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Climate Change and Socio-Economic Vulnerability Assessment of Marginal Community in Malakand Division, Pakistan

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Abstract

Mountain communities in the Hindu Kush are facing growing pressures from climate change and the decline of forest resources, but the ways in which these changes shape household vulnerability remain insufficiently understood. This study examines the relationship between climate change and household vulnerability in Malakand Division, Khyber Pakhtunkhwa, Pakistan, over the period 1985–2025. The analysis combines long-term climate records, district-level disaster data, and a structured survey of 1,000 households. Mean annual temperature increased by 2.7°C during the study period, with stronger warming at higher elevations, while annual rainfall declined by 170 mm and became increasingly erratic. More than 80% of households surveyed reported moderate-to-high dependence on forest resources, and 77.2% observed a decline in local forest cover. The mean household vulnerability score was 81.96 (SD = 15.58), with relatively limited differences across districts. Regression analysis showed that forest dependency ($\beta = 0.687$, $p < .001$), temperature increase ($\beta = 0.273$, $p < .001$), and rainfall change ($\beta = 0.254$, $p < .001$) were positively associated with vulnerability and together explained 61% of its variance, while education had a small protective effect. Climate-related livelihood impacts were widespread, including reduced crop productivity (57.8%) and declining household income (50.0%). Nearly one in five households reported migration as an adaptation response. Overall, the findings suggest that household vulnerability in Malakand is shaped less by location alone than by dependence on increasingly stressed forest and land resources. Effective adaptation will require targeted community forestry, access to alternative energy, livelihood diversification, and climate-resilient development for vulnerable mountain households.

Keywords: Climate Change; Household Vulnerability; Forest Dependency; Deforestation; Adaptation Strategies

Introduction

Climate change is increasingly affecting mountain communities whose livelihoods depend closely on agriculture, forests, water resources, and other climate-sensitive systems. Changes in temperature and rainfall can alter agricultural productivity, water availability, and the frequency or severity of floods, landslides, and other hazards. However, the consequences of these changes are not experienced equally. Households in marginal communities differ in their exposure to environmental hazards, their dependence on natural resources, and their ability to cope with and adapt to changing conditions. Understanding these differences is therefore important for assessing how climate change translates into household-level vulnerability, particularly in mountain regions where livelihood options are often limited.

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The Hindu Kush Himalaya (HKH) is among the regions considered highly sensitive to climate change. Rising temperatures, changing precipitation patterns, declining snow and ice, and increasing exposure to floods and landslides are creating growing challenges for mountain ecosystems and the communities that depend on them (IPCC, 2022). Studies from northern Pakistan and the wider HKH region have reported significant changes in temperature and rainfall, with implications for agriculture, water resources, and natural hazards (Shah & Habib, 2013; Mahmood & Khan, 2014; Ren et al., 2017; Sharif et al., 2013). These changes are particularly important for rural households whose livelihoods depend on climate-sensitive activities such as farming, livestock rearing, and forest-resource collection. Forest resources form an important part of this livelihood system. Forests regulate water flows, protect soils, support biodiversity, and provide timber, fuelwood, fodder, food, and other resources to rural communities (FAO, 2021). Their importance is especially evident in mountainous areas where households may have few alternatives to natural resources. In Pakistan, national forest cover declined from approximately 5.1% of total land area in the 1990s to around 4.6% in 2020 (FAO, 2021).

Household vulnerability is not determined by exposure alone. It also depends on how sensitive households are to environmental changes and on the resources available to them for responding to those changes (Smit & Wandel, 2006). Households with limited land, low incomes, fewer livelihood options, weak access to services, and high dependence on natural resources may have fewer opportunities to adapt (Adger, 2006; Turner et al., 2003). Forest dependency is particularly relevant in this context because households that obtain a substantial share of their fuel, fodder, income, or other necessities from forests may be more affected when forest resources decline or climatic conditions become less favourable. Education, livelihood diversity, access to information, land ownership, and social support may also influence how effectively households respond to environmental pressures. Examining these factors together can provide a clearer understanding of why vulnerability varies between households living within the same broader climatic environment.

Despite increasing research on climate and environmental change in northern Pakistan, the relationship between long-term environmental change and household vulnerability remains insufficiently explored at the scale of an entire mountain division. Previous studies have documented forest loss in individual districts of Khyber Pakhtunkhwa using remote sensing (Ali et al., 2017; Shehzad et al., 2014; Mannan et al., 2022), while other research has examined temperature and rainfall trends across the HKH region (Ren et al., 2017; Sharif et al., 2013). These studies provide valuable evidence of environmental and climatic change, but they have generally not been integrated with household-level socio-economic assessment. As a result, there is limited understanding of how observed changes in climate and natural resources are reflected in household vulnerability and which characteristics make some households of marginal communities more exposed or less able to adapt.

Against this background, this study examines the linkages between climate change and household vulnerability in Malakand Division over the period 1985–2025. The study aims to examine long-term changes in temperature, rainfall, and selected climate-related conditions and to assess household vulnerability and identify the socio-economic and environmental factors associated with differences in vulnerability. The study contributes to a more integrated understanding of vulnerability in mountain environments by connecting long-term climate and

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land-cover changes with household socio-economic conditions. Rather than treating climate change, forest loss, and household vulnerability as separate issues, it examines how they intersect within the same landscape and influence the capacity of households to cope with environmental change. This perspective can support more targeted approaches to climate adaptation, livelihood diversification, forest management, and resilience planning in Malakand Division and other Hindu Kush Mountain communities facing similar challenges.

Materials and Methods

Study Area

This study was conducted in Malakand Division, located in northern Khyber Pakhtunkhwa, Pakistan, within the southern foothills of the Hindu Kush mountain system. The division comprises six administrative districts, Swat, Dir Upper, Dir Lower, Malakand, Buner, and Shangla, spanning a wide elevation gradient from subtropical river valleys to high alpine terrain. These districts were selected because they share a common dependence on climate-sensitive livelihoods, principally agriculture, forestry, and livestock, while differing enough in elevation, land cover, and disaster exposure to allow meaningful district-level comparison.

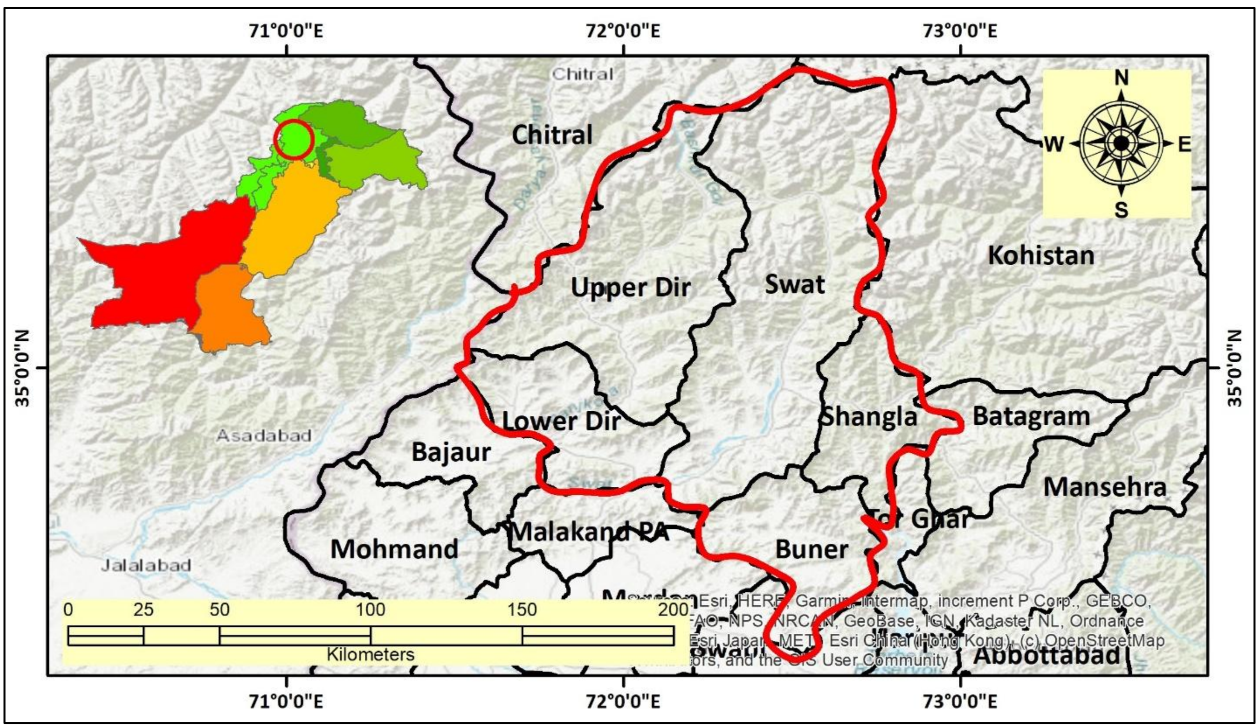

Figure 1: Map of the Malakand Division (The Study Area)

Climate and Disaster Data

Long-term climatic change was assessed using secondary meteorological records for mean annual temperature and total annual rainfall, compiled for five reference years spaced at roughly decadal intervals between 1985 and 2025. This 40-year window was chosen to align with the period over which land use and land cover change was also assessed, allowing the two datasets to be read together. Seasonal temperature values (winter, spring, summer, autumn) were compared between the start and end years of this period to identify which season had warmed most. District-level temperature and rainfall records for 1990–2025 were compiled separately to capture spatial variation across the division that division-wide averages would otherwise obscure.

Household Survey

Primary data on household-level vulnerability were collected through a structured questionnaire survey administered to 1,000 respondents drawn from across the six districts of Malakand Division. Respondents were selected to represent the range of livelihoods present in the division, agriculture, forestry, livestock rearing, and other occupations, and included both male and female household members where accessible, though participation skewed male given the gendered nature of forestry and outdoor agricultural work in the area.

The questionnaire captured five broad categories of information: (i) socio-demographic characteristics, including gender, age, education, and main occupation; (ii) the household's degree of dependence on forest resources, fuelwood, fodder, timber, and non-timber products, rated on a three-point scale from low to high; (iii) perceptions of deforestation and awareness of climate change, using five-point Likert-type items; (iv) direct observation of four climate indicators (temperature increase, rainfall change, flooding, and water shortage) and five livelihood impacts (decline in forest products, crop productivity loss, income reduction, livestock problems, and migration); and (v) the adaptation strategies household of marginal community had adopted in response, including water conservation, crop diversification, tree plantation, alternative income generation, and migration.

Construction of the Vulnerability Score

A composite household vulnerability score, scaled from 0 to 100, was constructed for each respondent by combining three components drawn from the survey: the household's forest dependency rating, its cumulative exposure to observe climatic hazards, and the severity of the livelihood impacts it reported. These components were combined into a single index so that vulnerability could be compared consistently across respondents and aggregated to the district level, rather than relying on any single indicator in isolation.

Statistical Analysis

Descriptive statistics (means, percentages, and standard deviations) were used to summarize the socio-demographic profile of respondents and the distribution of forest dependency, awareness, perceptions, and adaptation strategies. District-level comparisons of mean vulnerability score and the proportion of respondents in the top vulnerability quartile (defined as the 75th percentile of the overall distribution) were used to assess spatial patterns in vulnerability.

Bivariate relationships between the vulnerability score and its likely predictors, forest dependency, temperature increase, rainfall change, crop loss, water shortage, income reduction, and education, were examined using Pearson correlation coefficients. To identify the independent contribution of each factor once the others were controlled for, a multiple linear regression model was estimated with the composite vulnerability score as the dependent variable and forest dependency, temperature increase, rainfall change, perceived forest decline, and

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education level as predictors. Statistical significance was assessed at the conventional $p < 0.05$ threshold throughout.

Results

Socio-Demographic Profile of Respondents

A structured household survey was administered to 1,000 respondents across the six districts of Malakand Division (Swat, Dir Upper, Dir Lower, Malakand, Buner, and Shangla). The socio-demographic profile of the sample is summarized in Table 1.

Male respondents accounted for 72.0% of the sample, and female respondents for 28.0%, reflecting the gendered division of forestry, livestock, and outdoor agricultural work in the study area. In terms of age, 43.0% of respondents were aged 31–45 years and 24.4% were aged 46–60 years, together comprising the majority of the sample; 24.8% were young adults aged 18–30, and 7.8% were above 60 years of age. Educational attainment was generally low: 31.2% of respondents reported no formal education, approximately one-quarter had only primary-level schooling, and 14.6% had attained graduate-level education or above. With respect to livelihood, agriculture accounted for 38.4% of household livelihoods and forest-related activities for a further 21.6%; combined with livestock rearing (15.2%), 75.2% of respondents depended directly on land- or forest-based livelihoods.

Table 1: Socio-demographic profile of surveyed households from Marginal Community

Variable	Category	% of Respondents (n = 1000)
Gender	Male	72.0
	Female	28.0
Age (years)	18–30	24.8
	31–45	43.0
	46–60	24.4
	>60	7.8
Education	No formal education	31.2
	Primary level	~25.0
	Secondary/higher secondary	~29.2
	Graduate and above	14.6
Main livelihood	Agriculture	38.4
	Forest-related activities	21.6
	Livestock rearing	15.2
	Other (trade, services, labour)	24.8

Long-Term Climate Trends in Malakand Division (1985–2025)

Mean annual temperature in Malakand Division rose from 18.4°C in 1985 to 21.1°C in 2025, an increase of 2.7°C over the 40 years (Figure 2). Warming proceeded gradually during 1985–2005 (+1.2°C) and accelerated during 2005–2025 (+1.5°C).

Seasonal disaggregation of the temperature record showed that summer temperatures increased most sharply, from 29.4°C in 1985 to 32.8°C in 2025 (+3.4°C), while winter temperatures rose

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by a comparatively smaller 1.7°C. Spring and autumn temperatures increased by 2.5°C and 2.7°C, respectively (Figure 3).

Annual rainfall declined from 820 mm in 1985 to 650 mm in 2025, a reduction of 170 mm (20.7% of the 1985 baseline). Unlike temperature, which accelerated after 2005, the decline in rainfall proceeded at a broadly steady pace across the four decades, with decade-wise losses of approximately 40 mm, 60 mm, 30 mm, and 40 mm (Figure 4).

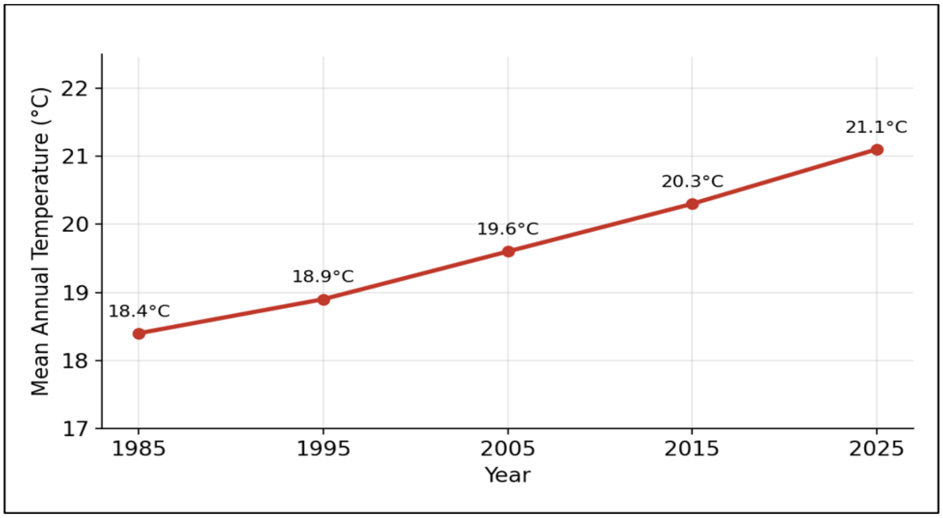

Figure 2: Mean annual temperature trend in Malakand Division, 1985–2025

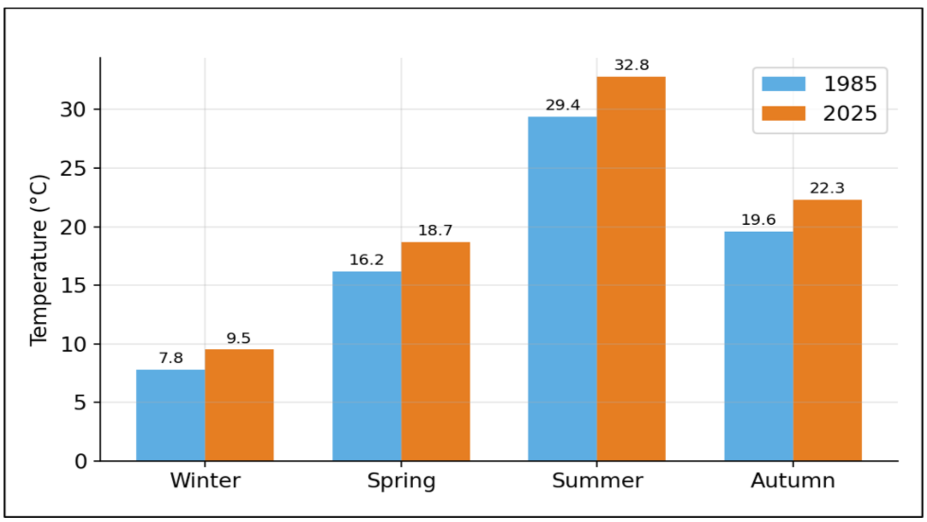

Figure 3: Seasonal temperature comparison between 1985 and 2025

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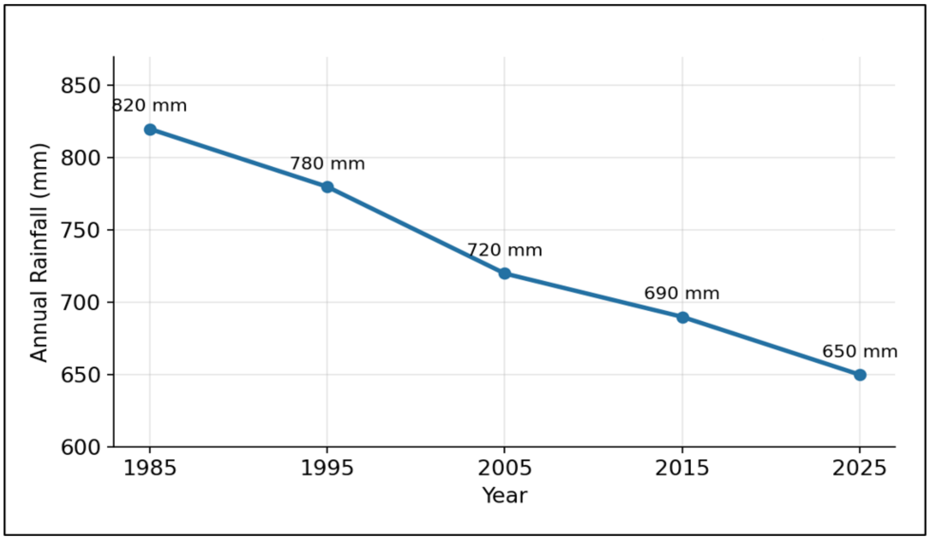

Figure 4: Annual rainfall trend in Malakand Division, 1985–2025

Table 2 consolidates these indicators. All directional indicators- temperature, rainfall, climate variability, and the frequency of extreme events- changed in a consistent direction over the study period.

Table 2: Summary of climate change indicators, Malakand Division (1985–2025)

Climate Indicator	1985	2025	Overall Trend
Mean annual temperature	18.4°C	21.1°C	Increasing (+2.7°C)
Summer temperature	29.4°C	32.8°C	Strong increase (+3.4°C)
Annual rainfall	820 mm	650 mm	Decreasing (−170 mm)
Climate variability	Moderate	High	Increasing
Frequency of extreme events	Occasional	Frequent	Increasing

Sector-Wise Climate Vulnerability

A sector-wise assessment classified agriculture as having very high vulnerability to temperature increases and rainfall variability. Water resources and forestry were rated as highly vulnerable, livestock as medium-to-high, tourism as medium, and human health vulnerability as increasing (Table 5).

Table 5: Sector-wise climate vulnerability assessment

Sector	Vulnerability Level	Main Climate Driver
Agriculture	Very High	Temperature increases and rainfall variability
Water resources	High	Reduced and erratic rainfall
Forestry	High	Warming, drought, and land degradation
Livestock	Medium-High	Heat stress and pasture decline
Tourism	Medium	Extreme weather events
Human health	Increasing	Heat waves and water-related stresses

Vulnerability of Marginal Community

Figure 5 shows vulnerability of marginal community in Malakand Division due to climate change. Forest dependency was the strongest predictor of livelihood vulnerability (β = 0.687, $p < .001$), indicating that households more dependent on forest resources were considerably more vulnerable. Temperature increase (β = 0.273, $p < .001$) and rainfall change (β = 0.254, $p < .001$) also showed significant positive associations with vulnerability. Education had a small protective effect (β = −0.040, p = .044), while perceived forest decline was not significant (β = 0.001, p = .958). Overall, the results show that actual dependence on forest resources and exposure to climatic changes are more important for explaining vulnerability than perceptions of forest decline alone.

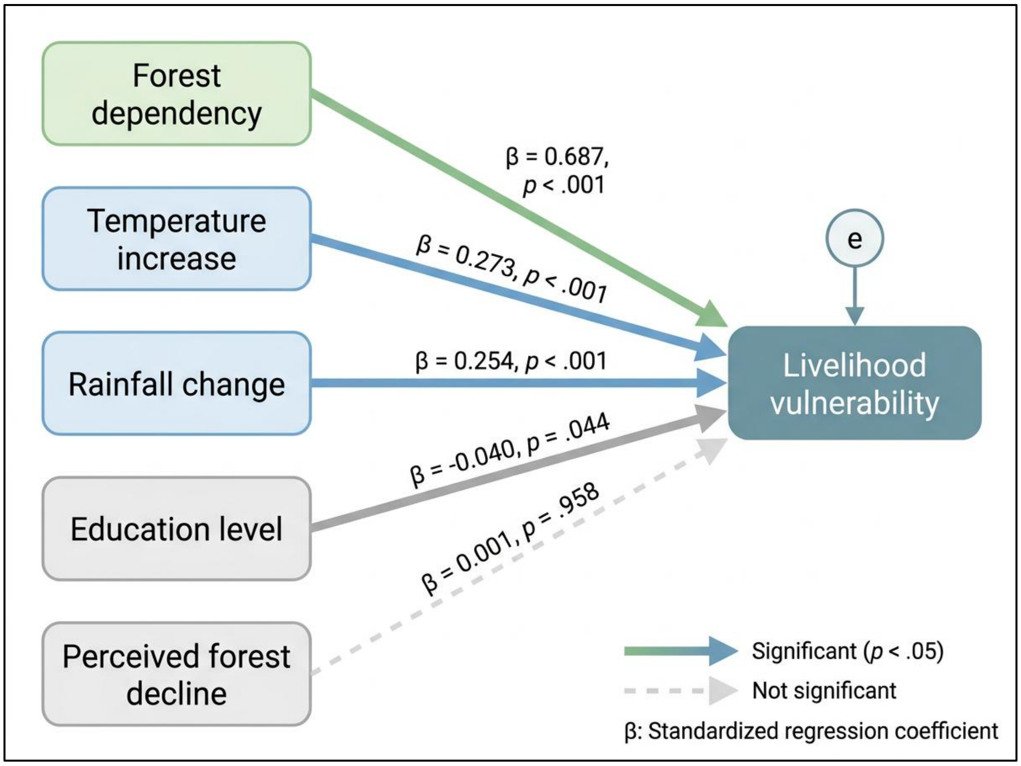

Figure 5: Vulnerability of Marginal Community in Malakand Division

Discussion

The climatic and socio-economic findings from Malakand Division are broadly consistent with evidence from the wider Hindu Kush-Himalaya (HKH) region. The observed warming of 2.7°C between 1985 and 2025, particularly at higher elevations in Dir Lower, Buner, and Shangla, reflects the elevation-dependent warming reported across the HKH. Ren et al. (2017) found that temperature increases have been stronger at higher elevations and along the southern margins of the HKH, including northern Pakistan. Although their study reported a slight long-term decline in overall precipitation, it also identified increasing rainfall intensity in more recent years, especially at higher elevations (Ren et al., 2017). A similar pattern is evident in Malakand Division. Annual rainfall declined by about 170 mm, yet some higher-elevation districts experienced increasingly erratic rainfall and flash-flood events. This suggests that changes in

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rainfall intensity and timing may be more important for local livelihoods than changes in annual totals alone.

The concentration of floods and landslides in Buner, Shangla, and Swat also agrees with earlier research. Khan and Mohmand (2011) identified intense rainfall interacting with steep and unstable terrain as a major cause of the severe 2010 floods in Khyber Pakhtunkhwa. Muzamil et al. (2021) similarly showed that deteriorating natural resources, including deforestation, increased the effects of flooding on farming and tourism livelihoods in Swat. The 34.2% reduction in forest cover observed across Malakand Division, particularly in districts experiencing frequent hazards, adds further support to this relationship. Bradshaw et al. (2007) found across developing countries that deforestation can increase both the frequency and severity of flooding by reducing the landscape's capacity to regulate runoff and retain soil moisture. The simultaneous reporting of flooding (71.0%) and water shortages (68.5%) by households further illustrates the complex hydrological pressures facing the region.

The observed winter warming also deserves attention because of its potential implications for snowmelt and seasonal water availability. Sharif et al. (2013) documented changes in the timing and magnitude of river flows in the Upper Indus Basin associated with changing snowmelt patterns. Since the Swat and Panjkora rivers are partly sustained by snowmelt from the surrounding Hindu Kush, continued warming during winter could similarly influence the timing of water availability and downstream flow patterns.

At the household level, forest dependence emerged as the strongest predictor of vulnerability ($\beta = 0.687$). This finding is consistent with Ullah et al. (2018), who showed that household vulnerability in Khyber Pakhtunkhwa is closely associated with dependence on natural resources. The present study extends this evidence to Malakand Division, where more than 80% of households surveyed reported moderate-to-high dependence on forests. The fact that 77.2% of respondents also perceived a decline in local forest cover indicates that this dependence is occurring in the context of a shrinking resource base. Evidence of continued illegal logging in Swat and Dir reported by The Friday Times (2024) further suggests that forest degradation remains an ongoing concern rather than simply a legacy of past land-use change.

Fuelwood dependence was widespread across occupational groups, exceeding 60% in each category. This finding is consistent with the long-standing role of fuelwood in rural Pakistan. The Food and Agriculture Organization (1997) reported that fuelwood historically accounted for more than half of rural household energy consumption, largely because affordable alternatives remain limited. Similarly, Ullah et al. (2021) found that dependence on fuelwood in Basho Valley places continued pressure on forest resources regardless of household occupation.

The reported livelihood impacts also correspond with findings from other parts of Khyber Pakhtunkhwa. More than half of respondents reported reduced crop productivity (57.8%) and declining income (50.0%). Abid et al. (2019) found that farmers in Pakistan perceive long-term changes in temperature and rainfall and associate these changes with declining agricultural productivity and income. Khan et al. (2020), based on a survey of 720 households across six KP districts, likewise identified climate-related livelihood risks and adaptation responses such as crop diversification. The strategies reported in Malakand including water conservation, crop diversification, and alternative income generation reflect this broader pattern. Migration, reported by 19.9% of households, is particularly important because Fahad and Wang (2018) describe migration as a common last-resort response when other adaptation options become increasingly difficult.

Education showed a modest but significant protective association with vulnerability ($\beta = -0.040$). This finding is in line with Abid et al. (2016), who found that better-educated farmers in rural Pakistan adopted a wider range of adaptation measures and experienced smaller income losses associated with climate variability. In Malakand Division, where 31.2% of respondents had no formal education, limited educational attainment may restrict access to climate information, new livelihood opportunities, and other adaptation resources.

Finally, the relatively small differences in mean vulnerability scores between districts, despite wider differences in the proportion of highly vulnerable households, indicate that vulnerability cannot be explained by geography alone. Muzamil et al. (2021) reached a similar conclusion for Swat, emphasizing the combined influence of resource dependence, livelihood structure, and governance. This also corresponds with the IPCC (2022), which identifies agriculture, water resources, and forest ecosystems as highly exposed sectors in mountain regions because of their dependence on climatic conditions and limited capacity for short-term substitution. Overall, the findings suggest that climate adaptation in Malakand Division would be more effective if it focused on households with high forest dependence and limited livelihood alternatives, rather than relying only on district-level assessments of vulnerability.

Conclusion

This study shows that climate change is becoming an increasingly important part of the livelihood challenges faced by households in Malakand Division. Over the period 1985–2025, the region experienced a rise in mean temperature of 2.7°C, a decline in annual rainfall of about 170 mm, and a reduction of roughly one-third in forest cover. These changes are taking place in a mountain landscape where many households depend directly or indirectly on agriculture, livestock, and forest resources. The household findings add an important dimension to this picture. Forest dependency was the strongest factor associated with household vulnerability in the regression analysis. Families relying heavily on fuelwood, fodder, timber, and other forest products were more vulnerable, regardless of whether forestry was their main occupation. This suggests that vulnerability in Malakand is not simply determined by exposure to climate hazards or by the district where a household happens to be located. It is also shaped by how households make their living and the resources available to them when environmental conditions change. The experiences reported by households show that these pressures are already being felt in everyday life. Crop losses, reduced income, and difficulties in maintaining agricultural livelihoods were common concerns. Households are responding in different ways, including conserving water, changing crops, planting trees, and seeking employment elsewhere. Migration, in particular, points to the limits of local adaptation when households have few alternatives for maintaining their livelihoods.

The findings call for a more locally grounded approach to climate adaptation in the Hindu Kush. Broad district-level interventions are unlikely to reach all vulnerable households equally. Greater attention should be given to families that depend heavily on forest resources, have limited livelihood options, and lack the capacity to cope with repeated environmental shocks.

Community-based Forest management, alternative energy sources, livelihood diversification, climate-resilient agriculture, and better access to climate information can provide practical avenues for reducing these pressures. Ultimately, the study suggests that forest conservation and household resilience cannot be treated as separate concerns in Malakand Division. The well-being of many mountain households is closely tied to the condition of the resources around them. Protecting those resources while expanding the economic and adaptive choices available to households will be essential for building more resilient communities in a changing Hindu Kush.

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