and 2 = very effective).

4 Results and Discussion

4.1 Socio-demographic characteristics of the respondent

Socio-economic determinants influence farmers' choice of adaptations (Islam & Paul, 2018). The socio-demographic features of the sampled respondents showed that younger respondents aged 20-30 years accounted for 18.8%, while those aged 30-40 years accounted for 29.3%. Respondents aged 60 or older represent 13.5%. Regarding HH gender, 87.5% of respondents were male, and 12.5% were female. The study also indicated that most HHs (58.9%) have completed tertiary education. About 31.3% of participants were pure livestock farmers, while the remaining 69% engaged in additional occupations such as daily wage work, business, or employment with the government or private sector. Residential tenures varied from 10 to over 40 years. Approximately 8.5% had lived in the area for 10 years or more, and 59.6% had resided there for more than 40 years. The total monthly income of participating farmers earning more than Rs. 60000 was 43.6%, while the smallest group, earning less than Rs. 30000, accounted for 30.1%. The family structure data showed that 70.7% lived in joint families, while 29.3% belonged to nuclear families.

4.2 Determinants of climate change adaptation choices among livestock farmers

To protect livestock from climate change vulnerability, the MVP model identified the determinants that shape the adaptation strategies adopted by farming communities. The likelihood ratio test (all $\text{Rho}_{ij} = 0$) the null hypothesis (Table 3) was rejected [(χ^2 (15) = 219.871, Prob > χ^2 =0.000)]. The null hypothesis shows that the regression coefficients of all the equations are simultaneously zero and was rejected at less than the 1% significance level. The χ^2 results confirm that separate estimates of adoption of these adaptation strategies are biased, and the livestock keepers' decision to use any of these six adaptation strategies depends on the HH's decisions. To examine the presence of potential multicollinearity among independent variables, variance inflation factors (VIFs) were checked, and all the VIFs were below 5. Among the 13 variables (Table 3), monthly income, number of laborers, variation in rainfall, and occupations positively and significantly affect the livestock keeper's choice of adaptation. Thus, keeping in mind the six (6) strategies discussed below, the results for these four significant variables (including family size in one case) are presented below. The results of the present research are in line with those of previous literature (Behmanesh et al., 2025; Mulwa et al., 2017; Ojo et al., 2021; Takele et al., 2019). In contrast, a lack of livestock farming experience and limited access to climate change information have made livestock more vulnerable.

4.2.1 Rotational Grazing

Rotational grazing is a system where only one part of a pasture is grazed while the remaining parts are rested to allow for recovery (Undersander et al., 2002). Rotational grazing is an adaptation strategy that is heavily influenced by our four identified socio-economic and environmental factors. Among these, the number of laborers has the strongest positive effect (coefficient = 0.469, p-value = 0.000) on the adoption of rotational grazing, indicating that more laborers help facilitate the intensive management needed for pasture rotation. The second influential factor is family size (coefficient = 0.332, p-value = 0.036), as larger families can provide the necessary labor to manage rotational grazing. Rainfall variation is the third influential variable, affecting rotational grazing positively (coefficient = 0.23, p-value = 0.010), as it supports rotational practices to avoid overgrazing and promote plant and forest restoration (Nketsang et al., 2025). Monthly income ranks fourth (coefficient = 0.177, p-value = 0.000), suggesting that higher income allows farmers to invest in infrastructure such as water systems, fencing, and other essentials for effective rotation (Boyer et al., 2022). Respondents' occupation also has a positive, modest impact (coefficient = 0.008) on adopting the rotational grazing strategy. Off-farm earnings, beyond livestock farming, provide financial support that increases farmers' investment in improved grazing systems. Thus, our findings are consistent with studies of (Ojo et al., 2021; Takele et al., 2019).

4.2.2 Heat-Tolerant Breed

A heat-tolerant livestock breed is defined as a livestock genotype that maintains a normal body temperature suitable for production and reproduction under heat stress (Henry et al., 2018). Variables such as the number of laborers (coefficient = 0.41, p-value = 0.000) indicate that larger HH workforces facilitate better management and supervision of heat-tolerant breeds. Study of (Assaye et al., 2020) also support our result. Factor such as monthly income (coefficient = 0.159, p-value = 0.000), suggests that higher income of livestock farmers enables them to buy and maintain livestock breeds that are easily adjusted in their environment by increasing productivity, and reducing risk of disease (Dang et al., 2019; Fernandez-Gimenez, 2000). The variable variations in rainfall (coefficient = 0.133, p-value = 0.000) reflect the level of climate-induced heat that influences farmers ' preferences for livestock breeds that can survive in harsh weather conditions(Kabote et al., 2014; Thornton et al., 2009). Finally, occupation, especially off-farm employment, has a very minor but significant effect (coefficient = 0.030, p-value = 0.048), indicating that additional income increases investment capacity, reduces dependence on credit, and supports local strategies. In the study area, respondents recognized both indigenous and exotic breeds appropriate to local weather conditions. Achai and Gabrali in cattle, Azikheli in buffaloes, Harnai, Damani, Hashtnagri, and Kaghani in sheep, and Pothohari, Kaghani, Damani, and Ghizeri in goats. Exotic breeds, such as Jersey cattle, Holstein Friesian, and Nili Ravi buffalo, are also raised for their high production and adaptability to local climates.

4.2.3 Communal Grazing

This strategy is defined as a system in which livestock from multiple HHs graze on common pasture and rangelands, and the access is administered by the community rather than sole ownership (Tokozwayo et al., 2021). Communal grazing, especially for sheep, goats, and buffaloes, is influenced by several key factors. The number of laborers is a significant variable (coefficient = 0.399, p-value = 0.000), indicating that large herds distribute responsibilities, thereby reducing workload and costs. Likewise, the second factor, variation in rainfall (coefficient = 0.141, p-value = 0.038), in areas where irregular rainfall causes poor growth of grass and dried rangelands, so in that state, communal grazing becomes a more realistic strategy to manage herds grazing (Hein, 2006). Occupation ranks third (coefficient = 0.09, p-value = 0.029), suggesting that farmers with off-farm employment are more likely to choose shared grazing, primarily due to time restraints or financial constraints (Paudel et al., 2022). Lastly, monthly income has a minor and statistically significant effect (coefficient = 0.004). Farmers across income groups consider communal grazing due to limited resources. Yet, some farmers also adopt private ownership grazing systems to increase their livestock production (Feleke et al., 2016).

4.2.4 Herd Size Reduction

Herd size reduction is due to limited access to pasture, rangelands, and also due to climate extremes (Theodory, 2021). The decision to adopt a herd size reduction strategy is influenced by various factors. The most significant variable is the number of labor (coefficient = -0.279, p-value = 0.030), which causes herd reduction. HHs with a larger labor force are equipped to manage their livestock even under any climatic condition, so they are less likely reduce their herd size. Occupation (coefficient = 0.16, p-value = 0.001), indicates that livestock farmers who are involved in other employment and cannot manage their livestock are inclined to reduce herd size to lessen vulnerabilities (Fiseha, 2020). Monthly income shows a significant negative relationship (coefficient = -0.152, p-value = 0.005), suggesting that higher income reduces the likelihood of reducing herd size. Lastly, variation in rainfall size (coefficient = 0.006, p-value =

0.032) has the least impact on the decision to minimize herd. Rainfall increases water availability and green fodder, reducing pressure on farmers. Herd size reduction is an adaptation strategy inversely related to resource availability (Barón et al., 2022).

4.2.5 Growing Drought-Resistant Plants

Drought-resistant plants support the early crop plantation, reducing food insecurity for livestock. This strategy is influenced by various key factors, including rainfall variation (coefficient = 0.190, p = 0.043). The coefficient values suggest that the severity of droughts has encouraged farmers to promote the growth of resilient plants that are capable of surviving under heat-stress (Haider et al., 2024). The second factor, respondents' occupation (coefficient= 0.095, p-value 0.025) means that farmers earning from non-farm income prefer drought-tolerant crops, due to awareness and access to extension services (Kabote et al., 2024). Monthly income (coefficient = 0.038, p-value = 0.019) indicates that respondents with higher income levels prefer planting seeds and crops that reduce the risks associated with other crop varieties. Lastly, the number of laborer’s (coefficient=0.5, p-value=0.058) has a significantly positive impact on the adaptation strategy. Labor supports drought-resistant crops by easing the additional burden of field management practices, as proved by earlier literature (Amole & Ayantunde, 2016; Maru et al., 2021)

4.2.6 Efficient Water Practices

The practice of collecting and storing rainwater and utilizing it during droughts is an adaptation strategy (Pandey et al., 2003). Factors that influenced the adoption of efficient water practices are the number of laborers (coefficient = 0.349, p-value of 0.001), which clearly shows that HHs with more laborers can manage water-saving infrastructure, which is a more labor intensive activity (Abazinab et al., 2022; Kahinda et al., 2010). The second variable, rainfall variation (coefficient = 0.14, p-value = 0.043), is the most significant. Variation in rainfall encourages livestock keepers to adopt water conservation techniques to better ensure water availability for livestock (Jafari Shalamzari et al., 2016). The variable occupation (coefficient = 0.85, p-value = 0.046) suggests that farmers engaged in off-farm employment are more likely to invest in water-saving systems because of their stable financial means. Finally, monthly income has a positive but comparatively minor impact (coefficient = 0.72, p-value = 0.05). These findings align with previous research (Matimolane et al., 2023), highlighting that both human and financial capital facilitate access to sustainable climate-resilient water management practices in rural livestock systems. The analysis reveals the most influential factors of climate adaptation strategies: Labor availability was the most critical, ranking 1st in 4 strategies, followed by Monthly income (top 3 in 5/6 strategies), Rainfall variation (1st in drought-resistant plants strategy), Off-farm occupation (key for herd reduction), and Family size (key in rotational grazing).

Table **2** : Multivariate Probit Model: Determinants and Climate Change Adaptation Practices for Livestock

Explanatory Variables	Climate change adaptation practices for livestock					
	Rotational grazing	Heat tolerant Breed	Communal grazing	Herd size Reduction	Growing drought-resistant plants	Efficient water practices
Age	-.143 (0.040)^{b}	-.108 (0.091)^{ns}	-.100(0.110)^{ns}	.126(0.097)^{ns}	.035(0.576)^{ns}	-.179(0.006)$^{a, b}$
Gender	-.576(0.018)^{b}	.092(0.681)^{ns}	.296(0.185)^{ns}	.171(0.535)^{ns}	-.104(0.647)^{ns}	.167(0.441)^{ns}
Education	-.136(0.096)^{ns}	-.039(0.617)^{ns}	-.016(0.823)^{ns}	-.058(0.514)^{ns}	.037(0.619)^{ns}	-.011(0.885)^{ns}
Years stayed	.023(0.726)^{ns}	.041(0.513)^{ns}	.059(0.351)^{ns}	-.164(0.040)^{b}	.178(0.006)$^{a, b}$	.0003(0.959)^{ns}
Occupation	.008(0.085)^{c}	.030(0.048)^{abc}	.094(0.029)^{b}	.161(0.001)^{abc}	.095(0.027)$^{a, b}$	.0858(0.046)^{abc}
Total monthly income	.177(0.000)^{abc}	.159(0.001)^{abc}	.004(0.027)^{abc}	-.152(0.005)^{abc}	.038(0.019)^{abc}	.072(0.051)^{abc}
Family Size	.332(0.036)^{b}	.221(0.140)^{ns}	-.015(0.916)^{ns}	-.217(0.221)^{ns}	.298(0.056)$^{a, b}$	.086(0.556)^{ns}
Labors	.469(0.000)^{abc}	.413(0.000)^{abc}	.399(0.000)^{abc}	-.279(0.030)$^{a, b}$	.005(0.058)$^{a, b}$	.349(0.001)^{abc}
Variation in rainfall	.235(0.010)^{abc}	.133(0.005)^{abc}	.141(0.038)^{abc}	-.006(0.032)^{abc}	.019(0.1081)^{ab}	.140(0.043)^{abc}
Drought's event	-.077(0.307)^{ns}	.092(0.202)^{ns}	.033(0.645)^{ns}	-.029(0.736)^{ns}	.230(0.002)^{abc}	.041(0.566)^{ns}
Increase in temperature	-.179(0.086)^{ns}	-.121(0.246)^{ns}	.058(0.572)^{ns}	.176(0.138)^{ns}	-.075(0.470)^{ns}	.120(0.242)^{ns}
Livestock farming experience	-.055(0.411)^{ns}	-.102 (0.108)^{c}	-.085(0.175)^{ns}	.086(0.250)^{ns}	.063(0.325)^{ns}	-.085(0.166)^{ns}
Access to climate change information	-.018(0.763)^{ns}	-.086(0.136)^{ns}	-.063(0.271)^{ns}	.117(0.091)^{c}	-.004(0.945)^{ns}	.138(0.017)^{abc}
Constant	-.133(0.029)^{ab}	-.668(0.268)^{ns}	-.894(0.126)^{ns}	.885(0.028)^{ab}	-.029(0.961)^{ns}	-.904(0.120)^{ns}

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0

Number of observations 399, χ^2 = (15) = 219.871 Prob > χ^2=0.000

Values inside the parentheses represent the probability values, while those outside represent the p-values. The values abc indicate significance at 1%, 5%, and 10%, respectively, and "ns" indicates non-significance.

Source: Estimated, Field Survey Results, 2024

4.3 Importance of Climate Change Adaptation

Table 4 outlines the adaptation strategies HH employs to address climate change. The most commonly adopted practices among livestock farmers include reducing herd size, rotational grazing, using heat-tolerant breeds, communal grazing, and efficient water use. The WAI index indicated that the top adaptation strategies were herd size reduction (WAI = 1.07), the use of drought-resistant plants (WAI = 0.82), and communal grazing (WAI = 0.70). Many HHs documented that these strategies help to tackle food insecurity and help in poverty alleviation. Furthermore, drought-resistant plants are critical for alleviating the impacts of rain in rain dependent livestock communities and minimize the potential impacts of deficit rainfall;

providing feed and green fodder throughout the year for the animals (Marie et al., 2020). Efficient water practices (WAI = 0.66), rotational grazing (WAI = 0.58), and selection of heat-tolerant breeds (WAI = 0.56) are considered cost-effective for improving local livelihoods and the livelihoods of livestock-dependent farmers. The ranking of adaptation strategies to climate change is an essential factor for farmers in shaping decision making (Champalle et al., 2015). Discussion with livestock farmers revealed that adaptation strategies and their implications in the context of livestock farming align with environmental, social, and economic sustainability. Drought-resistant plants and reduced herd size contribute to environmental and economic sustainability. Economic sustainability helps minimise costs and maximise profits. It also helps ensure the availability of fodder and pasture, adding to environmental sustainability. Similarly, the strategy of rotational and communal grazing underscores and enhances social sustainability through joint actions and family labor contributions. Our approach to efficient water use spans all three pillars: conserving limited resources, safeguarding livestock production and its output, and ensuring equal access to water at home. Heat tolerance is ranked the lowest by the WAI analysis, representing a significant step towards environmental and economic resilience. Together, all the results proved that among all the socio-economic and environmental variables, only income, labour, rainfall variability, and occupation are enablers of adaptation strategies. However, it also helps shape adaptation strategies that contribute to SDGs 2, 6, 8, 12, 13, and 15.
The ranking of adaptation strategy effectiveness revealed significant trade-offs. Herd size reduction is a short-term adaptation strategy that may help the livestock farmer to mitigate the threat of climate change and reduce the constraint of feed, fodder, labour, and water. On the other side it may undermine the long-term benefits accumulated from livestock such selling milk meat. However, the remaining strategies that have a substantial effect to boost resilience and productivity of animals over time are perceived to be less effective, pointing to the cultural or capacity-related barrier. This mismatch creates a decisive intervention of policymakers to provide extension services, awareness workshops and demonstrations to reframe the most beneficial and viable options.

Table 3: Climate Change Adaptation Strategies using WAI(N=399)

Variables	Not Effective	Somehow Effective	Most Effective	WAI	Rank
Herd size reduction	62	245	92	1.07	1st
Use of drought-resistant plants	140	188	71	0.82	2nd
Communal grazing	230	58	111	0.70	3rd
Efficient water practices	224	85	90	0.66	4th
Rotational grazing	251	63	85	0.58	5th
Selection of heat-tolerant breeds	246	82	71	0.56	6th

Source: Estimated, Field survey results 2024

5 Conclusions

Livestock farmers in Pakistan have expressed deep concern about climate change, including high temperatures, rainfall variability, and droughts. The impact of climate change on Pakistani livestock cannot be overlooked, as it poses a common challenge for farmers. As well as endangering food security and rural HH incomes, thereby supporting the achievement of SDG 2, 6, 8, 12, 13, and 15, which aim for zero hunger. The MVP models' results confirm that HH socio- demographic and climate factors such as income, the number of labourers, rainfall variability, and farmers' occupations all play a significant and decisive role towards the adaptation strategies. To mitigate the impacts of climate change, livestock farmers have been using several adaptation strategies, including reducing herd size, using drought-resistant plants, and communal grazing. This study concludes that while livestock keepers in KP are aware of climate change and its negative impacts, their capacity to adopt effective strategies remains limited, thereby worsening social, economic, and environmental sustainability.

6 Limitations and future directions

The research found that concerned departments and development agents must continually update their extension knowledge to improve livestock production and productivity. Strengthening local institutional frameworks and extension services in KP, the study's results point to major priorities. Farmers must be provided with extension services, as well as generic awareness, training, and raising the practice level through specific workshops and demonstrations on adaptation strategies' at federal and provincial livestock department and metrological departments needs to hire climate advisories and train them in local language and integrate them to regulate extension visits so that farmer receive timely guidance information on the adjustment of water, feed, fodder and grass for their livestock. Likewise, district livestock officers in collaboration with government NGOs, should design a small support package to subsidize the small farmer and help them during drought and provide certain feed and fodder. Validating and integrating indigenous knowledge can improve technical support, which is essential for resilient, climate-dependent communities. The study recommends the need to build climate-resilient livestock farming in line with sustainable options that require a robust policy framework and its practical implementation.

Further comparative studies between adopters and non-adopters of climate change adaptation are needed, along with additional research across different regions. A cross-sectional survey may overlook the crucial long-term trends, resource availability and climate patterns which are significant for understanding adaptation strategies. Only SDGs 2, 6, 8, 12, 13, and 15 are linked in the present study; comparative research on SDGs and other goals, as well as various adaptation strategies, will be conducted across the country. Moreover, the present study did not address how local and national policies either promote or impede adaptation efforts. This specific approach to policy may hinder the proper identification and practical policy recommendations for developing the current adaptation support framework. Thus, the study recommends that future research and policy should focus on estimating the specific impacts of each adaptation strategy and its linkage with the SDGs on the livelihoods of HH farmers, to build their adaptive capacity and resilience towards climate change.

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