Climate Change Perception and Environmental Impacts in the Himalayan Region of Pakistan

Seema Batool[1], Naveed Abbas[2], and Waseem Haider[3,*]

[1]Department of Development and Environmental Studies, Paris-Saclay University, Paris, France
[2]Department of Electrical Engineering Technology, Karakoram International University, Gilgit, Pakistan
[3]Faculty of Engineering and IT, University of Technology Sydney, Sydney, Australia
Email: seemahaider417@gmail.com (S.B.); Naveedhaider416@gmail.com (N.A.); waseem.haider1@uts.edu.au (W.H.)
*Corresponding author

Manuscript received September 2, 2025; revised November 19, 2025; accepted December 23, 2026; published May 25, 2026

***Abstract*—Climatic change poses a growing threat to rural livelihoods in Gilgit-Baltistan, Pakistan, where a strong dependence on climate-sensitive natural resources significantly increases vulnerability. This study evaluates the adaptive capacity, livelihood strategies, and climate responses of rural communities exposed to increasing climate variability. Data were collected from 371 respondents across ten districts using semi-structured interviews, participatory rural appraisals, and direct field observations, and were analysed through percentage analysis, trend analysis, and chi-square tests. The results reveal that climate change has adversely affected agricultural productivity, with farmers reporting declining soil fertility, rising pest infestations, water scarcity, and premature crop maturation. These impacts disproportionately affect households reliant on subsistence farming, highlighting the heightened socioeconomic vulnerability of marginalised and indigenous tenant farmers. The study provides empirical evidence on local adaptation practices and identifies key constraints to effective adaptation, offering policy-relevant insights for strengthening climate-resilient and sustainable livelihood strategies in high-altitude regions.**

***Keywords*—environmental change, smallholder farmers, Himalayan region, livelihoods, adaptation, barriers to adaptation**

I. Introduction

Climate change has emerged as a major threat to rural livelihoods worldwide, particularly in mountainous regions where communities depend heavily on climate-sensitive natural resources. In the Himalayan region of Northern Pakistan, smallholder farmers face growing uncertainty as shifting weather patterns alter water availability, soil conditions, and cropping cycles. Gilgit-Baltistan—characterised by fragile agroecological systems, limited arable land, and isolated settlements—is highly vulnerable to even minor climatic fluctuations. Despite increasing recognition of these risks, empirical evidence documenting how rural households perceive climate change and how such perceptions shape livelihood responses remains limited for this region. Climate change is indubitable and has differential impacts across regions of the world. The most recent IPCC assessments (2021–2023) highlight unprecedented climatic alterations occurring more frequently and intensely, with particularly severe consequences for geographically isolated communities [1]. Individuals who rely heavily on natural resources—especially in agriculture, forestry, and pastoral systems—bear the greatest burden of these environmental changes. In Himalayan Pakistan, climate change is disrupting established precipitation patterns, shortening winter snowfall periods, and amplifying livelihood uncertainty for rural households [2, 3]. Resource limitations, environmental pressures, and the availability of information shape farmers' perceptions and responses to climate change. Evidence from [4] shows that although rural households generally recognise increasing climate risks, their ability to adapt remains constrained by socioeconomic vulnerabilities, institutional barriers, and limited support services. Similarly, Shahzad *et al*. [5] reports substantial variation across agro-ecological zones, where awareness of climate change is relatively high but the adoption of adaptation strategies is uneven, highlighting gaps in local capacity and resource access. Together, these studies emphasise the need for targeted interventions to strengthen climate resilience among farming communities. Pakistan ranks among the most climate-vulnerable countries in South Asia, facing recurrent droughts, rising temperatures, pest outbreaks, health challenges, and seasonal livelihood disruptions—all of which are projected to intensify [6, 7].

Climate variability increasingly threatens agricultural livelihoods across Asia. In Pakistan's high-altitude Himalayan region, Gilgit-Baltistan is warming faster than the global average, intensifying pressure on agriculture that underpins rural livelihoods [8]. Alongside climate stress, land degradation and chemically degraded soils further limit productivity, making soil-quality restoration essential for sustaining crop yields in mountain farming systems [9]. Concurrently, shifting climatic conditions are altering water flows, biodiversity, ecosystem structure, and the frequency of natural hazards such as landslides and glacial lake outburst floods, further affecting socioeconomic systems and community resilience [10, 11]. These multilayered challenges underscore the urgency of strengthening adaptive capacity and ensuring robust climate-risk management frameworks for mountain communities. Agriculture is one of the most climate-sensitive economic sectors and is affected both positively and negatively by climate change [12]. Evidence shows that variations in temperature, rainfall patterns, and extreme weather events directly influence crop productivity, household income, and poverty outcomes. In Pakistan's Northern Irrigated Plain and Northern Dry Mountains, changing temperature and rainfall regimes have altered wheat yields, increased pest and disease incidence, and affected food quality [13]. The country's dependence on glacier-fed water systems further compounds vulnerability: much of Pakistan's agricultural water is supplied by rivers originating in the Himalayas and Karakoram ranges. Accelerated glaciers melt and changing hydrological conditions have increased the formation of glacial lakes, heightening the risk of glacial lake

doi: 10.18178/ijesd.2026.17.3.1582

outburst floods (GLOFs) along the Hindu Kush–Karakoram–Himalaya region (HKH) corridor [14]. Studies also highlight how climate and environmental change shape farmers' perceptions and adaptive responses. For instance, [15] documents change in forest cover and climate in Skardu, showing how environmental degradation interacts with local livelihood systems. Households in high-altitude farming regions rely heavily on traditional knowledge and local experience to interpret climatic signals and adjust farming decisions accordingly. Broader research further demonstrates that climatic variability affects both human and natural systems, with implications for sustainable development trajectories across mountain regions. This study contributes a novel perspective by offering an integrated assessment of: (i) rural households' perceptions of shifting weather patterns; (ii) the socioeconomic consequences of these changes for smallholder farmers; and (iii) the adaptive capacity of marginalized indigenous tenants—groups often overlooked in vulnerability assessments. Using trend analysis, chi-square tests, and participatory field methods, this research provides empirical evidence on how climate risks are experienced, interpreted, and managed at the household level. The principal results reveal multi-dimensional vulnerabilities: farmers report declining soil fertility, reduced wheat yields, rising pest prevalence, water scarcity, and increased dependence on forest resources—factors that collectively diminish agricultural productivity, lower household income, and undermine overall well-being. These findings show that community perceptions closely mirror observable environmental changes, underscoring the value of integrating local knowledge into climate-adaptation planning. Guided by these gaps, the study tests hypotheses on whether climate change is reducing agricultural productivity, whether farmers are aware of its impacts, and whether they are adopting coping strategies to mitigate risks. These hypotheses are significant because they help identify which socioeconomic groups are most exposed and how adaptation varies by landholding size, income level, and livelihood dependence. Accordingly, the objectives are to document the impacts of weather changes on land resources and livelihoods; quantify effects on income, poverty, wheat production, and forest use; examine farmers' perceptions of climate patterns; assess consequences for agricultural output and household well-being; and identify the adaptation measures employed. The findings provide policy-relevant evidence to strengthen climate-resilient rural development in the Himalayan region of Pakistan.

II. Literature Review

A structured review of the literature is essential to understand the global context of climate change, Pakistan's unique climate vulnerabilities, and the specific livelihood challenges faced by Gilgit-Baltistan communities. Climate change refers to long-term shifts in temperature, precipitation, and atmospheric patterns driven by natural variability and human induced greenhouse gas emissions [16]. Rising global temperatures have intensified climatic, geological, ecological, and socioeconomic disruptions—such as glacier retreat, floods, droughts, and cyclones—that disproportionately affect mountain communities [17]. Remote and indigenous populations are particularly vulnerable because of their dependence on natural resources, geographic isolation, and limited adaptive capacity [18]. While major emitters such as the United States and China contribute most to global greenhouse gas emissions, low-emitting countries like Pakistan face severe climate impacts due to fragile ecosystems and limited resources for adaptation [19, 20]. This disparity is central to contemporary climate-justice debates, with Global South countries emphasizing their disproportional exposure to climate hazards and the need for robust loss-and-damage financing [21]. Recognizing these global dynamics helps contextualize Pakistan's high climate risk. Pakistan exhibits diverse climatic conditions—from glaciers and high-altitude cold deserts in the north to arid and semi-arid regions in the south—and has experienced significant warming and altered precipitation patterns over recent decades [22]. Mountainous northern regions, including Gilgit-Baltistan, Kashmir, Chitral, and Swat, remain highly susceptible to extreme climatic events such as heavy rainfall, snow avalanches, landslides, and GLOFs, all of which pose direct threats to agriculture and rural livelihoods [23]. Changes in temperature, rainfall variability, and hydrological systems influence monsoon cycles and moisture distribution, disrupting cropping calendars, increasing drought risks, and altering water availability [24]. These shifts cascade through ecological systems, affecting runoff patterns, forest resources, and water-dependent livelihoods [25]. Additionally, biophysical constraints, remoteness, and socioeconomic marginalization limit the adaptive capacity of mountain communities, heightening their vulnerability [26]. Gilgit-Baltistan is home to approximately 2.4 million people and hosts some of the world's highest mountain ranges, including the Karakoram, western Himalayas, and Hindu Kush [27]. These ranges contain iconic peaks—such as K2 and Nanga Parbat—and extensive glacier systems (e.g., Baltoro, Biafo, Batura) that shape the region's hydrology and ecology. Despite the importance of glacier-fed water, only about 40% of households in the region have access to piped water, leaving most families dependent on natural streams and channels [28]. Rugged topography and climatic extremes heighten exposure to hazards such as flash floods, avalanches, and landslides [29]. Climate change has further accelerated forest loss, altered cropping cycles, increased disease prevalence, and reduced biodiversity, threatening the livelihood security of smallholder farmers [30]. In response, households are adopting various adaptation strategies, including changing crop varieties, altering planting schedules, investing in water-saving irrigation, and diversifying income sources [31]. However, the speed and magnitude of climate change increasingly exceed the adaptive capacity of rural communities. Agricultural vulnerability refers to the degree to which farming systems are exposed to and sensitive to climate-induced risks [32]. Globally, temperature variability and irregular rainfall have reduced yields of staple crops such as rice (Vietnam), wheat (Turkey), and maize (Nepal), although in some contexts increased precipitation partially offsets warming effects [33]. Adaptive capacity varies widely across regions—high-income countries possess stronger institutional and technological resources, whereas low-income regions remain significantly constrained [34]. Climate-induced droughts, declining soil moisture, altered hydrology, and increasing frequency of extreme weather events have intensified production risks, reduced yields, and heightened livelihood insecurity. These cascading effects contribute to rising poverty, reduced household income, and declining nutritional well-being. Understanding how farmers perceive these risks, and how such perceptions influence adaptation behaviour, is critical for designing effective and equitable resilience strategies in climate-sensitive regions.

Fig. 1. Study area of Gilgit Baltistan.

III. Methodology

This study investigated how climate change affects isolated mountain communities in Gilgit-Baltistan using a mixed-methods approach that combined quantitative household surveys with qualitative interviews and focus group discussions. Data were collected from 371 households on demographics, farming practices, land use, resource access, technology, financial factors, and climate-change perceptions. Multiple measures—such as careful questionnaire design, interviewer training, pretesting, post-editing, and administering the survey in the local language—ensured reliability and validity. The findings consistently show that climate change is creating serious challenges for agriculture in the region, emphasising the need for stronger and more targeted adaptation strategies. The survey was conducted across the entire region of Gilgit-Baltistan, Pakistan, with a specific focus on the following districts: Nagar, Hunza, Gilgit, Diamer, Ghizar, Kharmang, Skardu, Shigar, Astore, and Ghanche.

A. Sampling Methodology

A total of 371 rural households were surveyed for this study. The sample size was determined using the standard finite-population sample-size formula at a 95% confidence level and a 5% margin of error to ensure statistical representativeness across Gilgit-Baltistan. Given the geographic and livelihood diversity of the region, a stratified sampling approach was employed. The sample size calculation is as follows:

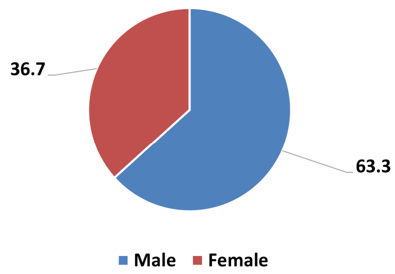
$$n = \frac{NZ^2 p(1-p)}{e^2(N-1)+Z^2 p(1-p)} \quad (1)$$

where N is the total number of rural households in Gilgit–Baltistan, $Z = 1.96$ corresponds to the 95% confidence level, $p = 0.5$ is the assumed population proportion used to maximize sample size, and $e = 0.05$ is the acceptable margin of error. The resulting estimate closely aligns with the achieved sample of 371 households.

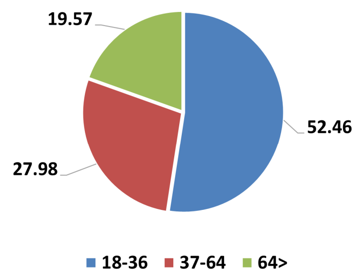
All ten districts of Gilgit-Baltistan were included as separate strata to capture variations in climate exposure, elevation, landholding size, and agricultural dependence. The selected districts are Hunza, Nagar, Gilgit, Ghizer, Diamer, Astore, Skardu, Shigar, Ghanche and Kharmang. These districts were chosen because they represent the full range of agro-ecological zones—upper, central, and lower GB—allowing for a comprehensive assessment of household perceptions of climate change and associated livelihood impacts. Fig. 1 presents a map of these ten districts and illustrates the geographical coverage of the study area. Within each district, villages were selected proportionally to their population size. From each selected village, households were chosen using systematic random sampling, ensuring that farming families from different ecological settings and socioeconomic backgrounds were adequately represented. This multi-stage stratified design provides a robust dataset for analysing climate perceptions, agricultural vulnerability, and adaptation strategies across the Himalayan region of Northern Pakistan. which have experienced significant climate change effects over the past 10–20 years. From April to June 2024, semi-structured interviews were conducted with residents aged 18 and above, with village leaders supporting participant selection and interview coordination. The sample comprised 63.3% males and 36.7% females, with 52.46% aged 18–36, 27% aged 37–64, and 19.57% aged 65 and above. Occupationally, respondents included government employees (30.14%), farmers (26.30%), private-sector workers (16.16%), unemployed individuals (15.07%), and business owners (12.32%). The demographic and occupational distributions are presented in Fig. 2.

B. Data Sources

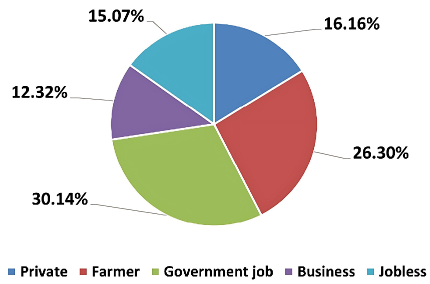
The primary data was obtained via semi-structured questionnaires and interviews. Interviews were conducted with key figures in the community, including the village's representatives, different societies, and local people aged 18-80. The community representative of the village affairs holds considerable respect. In addition, in a strategic move to gather precise insights, personal interactions were facilitated with the Duty Director of Agriculture and many other agricultural societies in each district, underscoring the significance attached to the data acquisition process, and climate specialists were engaged to provide opinions on the questioning guidelines, and their comments were implemented. The interviews lasted about 40 minutes on average. Thus, these individuals serve as valuable sources of comprehensive information about the village. In the focus group discussions (FGDs), participants were briefed on the study's objectives and assured that their information would be used solely for research purposes. They had the freedom to withdraw or skip questions at any time. The FGDs, lasting about 1.5 h, were conducted using semi-structured interviews, starting with predetermined questions but allowing for follow- up queries to explore topics in depth. Participants discussed regional environmental issues, perceptions of climate change and its impacts on their livelihoods, and potential solutions. According to the findings, the destructive consequences of climate change and recent glacial floods have caused many farmers to lose productive land, crops, and fruit orchards, resulting in low crop yields and agricultural income. Ten interviews were conducted during the research project to gain a comprehensive understanding of local conditions. These interviews included key informants and subject-matter experts. The questions were mostly open-ended and semi-structured, allowing respondents to share their insights and knowledge freely. Key informants, interviewed in both Urdu, English, and their native language, were bilingual and selected based on their specialized knowledge or expertise in climate change, its impacts, and response mechanisms. The interviews aimed to gather information on the province's policies, trends, and capacity to adapt to climate change. The study reviewed various papers, books, and other resources. To ensure the accuracy of the survey results, pretesting the questionnaires was essential. Enumerators visited the area to understand the ground realities and become familiar with the local environment. The pretesting process allowed the inclusion of missing information suggested by the enumerators after field visits and the removal of unnecessary details.



[Gender]



[Age]



[Nature of Employment]

Fig. 2. Gender, age and nature of employment categories of collected data.

C. Data Analysis Techniques

1) Quantitative data analysis: Quantitative data were collected through a structured questionnaire consisting primarily of closed-ended questions with a small number of open-ended items. After field collection, all responses were manually entered into Excel and cross-checked for accuracy. Each variable was assigned a numerical code to facilitate systematic tabulation and minimize data-entry errors. The cleaned dataset was analysed using descriptive and inferential statistical techniques. Descriptive statistics—including frequency distributions and percentages were used to summarise household characteristics, climate perceptions, and livelihood impacts. Inferential analysis was conducted to examine associations between socioeconomic characteristics and climate-related perceptions.

2) Qualitative data analysis: Qualitative information was collected through key informant interviews and focus group discussions. A thematic content analysis approach was used to interpret these data. First, transcripts and notes were reviewed and openly coded to identify recurring ideas, concerns, and experiences. In the second stage, similar codes were grouped into broader themes such as climate impacts on agriculture, water scarcity, environmental change, livelihood stress, and adaptation strategies. Illustrative quotes from respondents are presented in the results to support the identified themes. This qualitative component enriches the quantitative findings by providing contextual detail on how households perceive and respond to climatic changes.

3) Statistical analysis: Quantitative statistical analysis was performed using Microsoft Excel 2010 and MATLAB R2023B. Descriptive statistics were used to present the distribution of household and climate-perception variables. Inferential analysis focused on identifying significant relationships between socioeconomic variables (e.g., gender, education, occupation, district) and perceptions of climate change impacts.

D. Mathematical and Statistical Framework

The mean is used to determine the average response for the different questions related to climate change impacts.

$$Mean = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$

whereas: x_i denotes each data point, and n represents the total number of data points.

The standard deviation is utilized to quantify the variation or dispersion of participants' answers.

$$\text{Standard Devation} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (x_i - \mu)^2} \tag{3}$$

whereas: x_i is an individual response, μ is the mean of the data, and n represents the total number of data points.

The chi-square test of independence was used to examine whether perceptions of climate change differed across categories of socioeconomic variables. This test was appropriate because both sets of variables were categorical. Examples of associations tested include:

- Perceived temperature increase × district
- Awareness of climate change × education level
- Reported crop losses × income group
- Perceived water scarcity × primary occupation

Contingency tables were constructed for each comparison, and chi-square statistics and p-values were generated at a 5% significance level. This analysis helped identify which groups were more aware of climate impacts and which were more vulnerable to climate-related livelihood stress.

To evaluate the association between socioeconomic variables (such as gender, age, district, and job status) and perceptions of climate change, the Chi-square test is used.

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \quad (4)$$

whereas: χ^2 is the chi-square value, Oi is the observed value, E_i is the expected value, and $(r - 1)(c - 1)$ is the degree of freedom.

$$DF = (r - 1)(c - 1) \quad (5)$$

whereas r is the number of rows (categories of the variable), and c is the number of columns (categories of perception). The test's p-value is compared with a significance level (usually 0.05) to determine if there is a significant association.

To calculate the expected frequencies for a chi-square test, use:

$$E = \frac{\text{(Total Row)(Total Column)}}{\text{Grand Total}} \quad (6)$$

where E represents the expected frequency for each cell.

Respondents rated the severity of climate-induced hazards using a scale (e.g., 1 = no impact to 5 = very high impact). Events included increased temperature, shifting rainfall patterns, drought, water scarcity, pre- mature crop ripening, pest attacks, soil degradation, and flood-related hazards.

$$\text{Average Impact Rating} = \frac{1}{n}\sum_{i=1}^{n} R_i \quad (7)$$

whereas: R_i is the individual rating for each weather event, and n is the total number of participants.

Percentages were used to indicate the proportion of respondents selecting a particular option or reporting a specific perception or impact.

$$\text{Percentage} = \left(\frac{\text{Respondents by specific option}}{\text{Total respondents}}\right) \times 100 \quad (8)$$

IV. Results and Discussions

The results reveal a clear and consistent pattern of strong climate change awareness among respondents across Gilgit-Baltistan. As illustrated in Fig. 3, an overwhelming 98% of participants acknowledge that climate change is occurring, reflecting widespread recognition of shifting weather patterns and environmental conditions in the region. Only 1.1% disagreed, indicating minimal skepticism, while 0.5% reported not know climate change, suggesting a small but notable awareness gap. Overall, these findings highlight a high level of community understanding regarding climate-related issues, reinforcing the importance of sustained education, outreach, and policy initiatives aimed at strengthening local adaptive capacity. Before examining district-level variations in perceptions, Fig. 4 displays the spatial distribution of respondents across the ten districts of Gilgit- Baltistan. This distribution ensures that the analysis captures perspectives from all major agro-ecological zones. The highest number of respondents was from Nagar (15.16%), followed by Skardu (14.32%) and Gilgit (14.06%). Other districts—Hunza, Astore, Diamer, Ghizer, Kharmang, and Ghanche—also contributed proportionally to the survey. Such balanced representation enhances the validity of the findings and provides a comprehensive picture of how climate change is perceived across diverse geographic and ecological settings.

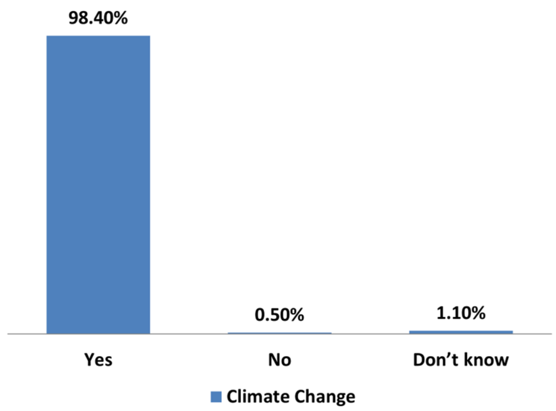


Fig. 3. Perceptions of climate change among respond.

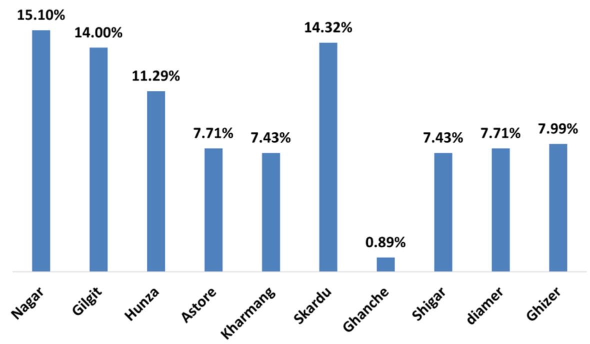


Fig. 4. Public perceptions on climate change in GB.

A. Impacts on Agriculture and Natural Resources

Table 1 presents the frequency distribution and descriptive statistics related to respondents' perceptions of the causes and impacts of climate change on agriculture, horticulture, soil resources, irrigation water availability, and forest ecosystems. The columns labelled 1 to 5 represent the percentage of respondents selecting each category on a five-point Likert scale (1= Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree).

The results in Table 1 reveal that respondents strongly perceive climate change to be affecting agricultural and natural resource systems in multiple ways. The highest-ranked statement- "The irregular seasons have badly affected crop/horticulture productivity"—received the highest mean (20.02) and ranked 1st, indicating that seasonal unpredictability is considered the most critical climate-related threat. Similarly, respondents widely agree that climate change has increased crop infestation and diseases (Rank 2nd) and contributed to a decrease in irrigation water availability (Rank 3rd). These issues reflect the region's dependence on glacier-fed irrigation systems, which are increasingly unstable under changing climatic conditions. Statements related to horticulture diseases, crop yield reductions, and declining forest resources also scored high, demonstrating a broad recognition of climate-related environmental stress. Although some standard deviation values reflect variability in responses, the overall patterns reveal strong consensus regarding the negative impacts of climate change. The consistently moderate-to-high mean values and modes (mostly 4 or 5) indicate that the majority of respondents agree or strongly agree with the listed impacts. This consensus suggests that climate change is widely perceived as a direct threat to agricultural productivity, soil health, water availability, and ecosystem stability in Gilgit-Baltistan. Overall, the descriptive results reinforce the urgency of promoting climate-resilient agricultural practices, strengthening water management systems, and implementing community-based adaptation strategies to protect livelihoods in the region.

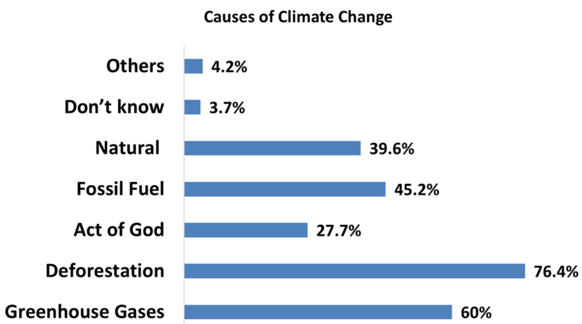


Fig.5. Respondents' perceptions of the causes of climate change.

As illustrated in Fig. 5, 76.40% of respondents identify deforestation as the most significant factor contributing to climate change, and a substantial 60% of respondents attribute climate change to greenhouse gas emissions and causes global warming. This highlights recognition of the critical impact that CO2 and other greenhouse gases have on the environment. According to 27% of respondents, natural events, such as volcanic eruptions and variations in solar radiation, are happening because of revenge from Allah. In addition, 45% of people believed that climate change is happening due to the burning of fossil fuels and 39.60% of respondents attribute climate change to natural causes, including volcanic activity and changes in solar radiation. Additionally, 4.2% of respondents believe that there are other, unspecified sources contributing to climate change, indicating some level of uncertainty or recognition of additional factors not covered in the survey. Meanwhile, 3.7% of respondents are unsure about the causes of climate change, reflecting a minor segment of the population with limited understanding or clarity on the issue.

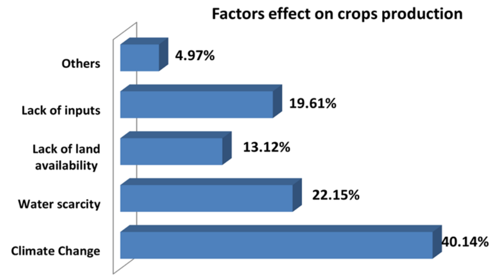


Fig. 6. farmer's perception about factors affecting the production of the crops.

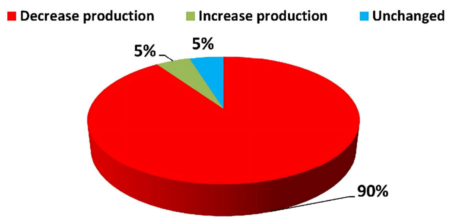


Fig. 7. Farmers' Observations about the Impact of Climate Change on farming activities.

Fig. 6 identifies climate change as the primary constraint on crop production (40.14%), followed by water scarcity (22.15%), limited agricultural inputs (19.61%), land constraints (13.12%), and other factors (4.97%). Fig. 7 shows that 90% of respondents expect climate change to reduce agricultural output, while only 5% anticipate an increase and 5% no change. Fig. 8 shows that despite these risks, adaptation remains limited, with 65.12% reporting no changes in cropping practices, even as farmers experience increasing climate-related hazards such as droughts, floods, landslides, windstorms, and GLOF events.

Table 1. Descriptive statistics of respondents' perceptions of climate change impacts

Statements	1	2	3	4	5	Mean	Mode	SD	Rank
The irregular seasons have badly affected crop/horticulture productivity.	2.8	15.5	20.7	26.6	34.5	20.02	5	11.94	1st
Decreased soil fertility due to climate change. Crop yields have decreased due to climate change.	4.2	7.0	26.0	30.2	22.6	19.84	4	10.39	8th
	2.4	9.1	27.4	32.8	28.4	19.42	4	12.46	5th
Decrease in the amount of water for irrigation. Climate change has led to crop infestation and diseases.	3.4	10.8	29.8	26.8	29.2	19.84	5	10.29	3rd
	3.4	8.3	26.6	29.3	32.4	19.84	5	10.43	2nd
Climate change has led to horticulture infestation and diseases.	2.4	7.2	30.8	30.5	29.1	19.84	4	11.19	4th
Decrease in fruit & crop production due to unpredictable rainfall and snowfall.	2.4	9.2	24.6	38.6	25.3	18.62	4	10.90	7th
Climate change has led to a decline in forest resources.	3.4	14.8	24.1	32.1	25.5	19.78	4	10.78	6th

Note: 1 = SD; 2 = D; 3 = N; 4 = A; 5 = SA.

Table 2. Climatic risks and hazards observed in Gilgit-Baltistan and their impacts on different vulnerability sectors

Threats	Agriculture	Water sources	Forest resources	Infestation & diseases	Infrastructures	Total	Rank
Flood	3	2	2	–	4	11	3rd
Windstorm	3	2	2	2	3	12	2nd
Landslide	3	2	4	–	3	12	2nd
Droughts	3	3	2	1	–	9	4th
GLOF events	4	3	2	2	3	14	1st
Total	16	12	12	5	13		
Rank	1st	3rd	3rd	4th	2nd		

Note: 1 = low/no impact; 2 = medium impact; 3 = high impact; 4 = severe impact.

Table 2 summarizes the relative severity of major climatic hazards in Gilgit-Baltistan and their impacts across key vulnerability sectors. Among all hazards, GLOF events rank as the most severe, reflecting their extreme impacts on agriculture, water sources, forests, infestations and diseases, and infrastructure. Windstorms and landslides are ranked second, showing high to severe impacts, particularly on agriculture and infrastructure, while also affecting water and forest resources. Floods rank third, with strong effects on agriculture and infrastructure and moderate impacts on water and forest systems. Droughts, although widespread, rank fourth, primarily affecting agriculture and water availability, with comparatively lower impacts on infrastructure and forests. Overall, the results highlight that agriculture and infrastructure are the most vulnerable sectors, while water and forest resources also face substantial risks from multiple climate hazards.

Table 3. Chi-square test for assessing the association between socioeconomic variables and climate change perception

Variable	Category	Yes (%)	No (%)	Total (%)	χ^2	DF	P-value
Gender	Male	98.24	1.76	63.3	1.0219	1	0.31207
	Female	99.24	0.76	36.7			
Age	18–36	98.95	1.05	52.46	0.83267	2	0.65946
	37–64	98.00	2.00	27.98			
	> 64	98.55	1.45	19.57			
District	Nagar	96.30	3.70	15.16	6.9646	9	0.64081
	Gilgit	98.04	1.96	14.06			
	Hunza	97.37	2.63	11.29			
	Kharmang	100.00	0.00	7.43			
	Ghanche	100.00	0.00	6.89			
	Shigar	96.30	3.70	7.43			
	Astore	100.00	0.00	7.71			
	Skardu	100.00	0.00	14.32			
	Diamer	100.00	0.00	7.71			
	Ghizer	100.00	0.00	7.99			
Job	Private	100.00	0.00	16.16	10.4763	4	0.033125
	Farmer	100.00	0.00	26.30			
	Government servant	98.15	1.85	30.14			
	Jobless	94.44	5.56	15.07			
	Business	100.00	0.00	12.32			

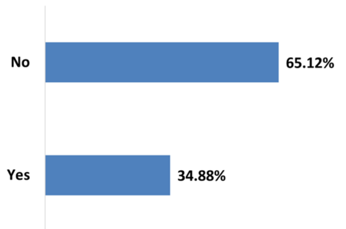


Fig. 8. Farmers' perceptions on shifts in planting seasons due to climate change.

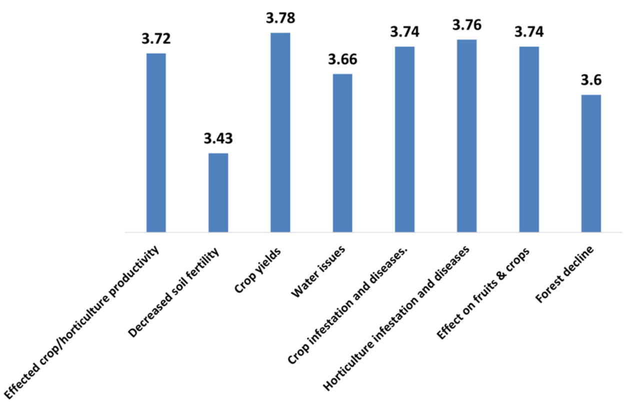


Fig. 9. Average perceived impact of climate change on agriculture and natural resources.

B. Statistical Assessment

Before conducting inferential analysis, frequency distributions were examined to confirm that climate change perception was widespread across the sample. To statistically assess whether this perception differed by gender, age group, district, or job status, a chi- square test of independence was applied. This test is appropriate because both the predictor variables (e.g., gender, district) and the outcome variable (perception of climate change: Yes/No) are categorical. Table 3 summarises the chi-square results for all socioeconomic variables included in the analysis. The results reveal that gender, age group, and district do not significantly influence climate change perception ($p > 0.05$). This indicates that awareness of climate change is consistently high across all demographic groups, regardless of location or age. In contrast, job status exhibits a statistically significant association with climate perception ($p = 0.033125$). Private-sector employees and farmers show 100% awareness, while jobless respondents reflect slightly lower awareness (94.44%). This suggests that individuals engaged in climate-sensitive livelihoods (e.g., farming) or organised employment may be more exposed to climate information and thus show higher recognition of climate change. Overall, the results indicate widespread acknowledgment of climate change in Gilgit-Baltistan, with job-related exposure emerging as the only socioeconomic factor significantly associated with perception.

The use of two different scoring scales in this study was intentional and reflects the distinct nature of the variables being assessed. Perception-based statements related to agricultural impacts measured respondents' degree of agreement, which is most appropriately captured using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). This scale is widely used in perception and attitude research because it effectively summaries respondents' agreement levels. In contrast, weather-shock variables required respondents to assess the severity or intensity of specific events—such as drought, heatwaves, untimely rainfall, and pest outbreaks. Since the magnitude of these shocks can vary considerably, a 0–10 impact scale was adopted to allow finer differentiation and to align with common practice in risk, disaster, and hazard- impact assessments. Thus, the scoring approach was determined by the conceptual purpose of each variable: agreement-based perceptions used the 5-point Likert scale, whereas severity-based weather impacts used the 0–10 scale. Fig. 9 presents the severity ratings of climate change's impact on various aspects of agricultural and horticultural productivity. Irregular and unpredictable seasonal patterns have caused a significant decline in overall productivity, with a severity rating of 3.72 out of 5. Soil fertility has also been notably affected, scoring 3.43 out of 5, as climate variations disrupt natural soil regeneration processes. This decrease in soil quality, combined with harsher growing conditions, has contributed to a 3.78 out of 5 reductions in crop yields, indicating substantial challenges for food production. Water availability for irrigation has been reduced significantly due to changing weather patterns, with a severity rating of 3.66 out of 5. This reduction in water resources has made it more difficult for farmers to sustain healthy crops, exacerbating productivity issues. Moreover, climate change has increased the prevalence of crop infestations and horticultural diseases, with respective severity ratings of 3.74 and 3.76 out of 5, as shifting temperatures and humidity levels create more favourable conditions for pests and pathogens. In addition, erratic rainfall and snowfall patterns have directly impacted fruit and crop production, leading to a decline rated at 3.74 out of 5. This unpredictability has made it increasingly difficult for farmers to plan and maintain stable yields. Finally, the impact of climate change extends beyond agriculture, as forest resources have also declined, with a severity rating of 3.60 out of 5, highlighting the broader environmental damage caused by changing climate conditions. Table 4 highlights key barriers to agricultural productivity, with population growth identified as the most significant concern at 11.99%. Close behind, lack of proper technology accounts for 11.89%, indicating a critical need for technological advancements in farming practices. Illiteracy and lack of knowledge play substantial roles, with 10.94% and 10.30% of respondents citing these as major issues, respectively. Other notable barriers include low soil quality (7.47%) and poor seed quality (7.03%), which directly impact crop yields. Additionally, insufficient cultivatable land (6.51%) highlights land availability challenges. The results emphasize the importance of addressing educational gaps, technological needs, and environmental conditions to improve agricultural productivity and ensure food security.

Table 4. Barriers to adaptation measures and ways to tackle the problem

Barriers	Response (%)	Tackle the Problem	Response (%)
Population growth	11.99	Plant more trees	29.65
Illiteracy	10.94	Install air conditioners	5.24
Low soil quality	7.47	Change in housing structure	8.99
Poor seeds	7.03	Migration	4.43
Lack of roads/infrastructure	9.68	Transfer to renewable energy	13.29
Insufficient cultivable land	6.51	Water conservation in agriculture	17.99
Lack of knowledge	10.30	Pollution control	19.86
Lack of proper technology	11.89	Others	0.54
Lack of technical know-how	8.88	—	
Lack of awareness of CC early warnings	10.30	—	
Others	0.70	—	

Table 4 outlines various proposed solutions to environmental challenges, with planting more trees emerging as the most favoured response, supported by 29.65% of participants. This suggests a strong consensus on the importance of forestation in addressing environmental issues. Pollution control follows closely at 19.86%, indicating a significant recognition of the need to manage pollutants for a healthier ecosystem. Additionally, water conservation in agriculture is a critical strategy, with 17.99% of respondents emphasising its importance for sustainable farming practices. The transfer from non-renewable to renewable energy received 13.29%, reflecting a growing awareness of the need for cleaner energy sources. Other options, such as changing housing structures (8.99%) and installing air conditioners (5.24%), garnered less support, while migration was the least favoured solution at 4.43%. Notably, only 0.54% of respondents suggested doing nothing, highlighting a general inclination toward proactive measures to tackle environmental challenges.

C. *Severity of Extreme Weather Events*

Fig. 10 shows that floods (6.33/10) and GLOF events (6.13/10) have the most severe impacts on crop yields, followed by temperature fluctuations (5.35/10), landslides (5.01/10), rainfall variability (4.81/10), storms (4.67/10), and droughts (4.52/10). In response, respondents prioritise plantation activities (29.69%), pollution control (19.89%), and water conservation (17.99%), while fewer support housing modifications (8.99%) or air conditioning (5.23%). Despite strong willingness to adapt, key barriers include population pressure (12.52%), limited technical expertise (12.43%), illiteracy (11.41%), lack of knowledge and outdated technology (10.76% each), constrained resources (10.12%), and poor soil and seed quality, highlighting structural and knowledge-based constraints on effective climate adaptation.

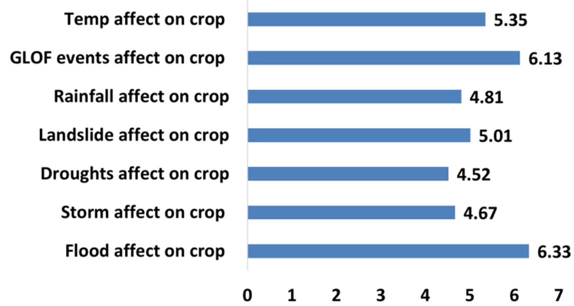


Fig. 10. Impact ratings of extreme weather events on crop yields.

Figs. 11 and 12 illustrate farmers' adaptation strategies to climate change and the key barriers limiting their adoption. Farmers mainly prioritise low-cost, nature-based measures such as plantation activities, water conservation, pollution control, and the use of renewable energy, reflecting practical responses to climate stress. However, adaptation efforts are constrained by population pressure, limited technical expertise, illiteracy, lack of knowledge, outdated technologies, poor soil and seed quality, and restricted access to resources, indicating that both structural and capacity-related barriers hinder effective climate adaptation at the farm level.

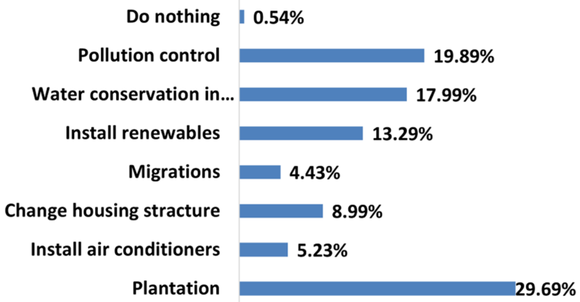


Fig. 11. Farmers' adaptation strategy against climate change.

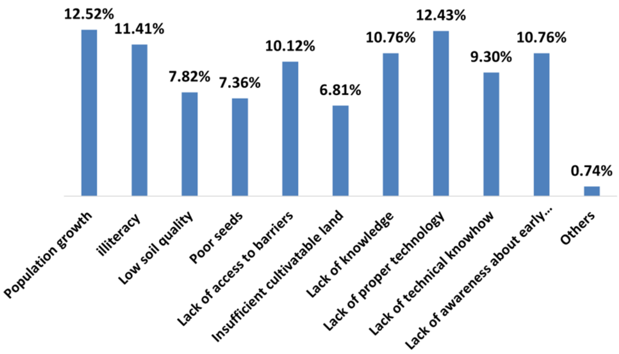


Fig. 12. Barriers to farmer adaptation to climate change.

D. Discussion

The findings of this study are consistent with broader evidence from high-mountain agricultural regions, where irregular seasons, declining soil fertility, reduced yields, and increased pest outbreaks are commonly attributed to changing climate conditions. Similar patterns of water scarcity linked to unstable glacier-fed irrigation systems have also been widely observed in other mountain environments. The reported decline in forest resources aligns with documented environmental stress in fragile upland ecosystems. Overall, the strong awareness and consistent responses across districts reflect what is broadly recognised in the literature: that mountain communities are highly sensitive to climatic shifts and experience multiple, interrelated impacts on agriculture, natural resources, and livelihoods.

V. Conclusion

This study examined community perceptions of climate change alongside its environmental impacts on agriculture and rural livelihoods in Gilgit-Baltistan. Local communities clearly perceive rising temperatures, irregular precipitation, extended dry periods, and increasing hazards such as floods, landslides, and GLOF events, closely aligning with observed environmental changes. These perceived climatic shifts are linked to declining soil fertility, reduced yields, greater pest pressure, and worsening water scarcity, which collectively undermine household income and food security, particularly for poorer and remote farmers. Although various autonomous adaptation measures are practiced, communities generally view them as insufficient to cope with escalating climate risks. The findings underscore the need for stronger institutional support, climate-resilient farming strategies, and improved water management. Overall, integrating local climate-change perceptions into policy and planning is essential for developing effective, context-specific adaptation measures and enhancing the resilience of vulnerable Himalayan farming communities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Seema Batool conducted the research, analysed the data, and wrote the original draft. Naveed Abbas data collected, validated and analysed data. Waseem Haider reviewed the paper and contributed to data collection, analysis, and writing - review & editing. All authors had approved of the final version.

References

[1] P. A. Arias *et al*., "Intergovernmental Panel on Climate Change (IPCC). Technical summary," *Climate Change 2021: The Physical Science Basis*, Cambridge Univ. Press, pp. 35–144, 2021.
[2] M. Sassi, Y. Ali, and I. Ali, "Climate change perception and adaptation among farmers in the mountains of Western Karakoram, Pakistan," *Development in Practice*, vol. 35, no. 1, pp. 3–20, 2024.
[3] A. Aftab, A. Ahmed, and R. Scarpa, "Farm households' perception of weather change and flood adaptations in northern Pakistan," *Ecological Economics*, vol. 182, 106882, 2021.
[4] I. Khan, H. Lei, I. A. Shah, I. Ali *et al*., "Farm households' risk perception, attitude and adaptation strategies in dealing with climate change: Promise and perils from rural Pakistan," *Land Use Policy*, vol. 91, p. 104395, 2020.
[5] L. Shahzad *et al*., "Vulnerability, well-being, and livelihood adaptation under changing environmental conditions," *Environ. Sci. Pollut. Res.*, vol. 26, no. 26, pp. 26748–26764, 2019.
[6] M. F. Ali and S. Rose, "Farmers' perception and adaptations to climate change: Findings from three agro-ecological zones of Punjab, Pakistan," *Environmental Science and Pollution Research*, vol. 28, no. 12, pp. 14844–14853, 2021.
[7] J. Smadja *et al*., "Climate change and water resources in the Himalayas," *Journal of Alpine Research*, vol. 103, no. 2, 2015.
[8] D. J. Merrey *et al*., "Evolving high altitude livelihoods and climate change," *Food Security*, vol. 10, pp. 1055–1071, 2018.
[9] M. H. Alvi, H. Ali, K. Haider *et al*., "Chemically degraded soil: Strategies for mitigating its toxicity," *J. Soil Sci. Plant Nutr.*, vol. 25, pp. 363–381, 2025.
[10] M. ur Rashid *et al*., "Impact of climate change on the stability of the Miacher Slope," *Climate*, vol. 11, no. 5, p. 102, 2023.
[11] K. R. Dahal *et al*., "Climate Change Impacts and Adaptation in a Hill Farming System," *Climate*, vol. 11, no. 1, p. 11, 2022.
[12] D. B. Rahut and A. Ali, "Coping with climate change and its impact on productivity, income, and poverty," *Int. J. Disaster Risk Reduct.*, vol. 24, pp. 515–525, 2017.
[13] I. Ali *et al*., "Smallholder perceptions of climate change in high-altitude farming," *Climate Services*, vol. 38, 100581, 2025.
[14] F. Ali *et al*., "Hazard vulnerability risk assessment of district Gilgit," *Modern Environmental Science and Engineering*, vol. 1, no. 5, pp. 255–268, 2015.
[15] R. Batool, T. Khan, R. Karim, and S. Ahmed, "Climate and forest cover changes in district Skardu," *IJEAB*, vol. 1, no. 4, pp. 907–911, 2016.
[16] M. F. Mbiafeu *et al*., "Climate, agroecology, and farm returns," *Front. Sustain. Food Syst.*, vol. 8, p. 1322568, 2024.
[17] S. Khawaja *et al*., "Media, disasters, and the global south," *Journalism and Media*, vol. 6, no. 2, p. 70, 2025.
[18] S. A. Kamboh, M. Ittefaq, and P. C. Pezzullo, "Articulating a loss and damage fund," *Environmental Communication*, vol. 18, no. 3, pp. 302–321, 2024.
[19] H. Guo, Y. Xia, J. Jin, and C. Pan, "The impact of climate change on agricultural efficiency," *Environ. Impact Assess. Rev.*, vol. 97, p. 106891, 2022.
[20] G. C. Adamson, M. J. Hannaford, and E. J. Rohland, "Re-thinking the present," *Global Environ. Change*, vol. 48, pp. 195–205, 2018.

[21] A. A. Chandio, H. Magsi, and I. Ozturk, "Examining the effects of climate change on rice production," *Environ. Sci. Pollut. Res.*, vol. 27, no. 8, pp. 7812–7822, 2020.
[22] N. Ahmed *et al*., "Separation of the impact of landuse/landcover change and climate change on Runoff," *Water Resour. Manage.*, vol. 36, no. 1, pp. 181–201, 2022.
[23] S. Tuladhar *et al.*, "Climate change, water and agriculture linkages in the upper Indus basin," *Front. Sustain. Food Syst.*, vol. 6, 1012363, 2023.
[24] Z. Zafar *et al.*, "Spatiotemporal dynamics analysis of surface water and snow cover area," *Physical Geography*, vol. 44, no. 5, pp. 600–619, 2023.
[25] E. N. Ali, T. Y. Baig, and F. Parveen, "Exploring women's perceptions of climate change," *Tezhib*, vol. 3, no. 3, p. 66, 2024.
[26] G. Gioli, T. Khan, and J. Scheffran, "Climatic and environmental change in the Karakoram," *Reg. Environ. Change*, vol. 14, no. 3, pp. 1151–1162, 2014.
[27] N. Batool *et al*., "Rainfall variability and cropping pattern dynamics," *SN Appl. Sci.*, vol. 1, p. 606, 2019.
[28] B. Bhatta *et al.*, "Evaluation and application of a SWAT model," *Catena*, vol. 181, 104082, 2019.
[29] M. Behnassi, M. B. Baig, M. El Haiba, and M. R. Reed, *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa: Climate Risks and Resource Scarcity*. Springer, 2021.
[30] U. Mustafa, M. B. Baig, and G. S. Straquadine, "Impacts of climate change on agricultural sector of Pakistan," *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa*, Springer, 2021, pp. 43–64.
[31] L. Piya, K. L. Maharjan, and N. P. Joshi, "Livelihood Impacts of Climate Change and Extreme Events," *Socio-Economic Issues of Climate Change*, Springer, 2019, pp. 153–160.
[32] R. Poornima *et al.*, "Climate change implications in the Himalayas," in *The Himalayas in the Anthropocene*, Springer, 2024, pp. 237–277.
[33] A. A. Dubovitski *et al*., "Assessment of the impact of climate risks on agriculture in the context of global warming," in *Proc. IOP Conf. Ser.: Earth Environ. Sci.*, IOP Publishing, 2021, 012145.
[34] N. Alam *et al.*, "Population growth poses a significant threat to forest ecosystems: a case study from the Hindukush-Himalayas of Pakistan," *PLOS ONE*, 2024. doi: 10.1371/journal.pone.0302192