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Research article

Assessing the impacts of climate change on high mountain land-based livelihoods: An empirical investigation in District Nagar, Gilgit-Baltistan, Pakistan

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ABSTRACT

Land-based livelihoods in Pakistan's high mountain regions are highly vulnerable to climate change due to the complex interactions between people and their natural environment. This study uses a mixed-method approach to explore how climate change affects land-based livelihoods in the high mountain Nagar District, Pakistan. Data were collected using a structured household survey of 430 randomly selected farmers, supplemented by focus group discussions and key informant interviews. The findings reveal that 87.7 % of farmers have observed negative impacts of climate change, such as increased crop diseases, reduced water for irrigation, and lower crop yields. Bivariate results indicate that factors related to farming practices, such as farming experience and cropping zones, significantly influence farmers' perceptions of impacts. The study emphasizes the urgent need for targeted government intervention and agricultural planning to boost the resilience of farmers in Nagar District. It calls for improved irrigation, crop disease management, and support tailored to high-mountain farming practices. The research highlights the importance of developing adaptation strategies to protect vulnerable farming communities from climate change impacts and supports the need for effective autonomous adaptation measures. This research contributes to a better understanding of climate change impacts on high-mountain agriculture and emphasizes the need to safeguard vulnerable farming communities.

1. Introduction

Scientists and researchers have a clear consensus that the world has undergone a rapid transition in global climate elements. The International Panel on Climate Change (IPCC) reported that this shift has severely impacted human and natural systems worldwide [1]. Climate-induced impacts are diverse and significant across various sectors of society, including the economy, health, biodiversity, and forests. However, agriculture is widely regarded as the most vulnerable to climate change [2,3]. This high susceptibility of agriculture is largely due to its heavy dependence on climatic variables and weather conditions [4,5], as well as its fragile relationship with the

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environment, which exacerbates challenges to food security and rural livelihoods for billions of disadvantaged people worldwide [6].

The impacts of climate change on agriculture are driven by a combination of factors, including extreme climate events and natural disasters resulting from fluctuations in global temperature and precipitation patterns [7]. For instance, rising temperatures, heat-waves, snowmelt, flooding, droughts, and rising sea levels have affected agriculture globally [8]. Similarly, erratic rainfall and the poleward spread of diseases and pests due to a warming atmosphere have also posed significant threats to food production systems [9]. Additionally, climate change has resulted in adverse impacts such as water scarcity, soil degradation, increased pest infestations, disease outbreaks, and declining crop yields [10]. Consequently, these climate-induced impacts have severely threatened rural livelihoods and global food security [11].

Though climate change is a global phenomenon, the adverse impacts of climate change are felt unevenly based on the adaptive competence of individual countries [12]. Evidence shows that developing countries are predominantly vulnerable to climate-induced impacts owing to characteristics like the land-based economy [13], limited resources [14], low financial and technological capacity, high vulnerability and low ability to lessen the undesirable impacts of climate change [15] making them unequipped to counter the likely adverse impacts of climate change [16]. Consequently, climate change gravely threatens economically disadvantaged nations' growth [17]. More specifically, the poor agrarian communities living in underdeveloped countries are considered as exceptionally susceptible to the adverse consequences of changing climate, although they are contributing only 10 % to the emissions of global carbon dioxide (CO_2) and other greenhouse gases [13].

Like other developing countries, the agriculture sector in Pakistan has experienced a wide range of climate-induced impacts [18, 19]. The adverse impacts of climate change are severe and occur with high speed and intensity [20]. Consequently, Pakistan has faced climate impacts in the form of glacial lake outburst floods [21], intense heat waves [20], unexpected rainfall, erratic flooding, variation in temperature, droughts and decreases in water availability [22], and occurrence of pests diseases and seasonal changes [23]. Across Pakistan, different communities perceive climate-induced impacts in varying degrees based on their socio-economic and geographical settings. For instance, the farmers in arid regions and the small farmers in high mountain areas are at high risk of climate-induced adverse effects [14].

Gilgit-Baltistan is a remote high mountain region in Pakistan situated at the interaction of Hindu Kush Himalaya (HKH) mountain ranges [24] characterized by multi-faceted and fragile institutional setup and social fabrics [25]. Evidence shows that modifying climate elements is the most apparent phenomenon in this high mountain region [26], rendering these communities exceptionally vulnerable to its impacts [27]. The high vulnerability to climate change-induced impacts is attributed to small per capita landholdings [28], subsistence farming [27], inadequate livelihood opportunities [29], and fragile mountain ecosystems [26,30]. People are deprived of life's necessities and more susceptible to shocks [31]. Changes in climatic conditions and the above-cited factors have created significant challenges for the farming community and their land-based livelihoods in this region [27].

Across the Gilgit-Baltistan province, several academic endeavours have been conducted concerning climate-induced impacts on agriculture. The most recent research studies such as Ali et al. [32], Hussain et al. [33], Baig et al. [28], and Hussain et al. [26] in Gilgit-Baltistan stated that climate-change-induced impacts have adversely affected the agriculture sector in this region. Like other parts of the Gilgit-Baltistan province, the climate effects are evident in the high mountain district Nagar (study area), and farming communities in this district are predominantly vulnerable due to subsistence farming [27] and low per capita landholding [34]. Over the last three decades, frequent extreme climatic events have consistently impacted the major crops, pastures, infrastructure, and livelihood sources of local farmers in Nagar Valley [35].

There is an urgent need to assess the on-the-ground realities of climate change impacts as perceived by farmers at the household level, particularly concerning their land-based livelihoods in the study area. However, the empirical studies on the effects of climate change on land-based livelihoods in the Nagar District are limited. Previous research by Bhatta et al. [36] and Spies [27] examined the impacts of climate change on agriculture in this area. Still, their scope was restricted to a few villages, focusing solely on male farmers and using a qualitative approach. Bhatta et al. [36] explored local perceptions of climate change in three villages, while Spies [27] assessed farmers' observations of climate variability. However, these studies were limited by their qualitative methods, lack of female representation, and a narrow focus on community-wide perceptions rather than specific impacts on land-based livelihoods.

This study seeks to fill these gaps by employing a mixed-methods approach that includes both male and female farmers, providing a more comprehensive understanding of farmers perceived impacts of climate change on the high mountain land-based livelihoods in the high mountainous Nagar District of Gilgit-Baltistan, Pakistan. By addressing the limitations of previous research in terms of geography, population, and methodology, this study aims to offer a more detailed and nuanced analysis of how climate change affects the land-based livelihoods of the farmers at the household level in the high mountain Nagar District, Gilgit-Baltistan, Pakistan. Such an assessment can highlight local environmental issues and disclose the impacts of climate change on the livelihoods of residents, but such an assessment is often ignored by statistical models [37]. Additionally, the evaluation of the impacts of climate change based on local realities can help agricultural planners and policymakers design context-specific climate mitigation and adaptation policies for local farmers. Additionally, the study aims to achieve the following sub-objectives.

- To assess the farmers' perceived impacts of climate change on land-based livelihoods at the household level.
- To evaluate the severity of climate-induced impacts on land-based livelihoods at the household level.
- To analyze the household-level determinants of farmers' perceived impacts of climate change on land-based livelihoods.

2. Literature review

Climate change has posed significant threats to the land-based livelihoods of farming communities globally. Particularly, the farming communities in the global south have experienced a range of climate-induced impacts on their land-based livelihoods. This section highlights some of the most important impacts of climate change on the land-based livelihoods of farmers, as reported by academic endeavours worldwide.

2.1. Impacts of climate change on land-based livelihoods – Global context

Research scholars worldwide have given considerable attention to the climate-induced impacts on land-based livelihood. For instance, the study by Žurovec and Vedeld [38] in Southeastern Europe has reported the negative impacts of climate change in the form of an increase in temperature, a decrease in yield, and a reduction in water availability. Inversely, Lal et al. [39] indicated that in rural United States, the climate-induced impacts vary across different regions. Some regions may benefit while others lose. For instance, the rural communities in the Northeast engaged in agricultural and related activities are at an advantage. At the same time, those in the South-west and Southeast are at a disadvantage as they face severe impacts of climate change in the form of hostile weather events and water stress. A recent study in Cameroon, Africa, by Chimi et al. [40] reported that the climate-induced severe droughts and harsh winds have negatively affected land-based livelihoods.

Similarly, Sraku-Lartey et al. [41] in Ghana, Africa, reported that the variations in climate elements have affected land-based livelihoods through a prolonged dry season, harsh winds, and decreased water availability. Similar impacts have been reported by Dendir and Simane [42] in Southeastern Ethiopia, where land-based livelihoods have been affected by droughts, frost, storms, and floods. In the same way, Schroth et al. [43] and Bunn et al. [44] reported estimated losses in the production of agro-products, i.e., cacao, Arabica, and coffee in Africa, due to harsh winds, severe droughts, and storms.

Likewise, Asian countries, particularly third-world countries, have encountered substantial climate-induced impacts due to their heavy reliance on agriculture [15]. For instance, Suresh et al. [45] have observed that in Sri Lanka, agricultural production has been detrimentally impacted by climate change, characterized by increasing temperatures and a decline in rainfall amounts, shortage of water, and crop diseases. Similarly, Kumar [46] noted that Bhutan has encountered adverse impacts caused by climate change, including the outbreak of diseases and pests, unpredictable rainfall patterns, storms, droughts, landslides, and floods. Similar results have been found by Kabir et al. [47] in Bangladesh, where most sampled respondents have observed weed and pest infections and a lack of water availability due to long seasons. Conversely, this study also reported some positive impacts, as around 65 % of respondents have observed increased crop yields and grain size. Meanwhile, in the rural villages of the Philippines, the hostile effects of climate variation on cash crop production are caused by extreme events like floods, droughts and typhoons [48].

2.2. Impacts of climate change on land-based livelihoods – National context

The land-based livelihoods in Pakistan look highly exposed to a range of adverse climate-bought impacts. For example, Ali et al. [24] reported that agriculture in Pakistan greatly depends on temperature and precipitation variations and is greatly exposed to harmful climate-induced events. Over the years, climate changes have induced various stressors like deviations in weather patterns, floods, heat waves, droughts, and Glacial Lake Outburst Floods (GLOF) in Pakistan [21]. The academic endeavour by Ateeq-Ur-Rehman et al. [6] reported that in the Rajanpur district of Pakistan, the climate had affected the agricultural output and income negatively due to unscheduled rains and floods. At the same time, Abid et al. [19] mentioned that in Punjab, the sampled farmers had noticed longer summer seasons for agriculture while a decrease in precipitation, which created a water scarcity problem in the rain-feed area.

Moreover, the findings of the research by Ullah et al. [3], Shah et al. [49], and Shah et al. [50] in Khyber-Pakhtunkhwa, Pakistan, show that climate-induced impacts, i.e., crop diseases, lack of water, and loss of social fertility, have adversely affected the land-based livelihoods of farmers. Similarly, Bacha et al. [51] found that in the Swat Valley of Pakistan, local farming communities have perceived the effects of changing climate in the form of temperature rise, irregular rainfalls, floods, droughts, heat waves, and retreating glaciers. Salik et al. [52]; Shah et al. [53] Shah et al. [54]; Shah et al. [55] revealed that the communities residing in the coastal areas of Pakistan have observed the adverse consequences of climate change in the form of rising sea levels, irregular variations in temperature and upsurge in the occurrence of climate-induced extreme events, and these events have negatively affected the local livelihoods.

2.3. Impacts of climate change on land-based livelihoods – Local context

Climate change is the most prominent phenomenon in the high mountainous areas in the Gilgit-Baltistan province of Pakistan [26]. Across the Gilgit-Baltistan province, several academic endeavours have been conducted concerning climate-induced impacts on farming and related livelihoods. The most recent research study by Ali et al. [32] found that climate-induced events like GLOF, flash floods, and landslides have significantly affected agricultural practices in the high mountain Gilgit-Baltistan, decreasing food security at the household level. Likewise, Hussain et al. [33] illustrated that in the Hindukush-Karakoram region of Gilgit-Baltistan, climate-induced impacts like pest attacks have increased, leading to a decline in crop productivity. As a result, household income has been negatively impacted, as reported by (Baig et al. [28]. Likewise, in the Naltar Valley of Gilgit, the amount of pasture has decreased due to climate-induced hazards, i.e., floods, avalanches and landslides; consequently, the farmers have reduced the number of livestock [26].

Conversely, Gioli et al. [25] reported that over the last ten years, residents in GB have witnessed a variation in temperature patterns. Mainly, summers are colder than earlier, and winters are severely colder. Consequently, the cropping cycle has been severely affected, affecting overall productivity. Moreover, the study by Habib [29] on climate change, livelihoods, and gender dynamics in

Gilgit-Baltistan revealed that women have perceived climate-induced hazards like temperature rise, uneven rainfalls, landslides, and flash floods concerning their land-based livelihoods.

Like other parts of the high mountainous Gilgit-Baltistan province, the climate effects are evident in the high-altitude Nagar Valley (study area). For instance, Bhatta et al. [36] reported that in Rakaposhi valley of district Nagar, residents have perceived impacts of climate change in the form of a rising trend in average temperature and alterations in precipitation patterns. Moreover, the study revealed that climate change has directly affected various aspects, including plant distribution, species composition, disease and pest infestation, availability of forage, and agricultural productivity. Similarly, Spies [56] mentioned that in the Nagar district, the thinning of glaciers has led to a decline in water sources for irrigation, transforming cropland into desert-like conditions. In another study, Spies [27] reported that farmers in Nagar Valley have experienced negative impacts from a water shortage for irrigation during spring and deficiency in soil moisture due to deteriorating soil cover. Similarly, the World Wildlife Fund for Nature – WWF[35] reported that over the last three decades, farmers' major crops, pastures, infrastructure, and livelihood sources in Nagar Valley have been consistently impacted by frequent extreme climatic events.

2.4. Determinants of climate change perceived impacts by farmers

2.4.1. Socio-economic and demographic determinants

Research from around the world indicates that the perceived impacts of climate change are shaped by various socio-economic and demographic factors [57,58]. For instance, Chimi et al. [40] found that in Cameroon, education and age significantly influence how climate change impacts are perceived. Similarly, Funatsu et al. [59] reported that perception of climate change tends to increase with age and that gender plays a role, with male farmers generally less likely to recognize climate changes than female farmers. Contrastingly, Sraku-Lartey et al. [41] in Ghana observed that while the age of farmers is a key factor in climate change perception, factors such as origin, educational level, and gender did not significantly influence their observations. Hasan and Nursey-Bray [60], focusing on coastal Bangladesh, highlighted that socio-economic status significantly shapes climate perceptions. Income has also been identified as a crucial determinant of climate change perception. Semenza et al. [61] found that farmers with higher income levels are likelier to be aware of climate change and its impacts. This finding is consistent with broader observations that economic resources can enhance access to information and education about climate change.

2.4.2. Farm-related determinants

Farm-related attributes significantly influence farmers' perceptions of climate change, as demonstrated by various studies. Farming experience, in particular, plays a key role in recognizing and responding to climate-induced impacts. Ojo et al. [62] highlight that older farmers, having accumulated extensive agricultural experience, possess a wealth of observation-based knowledge about the effects of climate change. This aligns with Dang et al. [63], who note that seasoned farmers develop a deep understanding of environmental changes over time through direct experience. Belay et al. [64], in their study in Ethiopia, found that factors such as household land size, access to extension services, and farming experience shape farmers' perceptions of climate change. Similarly, Suresh et al. [45] in Sri Lanka argue that membership in farmer organizations, access to climate-related information, and landholdings are crucial factors influencing farmers' awareness of climate change. These findings are consistent with recent research by Ali [57], who also observed that farmers in high-altitude areas of Pakistan, like those in Ethiopia and Sri Lanka, develop climate perceptions influenced by their farm-related attributes, including experience, access to information and land resources.

2.4.3. Institutional and environmental determinants

Institutional and environmental factors are critical in shaping farmers' perceptions of climate change. Several studies highlight the influence of both types of factors. For example, Adeagbo et al. [65] found that access to credit, extension services, farm-based organizations, climate information, and proximity to markets significantly shape farmers' climate change perceptions. These findings are supported by Abid et al. [19], who reported that the availability of extension services and market access strongly influence farmers' willingness to adapt to climate change. Similarly, Ojo et al. [62] emphasized the importance of farming experience, access to credit, agricultural training, extension services, and non-agricultural income in shaping climate perceptions.

In contrast, studying coastal Bangladesh, Hasan and Nursey-Bray [60] found that geographic features and prior disaster experiences were key factors influencing climate change perception. Maddison [66] also pointed out that outreach services, education level, soil type, and environmental conditions are crucial in shaping farmers' perceptions of climate impacts. Lastly, Khan et al. [18] highlighted the significance of advisory services and access to credit in shaping farmers' risk perceptions and attitudes toward climate change.

2.5. Theoretical framework

This study uses the Sustainable Rural Livelihood (SRL) Approach as a theoretical framework. The SRL Approach is an integrative and participatory framework that guides understanding how rural residents can enhance their livelihoods [67] while ensuring sustainability. This approach will not give reality, but it is dynamic and helps structure one's thoughts about the complex interactions in rural livelihoods [68]. Within the context of climate change, the SRL Approach emphasizes how diverse communities in rural areas can perceive the impacts of climate change based on their vulnerabilities. This framework emphasizes the significance of empowering the rural marginalized communities to take charge of their development and actively participate in policymaking processes that influence their livelihoods concerning climate issues. This framework also guides this study in recommending policies to improve farmers' resilience and adaptive capacities at the farm and household level for sustainable land-based livelihood outcomes.

2.6. Conceptual framework

The conceptual framework (Fig. 1) of this study comprises a dependent variable (Perceived Impacts of Climate Change) and several independent variables, including gender, age, education, farming experience, land holding, farming type, number of crops in a season, and cropping zones are also included as independent variables. This framework reveals how farmers' perceived impacts of climate change are influenced by their demographic and farming attributes.

3. Data and methodology

3.1. Study area

This study was undertaken in the high mountain district Nagar (see Fig. 2), situated at the intersection of the Himalaya Karakoram and Hindukush (HKH) mountain ranges in the Gilgit-Baltistan province of Pakistan [69,70]. District Nagar is divided into three agro ecological and cropping zones (single, intermediate, and double) based on the height from sea level and the number of crops produced in a calendar year [27]. The population of the Nagar district is primarily concentrated in approximately 24 villages, from 1850 to 2775 m above sea level [27]. The major source of livelihood in this region is farming, and the major land-based livelihood sources include wheat, potato, and barley, and horticultural products include fresh fruits and dry fruits [71]. The entire valley mainly relies on meltwater from glaciers and snow for irrigation [25]. Regarding workforce contributions, men are primarily responsible for earning supplementary income from non-farm activities, while women are mainly responsible for caring for the land and domestic work [71]. Out of ten districts in GB, Nagar district was chosen as a study site owing to observed variations in the climate elements like temperature, precipitation, and snowfall for the past 3-4 decades [27,36].

3.2. Research design

Given the nature of the research topic and objectives, this study utilized an Explanatory Sequential Mixed Methods design, a method previously employed by scholars in similar research (e.g., Ali et al. [69]; Ali 2023 [57]; Bacha et al. [51]; Abid et al. [19]. This approach begins with collecting and analyzing quantitative data (e.g., household surveys), followed by qualitative data collection (e.g., focus group discussions and key informant interviews) to further explain and elaborate on the initial findings [73–75]. By integrating quantitative and qualitative methods, this design provides a comprehensive understanding of complex issues, such as climate change, which impacts various aspects of life in high mountain areas in Pakistan. This mixed-methods approach is particularly effective in capturing both measurable changes in climatic variables and the lived experiences of those affected by climate change, making it well-suited for research in the social sciences [60,76,77].

3.2.1. Data collection

Quantitative data were collected using a well-structured household survey questionnaire, followed by qualitative data collection through focus group discussions (FGDs) and key informant interviews (KIIs). The survey questionnaire and key informant interview guide were designed with careful consideration of the study objectives and the nature of the research. The questionnaire was developed with input from three experts in climate science, economics, and sociology. For the household survey, respondents were selected using a random sampling technique based on the formula proposed by Yamane [78], which is used to determine the sample size for a known population with a 95 % confidence level and a P-value of 0.5 (see Equation (1)). From a total population of 7868 households in the

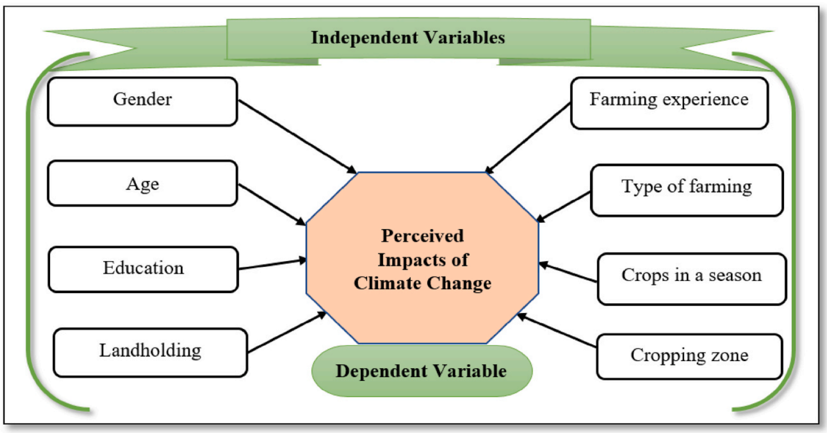

Fig. 1. Conceptual framework.

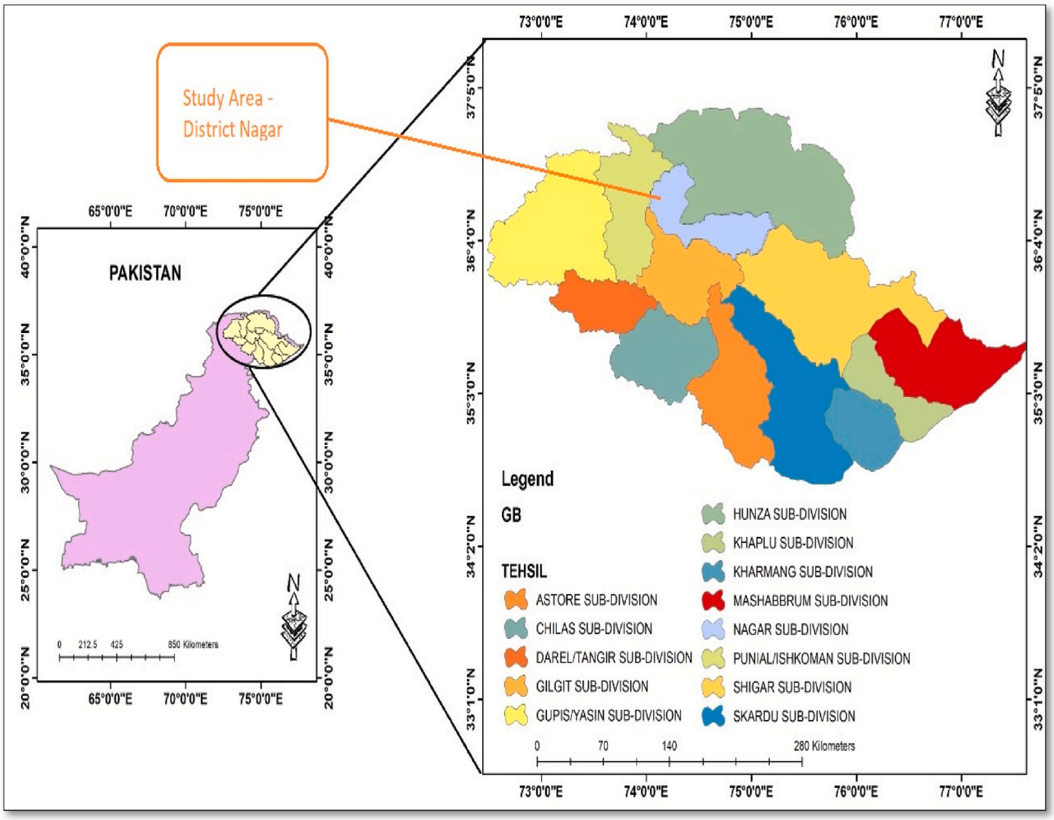

Fig. 2. Study area map Source: Ali et al. [72].

Nagar district, a sample of 381 was initially calculated. However, recognizing that a larger sample size can yield more reliable results, the study opted to increase the sample to 430 farmers.

$$n = \frac{N}{1 + N(e)^2} \quad \text{Equation (1)}$$

Here, n represents sample size, N represents population size, and e is the level of precision.

$$n = \frac{7868}{1 + 7868(0.05)^2} = 381$$

The household survey was conducted between May and August with five trained field enumerators, all undergraduate students from Karakoram International University, Hunza Campus, Pakistan. These enumerators were hired and trained to help collect data. Due to cultural sensitivities, particularly when engaging female respondents, male and female enumerators were involved in the data collection process to ensure broader participation. The researcher also encountered language barriers during the survey. To address this, questions were asked in the local languages, i.e., Shina and Brusheski, while responses were recorded in English. To ensure thorough qualitative data collection, 27 Key Informant Interviews (KIIs) and 4 Focus Group Discussions (FGDs) were conducted until

Table 1
Distribution of sample.

Tehsils	Name of union councils (UC)	Households surveyed	FGDs/Key informant interviews (KIIs)
Nagar - 1	UC – Hoper	47	2 FGDs, 9 KIIs
	UC - Nagar Proper	49	
	UC – Askurdas	54	
Nagar -2	UC – Phekar	54	2 FGDs, 18 KIIs
	UC – Ghulmit	50	
	UC – Sikandarabad	56	
	UC – Chalt	120	

Source: Authors Illustration

data saturation was reached. Key respondents—including farmers, village organization leaders, social activists, and members of local agricultural cooperatives—were purposively selected with the help of village representatives based on their ability to provide valuable insights into climate change and its impacts on land-based livelihoods. The distribution of the sample for household surveys, FGDs, and KIIs is outlined in Table 1.

3.3. Ethical considerations

This research was conducted with the approval of the Examination Committee, College of Humanities and Development Studies, China Agricultural University, China (CAU-COHD-21-2012. Given the rural setting of the study (Nagar District) and in line with ethical research principles, informed consent was secured before data collection. Participants were briefed on the study's objectives, procedures, and benefits, and voluntary consent was obtained. In the male-dominated society of the study area, special attention was given to securing permission from male household heads before interviewing female respondents.

3.4. Data analysis

Quantitative data from the structured household survey was systematically entered, cleaned, and coded in Microsoft Excel 2016. The coded data was then analyzed using SPSS version 23, employing univariate and bivariate analysis techniques. The results were presented in various formats, including figures, graphs, tables, and cross-tabulations, for clarity and better understanding. Qualitative data collected through field notes, audio recordings, and personal observations was analyzed using thematic analysis. The findings were categorized under different themes to provide deeper context and support for the quantitative results. The integration of qualitative and quantitative data is visually summarized in Fig. 3, demonstrating how both approaches complement each other to enhance the overall analysis.

The qualitative data from FGDs and KIIs were integrated with the quantitative findings to understand the observed trends and patterns better. Qualitative insights were used to explain and contextualize the quantitative results, particularly for unexpected or complex outcomes. Challenges faced during this integration included discrepancies between the two data types and the potential for bias in interpreting qualitative responses. To address these issues, findings were cross-referenced across different qualitative sources for consistency, and multiple researchers were involved in the analysis to reduce bias. A systematic coding process aligned qualitative themes with quantitative data, enhancing the validity and robustness of the conclusions. Additionally, open-ended questions encouraged participants to share their experiences freely, ensuring that the qualitative phase addressed the specific issues raised by the quantitative results without introducing bias or preconceived notions.

4. Results and discussion

4.1. Socio-economic and farm-related attributes of respondents

Table 2 presents the socio-economic and farm-related characteristics of the respondents. Of the sample, 68.1 % were male and 31.9 % female. The largest age group was 31–40 years (39.8 %), followed by 41–50 years (28.8 %) and 51–60 years (18.1 %). Regarding

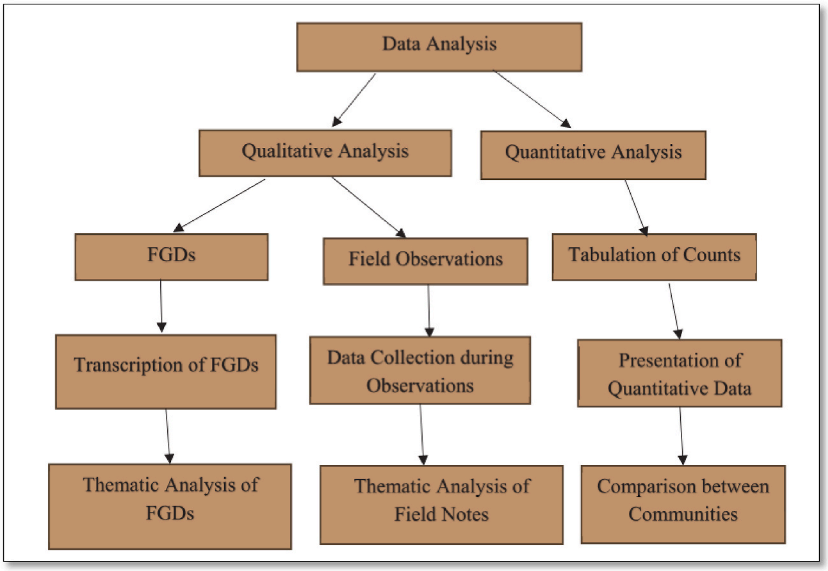

Fig. 3. Flow chart for the analysis of mixed method data.

education, 28.1 % were illiterate, 18.6 % were graduates, 14 % held postgraduate degrees, and the rest had varying middle to higher secondary education levels. Household sizes varied, with 47.2 % having 5–9 members, 26.7 % having 10–14 members, and 16.5 % having 15 or more members. Regarding farming experience, 29.1 % had over 30 years of experience, while the rest had between 10 and 30 years. Landholdings were mostly small, with 44.9 % owning 1–5 kanal and 29.8 % holding 6–10 kanal. Most respondents (48.8 %) identified as subsistence farmers, 41.4 % as mixed farmers, and 10.2 % as commercial farmers.

4.2. Respondent's major sources of livelihood in the study area

This section categorizes respondents based on their primary sources of off-farm and land-based livelihoods. As shown in Fig. 4, the majority (80.7 %) rely on agriculture as their main income source, followed by government jobs (39.1 %), business (33.7 %), pensions (23.5 %), tourism (8.4 %), private jobs (9.8 %), and labour (1.9 %). This highlights the strong dependence of most respondents on agriculture for their livelihoods. Fig. 4 also breaks down the main sources of land-based livelihoods, revealing that 85.5 % of respondents rely on crops, followed by horticultural products (59.2 %), livestock (50.7 %), and forest resources (26.3 %). This underscores the importance of crops and horticultural products as the primary components of land-based livelihoods in the study area.

4.3. Respondents perceived variations in climate change elements

Fig. 5 illustrates respondents' perceptions of climate change over the past 20 years. A large majority (86.3 %) observed an "increase in temperature," while 46.3 % noted "erratic rainfall." Regarding snowfall, 80.2 % of respondents did not observe an "increase in snowfall," and 21.6 % reported unpredictable snowfall patterns. Qualitative insights from the study reinforce these quantitative findings. During discussions about climate element variations, one key informant remarked:

> "Over the past five years, the temperature has increased, extending summer length, while snowfall has decreased. Regarding rainfall, it has increased and become erratic. He further argued that he has experienced unpredictable and unseasonal rainfall." (KII 2, October 22, 2022)

In the same way, the participants of the focus group discussion advocated that;

> "Over the past 20 years, temperature and rainfall have increased significantly while snowfall has decreased. However, participants noted snowfall has increased over the past 3–5 years. They also mentioned that the natural cycle of rainfall and snowfall has been disrupted, with no consistent timing for these events." (FGD 2, November 20, 2022).

Previous studies in the region, including Ali [79], Ali [57], Bhatta et al. [36], Spies [27], and WWF [35], have documented

Table 2
Socio-economic and farm-related attributes of respondents.

Socio-economic & farming attributes	Categories	Percent (%)
Gender	Female	31.9
	Male	68.1
Age (years)	31–40	39.8
	41–50	28.8
	51–60	18.1
	61 or above	13.3
Education	Illiterate	28.1
	Primary	9.5
	Middle	12.1
	Secondary	10
	Higher Secondary	7.7
	Graduation	18.6
	Postgraduate	14
Household size (numbers)	1–4	9.5
	5–9	47.2
	10–14	26.7
	15 & above	16.5
Farming experience (years)	Less than 10 years	21.9
	11–20 years	28.8
	21–30 years	20.2
	More than 30 years	29.1
Landholding (kanal)	1-5 kanal	44.9
	6-10 Kanal	29.8
	11-15 anal	11.4
	16-20 Kanal	6
	More than 20 kanal	7.9
Type of farming	Subsistence	48.4
	Commercial	10.2
	Mixed (Both)	41.4

Source: (Field Survey, 2022); 19.8 kanal = 1 ha

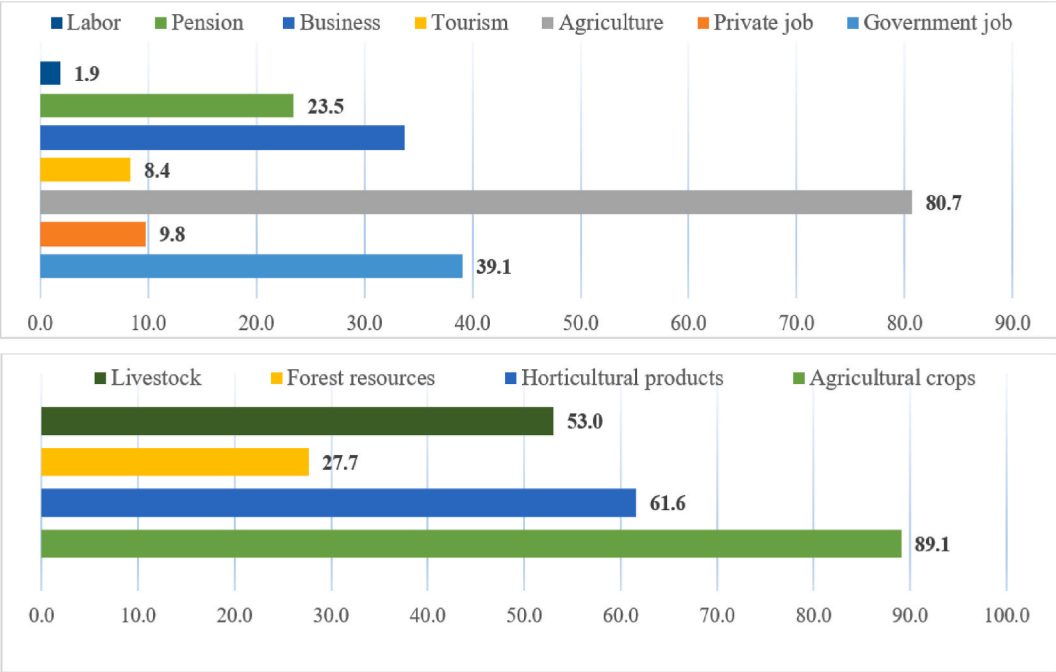

Fig. 4. Respondent's major sources of livelihoods (%).

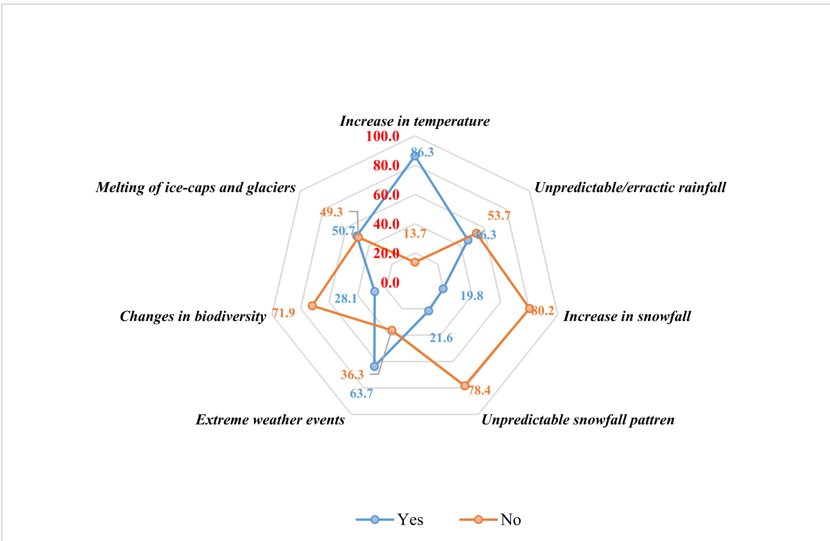

Fig. 5. Farmer's perceived variations in the climate elements (%).

significant climate variations, particularly in temperature and rainfall, which have triggered environmental events such as floods, glacier melting, and glacial lake outburst floods (GLOFs). These events have severely impacted land-based livelihoods, contributing to food insecurity [21]. The present study's findings align with these earlier reports, confirming similar climatic trends and their effects on livelihoods. However, this research provides additional insights by incorporating local perceptions of climate change and its direct impact on agricultural productivity and income. While climate-induced threats remain consistent, the study underscores the evolving local adaptation and resilience strategies, highlighting the need for more targeted policy interventions.

Fig. 5 further indicates that 63.7 % of respondents have experienced climate-induced "extreme weather events," and 71.9 % have observed a "change in biodiversity." Focus group discussions (FGD) revealed concerns that human-induced climate change has led to the disappearance of much of the region's biodiversity, including wildlife and bird species. These findings align with Bacha et al. [51], who reported similar observations of biodiversity loss in the mid-mountain areas of Swat Valley, Pakistan. Additionally, 50.7 % of respondents noted significant glacier melting over the past 20 years, corresponding with research by Spies [27] and Spies [56] in the high mountain Nagar District of Pakistan, where glacier retreat was linked to rising temperatures. This study supports these previous findings and offers deeper insights by highlighting the local impacts of glacier melting, such as reduced water availability and increased risks of GLOFs. Overall, while earlier studies have documented these environmental changes, this research provides a richer understanding of how these issues are experienced at the community level.

4.4. Impacts of climate change on respondent's land-based livelihoods

To evaluate the perceived impacts of climate change on land-based livelihoods, respondents were asked, "Has climate change affected your land-based livelihoods over the past 20 years?" The results (Fig. 6) show that 87.7 % of respondents reported that climate change has significantly impacted their livelihoods, while 12.3 % did not perceive any noticeable effects.

The study area is categorized into three agro-ecological (cropping) zones based on topography, elevation, and crop production per season [27]. Fig. 7 illustrates the perceived climate-induced impacts on land-based livelihoods across these three cropping zones. The data reveals that Zone-C experienced the highest level of perceived impacts (90.3 %), followed by Zone-B (88 %) and Zone-A (76.6 %). The elevated perception of impacts in Zone-C is primarily attributed to recent mega glacial lake outburst flood (GLOF) events, severely damaging the region's irrigation systems and agricultural land [57]. These results align with the findings of Dendir and Simane [42] in Southern Ethiopia, where farmers' perceptions of climate change impacts varied across different cropping zones.

Similarly, Bacha et al. [51] reported differential climate change impacts across agro-ecological zones in the mountainous Swat Valley, Pakistan. The current study also highlights varying perceptions of climate-induced impacts across cropping zones, with Zone-C experiencing the most severe effects due to recent GLOF events. While the findings in both Ethiopia and Swat reflect variability based on agro-ecological conditions, this study adds context by emphasizing how specific events, such as GLOFs, intensify the perceived impacts in certain zones, particularly in high-altitude areas.

4.5. Climate-induced impacts perceived by farmers over the past 20 years

Fig. 8 illustrates the climate-induced impacts perceived by farmers on land-based livelihoods over the past 20 years. The results indicate that flooding was the most commonly reported climate-induced event, with 75 % of respondents identifying it as a major issue, followed by changes in temperature (67.4 %) and landslides (61.2 %). These findings are consistent with Ajani and Geest [21], who also identified floods and heat waves as major consequences of climate variations. Similarly, studies by Bhatta et al. [36] and Spies [27] in the Nagar District reported comparable results. Participants in the focus group discussions in Union Council Hoper further corroborated these findings, highlighting the significant impacts of flooding and temperature changes on their livelihoods. *Participants in the focus group discussions in Union Council Hoper reported comparable findings.*

> "This summer, residents of Hoper Valley experienced 25 to 28 heavy floods in the village's main water channel over just 60 days. Participants in the FGD attributed these severe floods to glacial lake outburst floods (GLOFs), which have caused widespread destruction to the village's irrigation system, agricultural land, and forest resources on a massive scale." (FGD 1, November 12, 2022).

Likewise, the fourth major reported impact of climate change in the region is the prevalence of crop and horticulture diseases, affecting 54.4 % of the respondents. This is followed by decreased agricultural productivity (50.7 %), glacier retreat (50.5 %), road erosion (36.3 %), an increase in summer days (34.2 %), water channel erosion (32.6 %), a decrease in winter days (30.2 %), an increase in extreme weather events (29.5 %), and changes in flora and fauna (25.6 %). These findings are consistent with studies conducted by Hussain et al. [33] and Bhatta et al. [36] in the high mountain Hindukush-Karakoram region. Both studies report similar climate-induced impacts, particularly the rise in pest attacks, which have contributed to declining crop productivity and reduced household income, as corroborated by Baig et al. [28]. The adverse effects of climate change on agricultural productivity are not

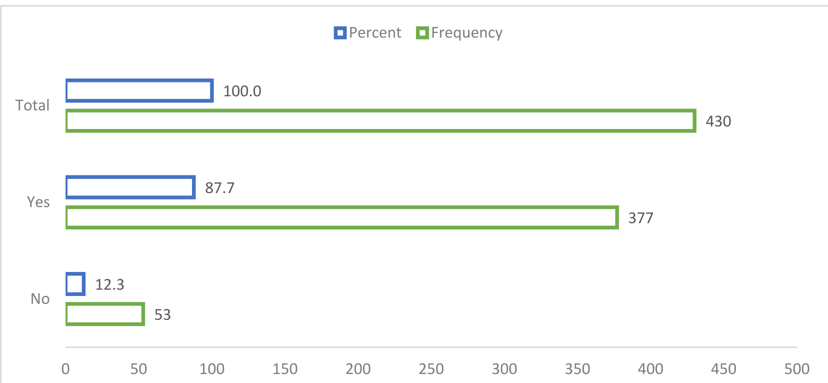

Fig. 6. Has climate change affected your land-based livelihoods.?.

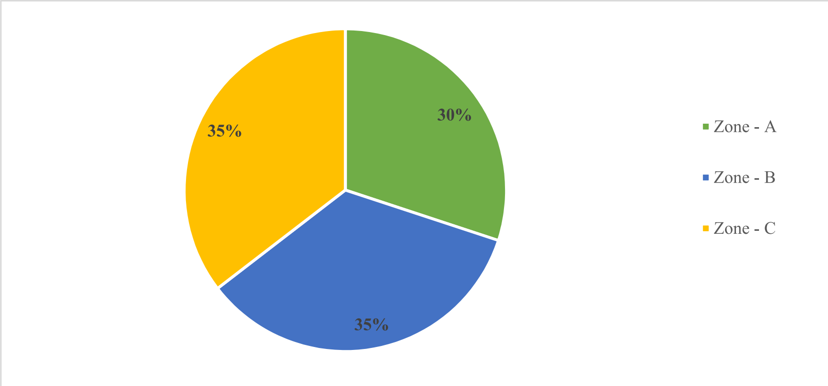

Fig. 7. Climate change impacts perceived by farmers across three cropping zones (%).

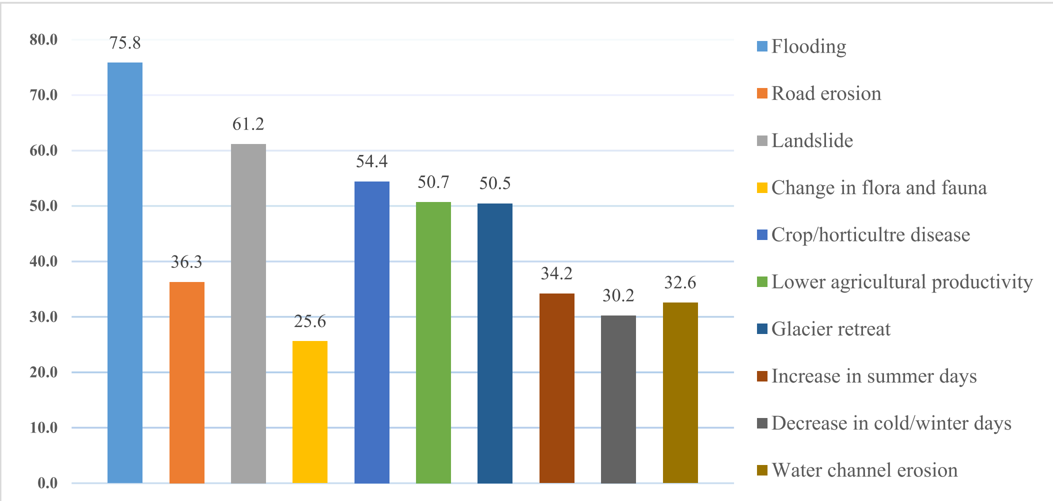

Fig. 8. Climate-induced impacts perceived by farmers (%).

limited to crop yield. Bhatta et al. [36] highlighted that plant distribution and species composition have also been affected, leading to broader ecological disruptions.

Similarly, one key informant from Minapin village emphasized that the climate changes have not only altered the growing season but have also introduced new pests and diseases, further exacerbating the challenges local farmers face. These local observations align with broader regional patterns reported in the literature, suggesting that the agricultural sector in high-mountain areas is particularly vulnerable to the cascading impacts of climate change. *While discussing the implications of climate change, one key informant from Minapin village explained:*

> "Due to changing climatic conditions, glacier melting has accelerated in Minapin, significantly reducing the length of the glaciers. As a result, water supply to the highland areas and pastures has been severely affected, causing the pastures and forests to dry up."(KII 13, November 19, 2022).

Previous studies by Spies [27,65] in the region have reported similar findings, noting that climate-induced glacier thinning has reduced water sources for irrigation in Nagar District. Similarly, Bacha et al. [51] observed glacial retreat in Pakistan's Swat Valley due to climate change, further corroborating these findings.

Some key informants from the study area highlighted the benefits of rising temperatures, stating:

> "The increase in temperature has extended the summer season and the number of summer days. This has been advantageous for us, as it now allows for double cropping in previously limited areas to a single cropping season. Additionally, we can now grow new horticultural products, such as fresh fruits like cherries and a wider variety of vegetables." (KI 14 & KI 25, November 12 & 20, 2022).

Similar studies conducted in the western Karakoram region of Pakistan found that farmers experienced improved cropping conditions due to the extended agricultural season [27,57]. However, contrasting results were reported by Abid et al. [19] in Punjab, where farmers observed longer summer seasons combined with decreased precipitation, leading to water scarcity issues in the rain-fed areas of the province.

4.6. Severity of the perceived impacts of climate change on land-based livelihoods

According to the results shown in Figs. 9 and 10, the most severe climate-induced impact farmers report is "temperature variation," with a mean value of 3.63. Approximately 34.7 % of respondents considered this hazard very severe. The second-ranked severe impact is "rainfall variation," with a mean value of 2.95, deemed very severe by 22.6 % of respondents. This issue was also highlighted in key informant interviews and focus group discussions, where participants shared:

> "For several years, we have observed unpredictable rainfall patterns in this region, which is detrimental to land-based livelihoods. Over the past 20–30 years, we have experienced less rainfall during the spring cultivation season, while more rainfall has occurred during the harvesting season (July–September), leading to the destruction of standing crops, the loss of horticultural products, and post-harvest losses." (FDG 4; KII 9, KII 12 & KII 24).

The third-ranked severe hazard identified by farmers is "landslides," with a mean value of 2.88, with almost 20 % of respondents considering it a severe threat to crops and horticulture. These findings align with studies by Ali et al. [69] and Hussain et al. [26] in Pakistan's high mountain areas, both of which reported climate-induced landslides as a major threat. Additionally, "floods" were identified as the fourth most severe climate-induced hazard in the study area. The fifth-ranked hazard was a "decline in snowfall," with a mean value of 2.80. GLOF (Glacial Lake Outburst Flood)-induced floods were perceived as very severe by 27.7 % of respondents. One key informant from UC Hoper elaborated on this issue, stating:

> "This year, we experienced heavy floods in July and August due to GLOF events. As a result, around 22 main water channels were severely damaged, causing a serious water crisis for irrigation in September and November. Furthermore, snowfall is the primary water source for irrigation during the cultivation season. Still, with the sharp decrease in annual snowfall over the past several decades, we have also faced water shortages, particularly in early spring, which is the cultivation season in this region." (KII 6, November 12, 2022).

A recent study by Ali et al. [69] in Gilgit-Baltistan reported similar findings, noting that climate-induced GLOF events and floods have significantly disrupted agricultural activities, leading to declining household food security.

4.7. Farmer's opinion on the impacts of climate change on land-based livelihoods

This section examines farmers' perceptions of various climate-induced impacts on land-based livelihoods. Based on descriptive statistics, the statements are ranked first to last, as shown in Table 3. This ranking highlights the most significant impacts of climate change. According to Table 3, the most influential impact perceived by farmers is statement number 6, with a mean value of 3.96 and a mode of 4. The mode value of 4 indicates that most respondents agreed with this statement. The second-ranked perceived impact is statement number 7, with a mean value of 3.86 and a mode of 4, again suggesting broad agreement. While discussing the negative impacts of climate change, a key informant from UC Ghulmit shared:

> "Rising temperatures have severely impacted the production of our traditional fruits, such as apricots and apples. In recent years, we've also witnessed unpredictable rainfall during apricot flowering, leading to diseases like 'black dots,' which have

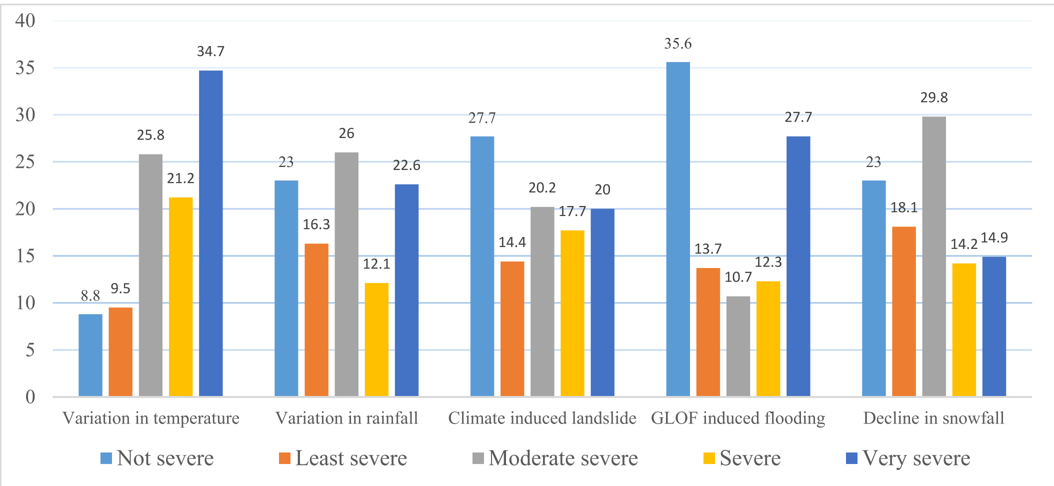

Fig. 9. Severity of the impacts of climate change on land-based livelihoods (%).

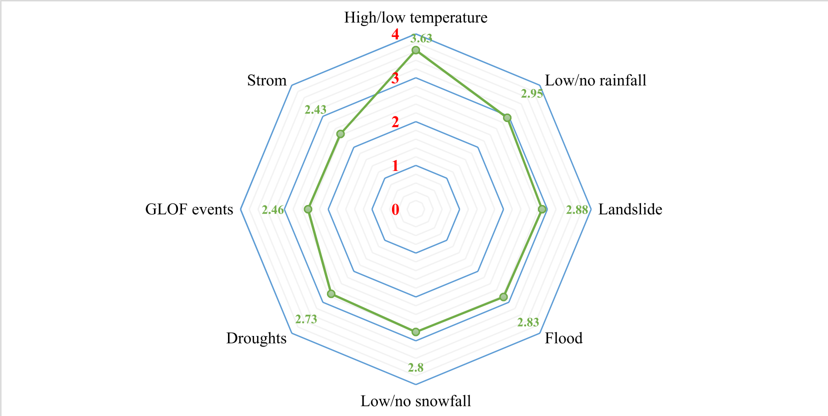

Fig. 10. Ranking of the severity of the impacts of climate change.

Table 3
Farmers opinion about the impact of climate change on land-based livelihoods.

Opinion Statements	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Mode	Rank
[1] The uneven seasons have badly affected crops and horticultural production.	5.6	29.5	37.5	22.8	0.7	3	*9*
[2] As a result of climate change, soil fertility has decreased over the years.	6.3	29.5	36.8	22.8	0.7	3	*10*
[3] As a result of climate change, crop yields have decreased over the years.	7.4	30.8	6.5	27.7	23.7	2	*5*
[4] Experiencing drying of crops owing to climate-induced reduction in soil moisture.	8.3	31.9	11.2	26.3	18.3	2	*7*
[5] As a result of climate change, the amount of water used for irrigation has decreased.	12.1	0.2	6.5	57.6	19.6	4	*3*
[6] Climate change-induced consequences have caused crop infection and diseases.	6.0	4.9	4.2	52.9	27.9	4	*1*
[7] Climate change-induced consequences have caused horticulture infestation and diseases.	6.0	7.1	4.2	55.1	23.4	4	*2*
[8] Climate change has caused the premature ripening of fruits and a reduction in the quality of fruits.	5.1	25.9	6.9	26.8	31.3	5	*4*
[9] Erratic rainfall and snowfall have affected the production of fruits and crops.	6.0	29.0	10.9	34.8	15.2	4	*6*
[10] Climate change has led to a decline in forest resources.	10.5	32.6	11.4	27.5	14.1	2	*8*

Note: 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree.

> reduced apricot yields. Cold waves caused by climate change have badly affected wheat production due to a local disease called 'Barchi." (KII 13, November 19, 2022).

Similar findings were reported by Suresh et al. [45] and Ullah et al. [3], who identified pests and crop diseases as significant impacts of climate change. Hussain et al. [33] also reported increased pest attacks in the high mountainous Hindukush-Karakoram region, leading to a decline in crop productivity. The third-ranked impact, statement number 5, had a mean value of 3.76, with a mode of 4, indicating that most respondents also agreed with this statement. Regarding the adverse effects of climate change on irrigation, a key informant noted:

> "This region relies heavily on glacial and snowmelt for irrigation, with more snowfall contributing to better soil moisture. However, over the past two decades, we've seen a sharp decline in snowfall, resulting in reduced soil moisture and lower crop production. For example, UC Phekar, with its higher annual snowfall, enjoys better soil moisture than UC Askurdas. We've been facing water shortages for irrigation in early spring due to this lack of snowfall." (FGD 2, November 23, 2022).

These findings are consistent with Žurovec and Vedeld [38], who reported declining water availability due to rising temperatures in Eastern Europe. Suresh et al. [45] and Sraku-Lartey et al. [41] similarly found that climate change has contributed to water shortages. Statement number 8 ranked fourth, with mean and mode values of 3.55 and 5, respectively, showing that most respondents strongly agreed. The fifth-ranked impact, statement number 3, had a mean value of 3.31, with a mode of 2, indicating disagreement among respondents. During a focus group discussion at UC Askurdas, participants shared:

> "Rising temperatures have disrupted the natural cycle of agricultural activities, negatively affecting the taste and quality of crops and horticultural products, especially fresh fruits. Heatwaves and erratic rainfall have damaged fruits like peaches, grapes, and pears, while we've also noticed burning in crops like wheat and potatoes. In addition, new insect infestations have emerged, attacking crops and fruits over the past 4–5 years." (FGD 4, November 27, 2022).

The sixth-ranked climate-induced impact on land-based livelihoods, statement number 9, had a mean value of 3.25 and a mode of 4, indicating agreement. Participants in UC Ghulmit expressed concerns about unpredictable rainfall:

> "In the past 10 years, we've experienced unpredictable, non-seasonal rainfall. In the last 2–3 years, intense out-of-season rains have damaged standing crops and reduced fodder production. Excessive rainfall has lowered wheat production and negatively impacted grain quality and size." (FGD 2, November 20, 2022).

These results align with a study by WWF [35], which reported that climate-induced extreme events have consistently affected major crops, pastures, and livelihoods in Nagar Valley over the past three decades. Similarly, Ateeq-Ur-Rehman et al. [6] noted that unscheduled rains and floods have negatively impacted agricultural output and income in Rajanpur, Pakistan. The seventh-ranked impact of climate change, statement number 4, had a mean value of 3.15 and a mode of 2, suggesting disagreement. These findings are consistent with those of Žurovec and Vedeld [38] in Southern Europe, where declining crop yields and the decreased quality of agricultural products were noted as major impacts of climate change. Furthermore, farmers in the study area reported water shortages due to rising temperatures. One key informant, a local welfare officer, mentioned some positive impacts of climate change, particularly rising temperatures:

> "In my observation, the weather has changed significantly compared to the past. Warmer temperatures have positively impacted land-based livelihoods in Union Council Hoper. Now, we can grow fresh fruits like apricots, cherries, and apples and cultivate vegetables like tomatoes, beans, and onions, which wasn't possible before due to cold weather and heavy snow." (KII 6, November 12, 2022).

Statement number 10 ranked eighth, with a mean value of 3.02 and a mode of 2, indicating disagreement among most respondents. The ninth-ranked impact, statement number 1, had mean and mode values of 2.83 and 3, respectively, suggesting neutral responses. Similar findings were reported by Hussain et al. [33] in the Hindukush-Karakoram region, where climate-induced pest attacks have led to a decline in crop productivity. The lowest-ranked impact, statement number 2, had a mean value of 2.81 and a mode of 3, indicating neutrality. This suggests that many respondents did not see climate change as the primary cause of declining soil fertility. Bhatta et al. [36] argued that in Nagar District, soil fertility decline is more closely linked to the overuse of chemical fertilizers and pesticides, which farmers employ to make their crops more climate-resilient. However, excessive use of these chemicals degrades soil fertility over time. Participants in UC Phekar echoed these concerns:

> "Farmers lack awareness of smart farming practices and rely heavily on chemical fertilizers to quickly improve soil fertility. While this works in the short term, it harms soil fertility in the long run. Nowadays, it seems impossible to grow crops without chemical fertilizers." (FGD 3, November 26, 2022).

One key informant, the president of a village agricultural cooperative society, raised concerns about glacier melting:

Table 4
Association between socio-economic/farming variables and the perceived impacts of climate change by farmers.

Variables	Category	Perceived impacts of climate change on land-based livelihoods			Gamma Value	Chi-square	P-value
		Yes (%)	No (%)	Total (%)			
Gender	Female	27.4	4.4	31.9	0.1	0.44	0.51^{NS}
	Male	60.2	7.9	68.1			
Age	31–40	36	3.7	39.8	−0.2	4.02	0.26^{NS}
	41–50	25.1	3.7	28.8			
	51–60	15.8	2.3	18.1			
	61 or above	10.7	2.6	13.3			
Education	Illiterate	23.5	4.7	28.1	0.2	11.62	0.07^{NS}
	Primary	7.9	1.6	9.5			
	Middle	10.7	1.4	12.1			
	Secondary	8.8	1.2	10			
	Higher Secondary	6	1.6	7.7			
	Graduation	17.9	0.7	18.6			
	Postgraduate	12.8	1.2	14			
Farming experience	<10 years	18.6	3.3	21.9	−0.9	7.53	0.05*
	11–20 years	26.3	2.6	28.8			
	21–30 years	18.8	1.4	20.2			
	>30 years	24	5.1	29.1			
Land holding	1-5 kanal	38.8	6	44.9			
	6-10 kanal	26.5	3.3	29.8	0.06	0.49	0.97^{NS}
	11-15 kanal	10	1.4	11.4			
	16-20 kanal	5.3	0.7	6			
	>20 kanal	7	0.9	7.9			
Type of farming	Subsistence	41.6	6.7	48.4	0.2	5.7	0.05*
	Commercial	8.1	2.1	10.2			
	Mixed	37.9	3.5	41.4			
No. of crops in a year	Single	36.9	58.5	39.5	0.4	9.08	0.003**
	Double	63.1	41.5	60.5			
Cropping zone	Single	9.5	20.8	10.9	0.3	6.46	0.04*
	Intermediate	48.5	47.2	48.4			
	Double	41.9	32.1	40.7			

"Temperatures have increased sharply, and we've witnessed rapid glacier melting over the past several years. This is alarming, and if glaciers continue to disappear, we could face severe water shortages for agriculture." (FGD 3, November 26, 2022).

These findings align with research by Ullah et al. [3] in Khyber-Pakhtunkhwa, Pakistan, which identified crop diseases, water shortages, and soil fertility loss as significant climate-induced impacts on land-based livelihoods.

4.8. Bivariate analysis: Association between the farmer's perceived impacts of climate change and socio-economic and farm-related characteristics

Table 4 describes the relationship between socio-economic and farming variables and farmers' perceived climate impacts using bivariate analysis (cross-tabulation). Table 5 reveals a significant negative association between farming experience and climate-perceived impacts, with Chi-square (7.53), Gamma (−0.9), and P (0.05*) values indicating that as farming experience increases, perceived climate impacts decrease. These results align with the finds of Abid et al. [19]. This suggests that older farmers, while more experienced, may have less awareness of changing climate conditions. Results in Table 4 further show that the type of farming has a significant positive association with perceived climate impacts, supported by Chi-square (5.7), Gamma (0.2), and P (0.05*) values. Additionally, the "number of crops per year" is positively associated with perceived impacts, as shown by Chi-square (9.08), Gamma (0.4), and P (0.003**), indicating that more crops lead to higher perceived impacts. Similarly, "cropping zones" have a significant positive association with climate impacts, with Chi-square (6.46), Gamma (0.3), and P (0.04*), showing that farmers in intermediate and double-cropping zones perceive more impacts than those in single-cropping zones.

The results in Table 4 further indicate that gender, age, education, and landholding have a non-significant association with climate change perception. Gender may not influence perception because male and female farmers experience similar climatic changes. Similarly, age-related differences are minimal, as individuals across age groups are equally exposed to climate impacts like erratic rainfall, with older individuals relying on experience and younger ones informed by education or media. These results align with the findings of Ali [57] and Sraku-Lartey et al. [41]. However, contrasting results were reported by Funatsu et al. [59], who found that climate change perception tends to increase with age and gender, with male farmers being less likely to perceive changes in the climate compared to their female counterparts. Education may also not significantly shape climate perception, as practical experience with land and weather patterns can outweigh formal education in rural areas. Thus, even those with less formal education may recognize climate change. While Maddison [66] found contrasting results, highlighting that education plays a significant role in shaping climate change perception. Landholding size similarly has little effect, as farmers with both large and small plots face common climate challenges, leading to a shared understanding of climate risks. Therefore, land size does not substantially alter one's perception of climate change impacts.

4.9. Hypothesis testing

Table 5 presents the results of hypothesis testing and decisions against each hypothesis through a non-parametric (Chi-square) test at a 5 % (α = 0.05) significance level. Results in Table 5 *"fail to reject the null hypothesis"* numbers 1, 2, and 3, while for hypothesis numbers 4 and 5, *"null hypothesis rejected alternate hypothesis accepted"*.

5. Conclusion and policy implications

This empirical investigation sheds light on the farmer's perceived impacts of climate change on high mountain land-based livelihoods in the high mountain Nagar district in Gilgit-Baltistan, Pakistan. Through rigorous fieldwork using mixed methodology, this study uncovered significant climate-induced challenges local farmers face. The study revealed that variations in climate elements, such as temperature, precipitation, and snowfall, have triggered extreme climate events, including floods, glacial lake outburst floods (GLOFs), glacial retreats, landslides, heat waves, and cold waves. Over the years, these climate events have significantly impacted the land-based livelihoods of local farmers. The study further revealed that farmers in this remote region have observed a marked decline in the production of crops and horticultural products due to climate-induced diseases. Additionally, water availability for irrigation, especially during the spring season, has decreased, further affecting land-based livelihoods. The study further revealed that farmers in single-cropping zones perceived climate-induced impacts more acutely and were significantly more vulnerable to these effects.

The study emphasizes the urgent need for targeted government intervention and agricultural planning to enhance the resilience of farmers in the Nagar District. It calls for a comprehensive approach that includes sustainable, climate-resilient farming practices. To achieve this, government and non-governmental organizations should introduce innovative, climate-resilient, and disease-tolerant seeds. Traditional irrigation methods like glacier grafting and ice stupas should be promoted to address water shortages. The research underscores the importance of improved irrigation, crop disease management, and tailored support for high-mountain farming practices. It also highlights the need for effective adaptation strategies to protect vulnerable farming communities from climate change impacts, contributing to a better understanding of climate change effects on high-mountain agriculture. These interventions can be supported through targeted government funding, partnerships with international development organizations, and the involvement of local communities in planning and execution. A collaborative and localized climate adaptation framework will build resilience in these fragile ecosystems. Beyond the regional context of Nagar, these findings have broader implications for climate adaptation policy in other high-mountain agricultural regions. Governments, international organizations, and climate adaptation agencies can leverage these insights to inform climate-resilient agricultural strategies, particularly for remote and vulnerable

Table 5
Hypothesis testing for perceived impacts of climate change by farmers.

Sr.	Hypothesis	(x^2)	(α)	Decision
H:1	**Ho:** There is no difference among the male and female farmers' perceived impacts of climate change. **Ha:** There is a significant difference between the male and female farmers' perceptions of the impacts of climate change.	$x^2 = 0.04$	0.51	Fail to reject the null hypothesis.
H:2	**Ho:** There is no difference between the young and old farmers' perceived impacts of climate change. **Ha:** There is a significant difference between the young and old farmers' perceived impacts of climate change.	$x^2 = 4.02$	0.26	Fail to reject the null hypothesis
H:3	**Ho:** Education has no association with farmers' perceptions of the impacts of climate change. **Ha:** Education has a significant association with farmers' perceptions of the impacts of climate change.	$x^2 = 11.6$	0.07	Fail to reject the null hypothesis
H:4	**Ho:** Farming experience has no association with farmers' perceptions of the impacts of climate change. **Ha:** Farming experience is significantly associated with farmers' perceptions of the impacts of climate change.	$x^2 = 7.53$	0.05*	Null hypothesis rejected Alternate hypothesis accepted
H:5	**Ho:** There is no difference in climate change perceived impacts among farmers in different cropping zones. **Ha:** Climate change perceived impacts among farmers in different cropping zones are significantly different.	$x^2 = 6.46$	0.04*	Null hypothesis rejected Alternate hypothesis accepted

communities. A comprehensive, multi-faceted approach is required to safeguard land-based livelihoods in the face of climate change.

CRediT authorship contribution statement

Iftikhar Ali: Formal analysis, Data curation, Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. **Ashfaq Ahmad Shah:** Supervision, Software, Methodology, Investigation, Formal analysis, Writing – review & editing. **Bader Alhafi Alotaibi:** Visualization, Validation, Funding acquisition, Writing – review & editing. **Amjad Ali:** Software, Resources, Project administration.

Limitations of the study

The study area operates under a patriarchal society, making it challenging for a male researcher to interact with female respondents for data collection directly. A group of female enumerators from a local university assisted with the data collection process to address this. As a result, the researcher interviewed 137 female respondents, representing 31.1 % of the total sample size (430). Additionally, due to difficult terrain and remoteness, the lack of adequate weather stations in Pakistan's high mountainous rural areas limits the availability of scientific climate data. In Nagar Valley, the study area, there is no weather station to collect data on climate elements such as temperature and precipitation. The researcher used data from weather stations in the adjacent Hunza district to overcome this. The researcher also encountered language barriers during data collection, as many respondents were illiterate.

Disclosure statement

The authors reported no potential conflict of interest.

Data availability statement

Data will be provided by the author upon request via email (iftikhar.ds@kiu.edu.pk; shahaa@cau.edu.cn).

Ethical statement

This research was conducted with the respondents' consent according to approval guidelines of the ethical review committee, College of Humanities and Development Studies, China Agricultural University (CAU), Beijing 100,193, China (CAU-COHD-21-2012).

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used ChatGPT 3.5 to improve the manuscript's language. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e39877.

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