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Climate change, water and agriculture linkages in the upper Indus basin: A field study from Gilgit-Baltistan and Leh-Ladakh

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The Indus is one of three largest river systems emerging from the Hindu-Kush Himalaya (HKH). In the Upper Indus Basin (UIB), water resources, agriculture and livelihoods are highly vulnerable to climate change induced hazards and risks. Present study investigates impacts of climate change on water availability, agriculture and livelihoods based on perception data collected through focus group discussions and key informant interviews from selected study sites in Gilgit-Baltistan and Leh-Ladakh subregions of the UIB. Findings revealed that climate change is inducing both direct and indirect impacts on water availability, agriculture, and livelihoods. Local people reported that changes in precipitations patterns, temperature and timing of seasons, and increased incidence of crop pest attacks are resulting in the decline of crop and livestock productivity (direct impacts). Climate change is also impacting productivity indirectly through degradation of rangelands/pastures and water variability in traditional irrigation systems. Local people are taking diverse adaptation measures to cope with climate change impacts. These measures include revival of less water intensive traditional crops, start of enterprises and value chain developments in Gilgit-Baltistan, and improvement in water management practices and integration of traditional agricultural products with tourism in Leh-Ladakh. Some adaptation measures are likely to have negative impacts on sustainability of local agriculture. For instance, inorganic agricultural practices in Gilgit-Baltistan, and unplanned shift to water intensive crops and improved breeds of livestock in both Gilgit-Baltistan and Leh-Ladakh. Based on findings, this study suggests establishing a learning mechanism for local communities through collaboration of local institutions from both sides of border and people to people connections.

KEYWORDS

agriculture, traditional irrigation systems, climate change, high mountains, upper Indus basin (UIB), water variability

1. Introduction

The Hindu Kush Himalaya (HKH) constitute a "water tower" supporting surrounding ten rivers on which over 1.9 billion people depend on for their livelihoods (Wester et al., 2019). There is evidence that climate change is having major impacts throughout these river basins, from the mountains to the sea. These impacts are exacerbated by rising demand for water in agriculture, industries and cities, increasing levels of water pollution, severe seasonal shortages and floods (Virk et al., 2020). The Indus is one of the three largest river systems emerging from the HKH. The Indus River Basin covers an area of around 1.12 million km^2 and accommodates the population of nearly 270 million (Sharma et al., 2019). The contribution of glacier and snowmelt to water discharge and its contribution to the irrigation by Indus River is around 60% (Abbasi et al., 2017), revealing that meltwater is the lifeline of agriculture, food security and livelihoods of the people in the Indus River Basin.

In the source regions of water, in the Upper Indus Basin (UIB), water resources, agriculture and livelihoods are highly vulnerable to climate change induced risks and hazards (Abbasi et al., 2017; Hussain et al., 2021a). Climate change has impacts on temperatures, snowmelt and hydrology of the river, leading to negative impacts on agriculture which is the main source of livelihoods in the basin (Winston et al., 2013). The HKH communities living in immediate downstream of glaciers are most vulnerable to glacial changes, mainly through reduced reliability of local water resources and increased occurrence of hazards including glacial lake outburst floods (Shrestha et al., 2015). Communities in the UIB are particularly vulnerable to climate change induced risks and hazards such as erratic precipitation patterns and hydrological imbalances, changes in temperature, frequent floods, and droughts (Abbasi et al., 2017). Climate induced risk and hazard has not only affected agriculture, but also triggered an increase in the degradation of forests and rangelands (Hussain et al., 2016). Therefore, the role of non-agricultural livelihood sources such as tourism, handicrafts, trade, wage labor has been increasing over time (Rasul, 2014; Rasul et al., 2014). Overall, climate change is one of the leading causes of high prevalence of food insecurity in the UIB (Hussain et al., 2021a). These trends are made worse by the local people's inadequate access to institutional services (i.e., market, extension services, climate information etc.) and production technology (Hunzai et al., 2011; Gerlitz et al., 2012, 2015; Hussain and Qamar, 2020).

In the UIB, local level studies (Dame and Nüsser, 2011; Rasul and Ahmad, 2012; Hussain et al., 2021a) have examined the changes in precipitation patterns, temperature rise and their impacts on the productivity of crops and livestock. However, there are rare in-depth studies conducted on climate induced impacts on water variability in traditional irrigation systems which are highly vulnerable to changes in precipitation patterns and timing of seasons. Any change in available water in traditional irrigation systems (locally known as *kuhl*) may have severe impacts on local agriculture. In Gilgit-Baltistan, around 5000 *kulh*s are active and irrigate almost 90% of agricultural land (Vander Velde, 1989; PCRWR, 2009; Ashraf and Akbar 2020). However, the statistics on *kuhls* from Leh-Ladakh are not available from reliable sources. In the UIB, farmers are taking autonomous adaptation measures to cope with the severe impacts of climate induced impacts including changes in cropping patterns, improvement in irrigation methods, shift to non-farm activities and introducing new breeds of livestock (Ishfaq and Saeed, 2018). However, a majority of subsistence and small farmers face challenges in taking adequate adaptive actions due to labor shortages resulting from outmigration, unaffordable adaptation costs, limited access to technology and inputs, and lack of awareness (Chhachhar et al., 2014; Maharjan et al., 2018, 2020; Naudiyal et al., 2019). However, local level studies have not been found on the adaptation to challenges caused by water variability in *kuhls*.

Cognizant of the high vulnerability of agriculture and livelihoods to climate induced risks and hazards in the UIB, this study has attempted to further investigate the local impacts of climate change on water variability in *kuhls*, agriculture and local livelihoods. The study also investigated the local adaptation measures taken to cope with the impacts of climate change, particularly on water availability in *kuhls* and agricultural activities. The study selected sites from two subregions, Gilgit-Baltistan and Leh-Ladakh subregions of UIB. This approach will help to identify the similarities as well as differences in climate induced challenges and adaptations on both sides of political borders. It will provide an opportunity for researchers and implementers for cross-learning on good practices.

2. Methodology

2.1. Study area

Dry mountain ranges in the western parts of the UIB are vulnerable to vast range of climate change induced risks and hazards. In this region, precipitation mainly comprises of snowfall, and its larger part does not receive monsoon rains. Agriculture and livelihoods heavily depend on traditional irrigation systems fed by glacier- and snow-melt water. These traditional irrigation systems (*kuhl*) have been working in the area for centuries (Vander Velde, 1989). Any slight change in the precipitation patterns and the timing of melting of glaciers (due to changes in timing of seasons) and retreat and surface lowing of glaciers may result into significant impacts on the availability of melt water in traditional irrigation systems and consequent negative impacts on agriculture and livelihoods (Ali et al., 2019; Khan et al., 2021). In view of these factors, this research has selected study areas from the western dry mountains of the UIB: Gilgit-Baltistan and Leh-Ladakh.

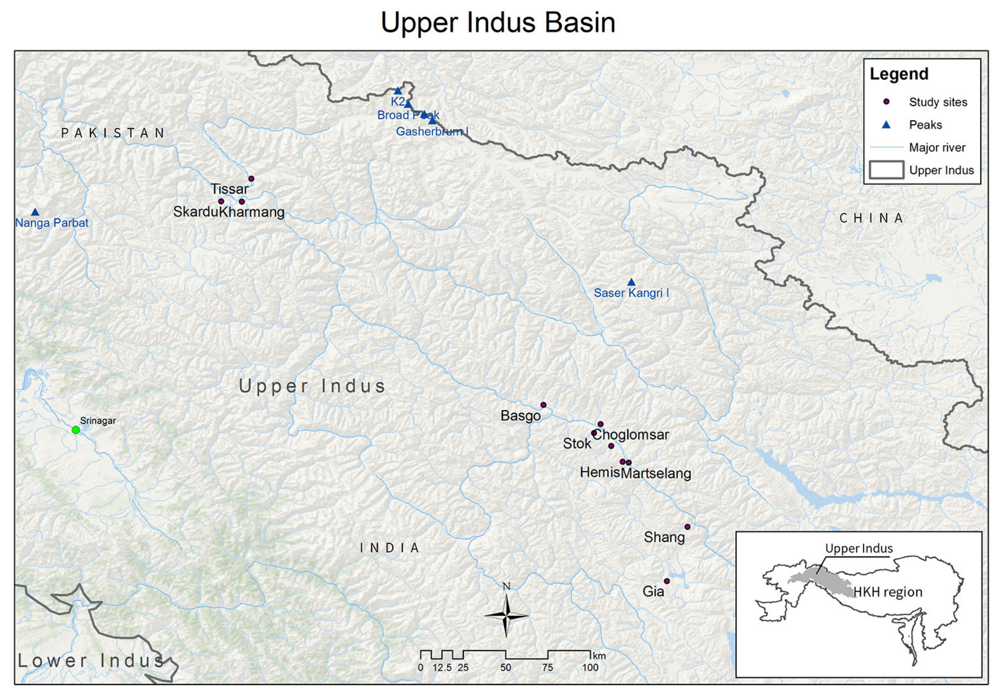

FIGURE 1
Map of study villages in Ladakh and Gilgit-Baltistan located within upper Indus basin.

Gilgit-Baltistan contains a vast range of mountain range where temperature ranges from −25 to +35°C. The region has only 1.50% agricultural land in the province, but agriculture remains very crucial for local food security and livelihoods. The main livelihood sources are agriculture and livestock, tourism, forest products, gems/minerals and remittances (MAFSO, 2015). Leh-Ladakh is high altitude area (around 3000–5500 m) characterized by cold-arid conditions. It is situated between the Greater Himalayan Range to the south and the Karakoram Range to the north (Nüsser et al., 2019). Most of the land is barren with igneous, metamorphic, and sedimentary rocks, and often called as cold desert (Giri et al., 2019; Dolma et al., 2020). Although on average annual precipitation is low (∼100 mm in Leh), there are occasional events of cloudbursts and torrential rainstorms (Thayyen and Gergan, 2010; Thayyen et al., 2013). Most precipitation falls during the monsoon period with regular summer snowfall at altitudes above 5000 m (Chevuturi et al., 2018). In Leh-Ladakh , main sources of livelihoods are agriculture, livestock and tourisms (Giri et al., 2019).

2.2. Selection of specific study sites

The study sites for this research (see Figure 1) were selected based on agro-ecological potential and vulnerability to climate change induced water challenges. The three villages – Hushey (3150 masl), Tissar (2700 masl) and Sundus (2228 masl) – were selected respectively from the districts of Kharmang, Shigar and Skardu in Gilgit-Baltistan based on cropping zonation (single, marginal double and double) in these villages. One village from each cropping zone was assumed to provide better understanding of climate change impacts on across diverse agriculture systems. These cropping zones are defined officially based on the altitude. Single cropping zone has a limited potential for the cultivation of crops. The zone is more suitable for traditional crops (i.e., buckwheat and barley), vegetables and livestock. The marginal double cropping zone has a potential for relatively broader range of agronomic crops (i.e., wheat, maize, barley and buckwheat), vegetables, fruits, nuts and livestock. The double cropping zone has a potential for diverse agronomic and horticultural crops, and livestock (Government of Gilgit-Baltistan, 2013; Rasul et al., 2018).

As mentioned earlier, Leh-Ladakh subregion has mainly high altitude (3000–5500 masl) and do not have cultivable areas with low and medium altitudes. From Leh district of this sub-region, nine villages were selected due to their high vulnerability to climate change (see Table 1). These villages were clustered into two categories of study sites – high altitude areas (≤3500 masl) and very high altitude areas (>3500 masl). These categories were developed based on the discussions with local key informants. In the field planning discussions, they highlighted that there is no significant difference in agricultural practices and vulnerability

TABLE 1 Study sites and data collection.

Indicators/tools	Gilgit-Baltistan			Leh-Ladakh	
	Low altitude	Medium altitude	High altitude	High-altitude	Very high-altitude
Cropping zone	*Double*	*Marginal double*	*Single*	*Single*	*Single*
Number of studied villages	1	1	1	6	3
Name of villages (district)	Sundus (Skardu)	Tissar (Shigar)	Hushey (Kharmang)	Basgo, Choglomsar, Martselang, Matho, Meru, Stok	Gya, Hemis, Shang
Height (meter above mean sea level)	2,228	>2,700	3150	<3500	>3500
Minimum and maximum temperature in summer	15°C 35°C	10°C 32°C	12°C 35°C	5°C 27°C	5°C 27°C
Minimum and maximum temperature in winter	−8°C 15°C	−9°C 15°C	−19°C 8°C	−13°C 10°C	−13°C 10°C
Type of data collection Method (structured questionnaire used for data collection)	Focus group discussion	Focus group discussion	Focus group discussion	Key informants (Farmers)	Key informants (Farmers)
	(farmers' groups – one each with male and female groups)	(farmers' groups – one each with male and female groups)	(farmers' groups – one each with male and female groups)		
Number of FDGs/key informant interviews	2	2	2	32	26

Field observations: Non-participant observation tool was used to examine cropping systems, water sources and micro-irrigation systems.

to climate change from 3000 masl to 3500 masl. However, they anticipated differences on altitude above 3500 masl (compared to ≤3500 masl).

2.3. Data collection

Focus group discussion (FGD) and key informant interviews (KII) were conducted for primary data collection. Enumerators also used non-participatory observation tool to observe the cropping patterns and irrigation systems. Initially as per research design, data collection was proposed through a mixed method approach using household level survey along with qualitative open-ended interviews. However, due to COVID-19 induced restriction and implemented standard operating procedures (SOP) by countries, primary data collection was limited to FGDs and KII.

Following the local government's SOPs, two FGDs (one each with men and women groups) were conducted in each of three selected villages of Gilgit-Baltistan. Participation of individuals from all social groups were ensured in the focus groups. In Leh-Ladakh, arranging FGDs was not possible due to strict SOPs imposed by the government. Therefore, data was collected through KIIs in the study villages. About 5–9 KIIs were carried out in each village to maintain consistency and ensure reliability of the data. Key informants were identified with the support of the local partners working in the village based on set criteria. A conscious effort was made to interview the informants from different genders (men and women) and social groups to ensure the representation of each group in data collected. For both FGDs in Gilgit-Baltistan and KIIs in Leh-Ladakh, participants/key informants of the age of 30–80 were included to document their perceptions of climatic and the socio-economic trends over the years. Although farmer-based households were given priority due to their dependence on the climatic factors, participants from other occupational backgrounds were also interviewed. Data was collected in local language from September to October in 2020 by local enumerators who were trained to administer data collection using a semi-structured community level checklist (see Appendix A1). Collected data was translated into English before it was entered and synthesized in Microsoft Excel spreadsheets. Data was mainly qualitative with some reported descriptive statistics such as averages, ranges and percentages.

3. Results

3.1. Socioeconomic characteristics and agriculture

Study sites are sparsely populated, except the medium altitude village 'Tissar' in Gilgit-Baltistan. Average landholding in study sites is also very small ranging from 0.05 to 1.3 hectare (Table 2). The farmers in sites are mainly smallholders and heavily rely on agriculture for their livelihoods. In study sites of Leh-Ladakh also, agriculture and livestock remain an important livelihood source.

In high altitude villages of both Gilgit-Baltistan and Leh-Ladakh, tourism is emerging as an important livelihood source. In Hushey village of Gilgit-Baltistan, the trophy hunting of ibex and community owned hotels for trekkers and mountaineers (for K2 peak) are contributing to the livelihoods of the local people. Other livelihood sources such as government and private jobs, small businesses and daily wage labor are also reported as important sources, indicating that local people rely on multiple livelihood sources in study sites (Table 2). Contrary to most areas in the HKH region, the outmigration rate in the study sites is lower, ranging from 3 to 7% households with out-migrants. Glacier melt water is the main source of drinking water, except Hushey village in Gilgit-Baltistan where spring is the main source.

Traditional food crops such as barley, buckwheat and millets were historically the main crops in the food systems of study sites. Barley is still a main crop in study sites of Leh-Ladakh. However, in study sites of Gilgit-Baltistan, wheat is reported as the most important crop. Only in one study site "Tissar", barley and buckwheat are reported among cultivated crops. In addition to cereals, vegetables and fruits are also being cultivated in study sites especially at high altitudes (Table 2). In study sites of Gilgit-Baltistan, agriculture is mainly inorganic, and in study sites of Leh-Ladakh organic practices still dominate in local agriculture despite the increasing presence of inorganic agriculture. Local communities also raise diverse livestock including cow, dzomo/dzo, cow/ox, goat, and sheep in study sites. However, in Leh-Ladakh, yak, donkeys and horses are also reported. Donkeys and horses are mainly used as beasts of burden for local activities and to facilitate tourists. Despite the cultivation of fodder crops, pastures remain an important source of grazing for livestock in study sites, except Sundus village in Gilgit-Baltistan. Overall, the local communities in study sites heavily depend on external food supplies for their local consumption. It clearly reveals that local food production is not adequate to fulfill local food demand.

3.2. Agricultural water resources

In study sites, agriculture mainly depends on snow and glacier melt water. Local people reported that *kuhls* (fed by snow and glacier melt water) are governed through locally formed management committees. Management committees establish water distribution mechanisms, formulate rules of water use and management, raise funds from farmers for repair and maintenance and engage local labor in repairing and desilting activities. Irrigation water is distributed among farmers on a rotation basis during operational periods (spring and summer). The committees are mainly comprised of farmers, however in Tissar village of Gilgit-Baltistan local youth is more active in management and maintenance of irrigation systems (Table 3). In this village, the committee does not receive any financial and technical support from external sources (government and NGOs). In Tissar and Hushey villages of Gilgit-Baltistan, management committees also impose monetary and non-monetary fines (e.g., more labor contribution in repair work) to the farmers in the case of violation of committee rules on water use and maintenance. In both study sites of Leh-Ladakh, local village leaders steer the management committee of irrigation systems and take care of water distribution and repair and maintenance operations with support from all beneficiary farmers. In study sites of both Gilgit-Baltistan and Leh-Ladakh, only a few local people reported incidences of conflicts over water distribution. However, local water management committees mostly resolve such issues peacefully though consensus.

3.3. Local perception of climate change, water related hazards and impacts on agriculture

In all study sites, local people perceived significant changes in climate. They reported an increase in average annual temperature and summer temperature, and a decline in winter temperature (Table 4). The trend of increase in temperature has been validated by many studies set around the study areas (Raza et al., 2016; Hasson et al., 2017; Bhatta et al., 2019; Hussain et al., 2021b). The local people also reported changes in precipitation patterns (rainfall and snowfall) and the timing of seasons (summer and winter). Local people have reported earlier start and delayed end of summer and vice versa in winter in almost all sites. It indicates that the duration of summer is expanding, and the duration of winter is shrinking. The shift in winter season in these elevated zones has been noted in a study by Satti et al. (2022). Notably, in two study sites Tisssar and Sundus (located at relatively lower altitude) in Gilgit-Baltistan, local people also reported an increase in overall snowfall and rainfall. The increase in rainfall complies with findings by Moazzam et al. (2022). It shows that either the incidence of heavy snowfalls in winter or the incidences of unexpected snowfall in spring have increased. This may have resulted partly due to a decrease in temperature during winters. However, in the higher altitude snowfall is reported to have decreased. These observations are in agreement with the findings that show

TABLE 2 Socio-economic characteristics and agriculture.

Characteristics	Gilgit-Baltistan			Leh-Ladakh	
	Low altitude (Sundus)	Medium altitude (Tissar)	High-altitude (Hushey)	High altitude site (cluster of villages)	Very high altitude site (cluster of villages)
Number of households	280	750	160	273*	79*
				(34–400)	(46–140)
Average landholding size (hectare)	0.5	0.25–0.35	0.20–0.30	0.05–1.26	0.05–0.15
Main livelihood sources (%)^	Agriculture (95)	Agriculture (100)	Agriculture (100)	Government job (45)	Agriculture (55)
	Livestock (75)	Livestock (100)	Tourism (100)	Agriculture (40)	Livestock (20)
	Government and private jobs (75)	Daily wage labor (55)	Community based enterprises (100)	Livestock (30)	Government job (20)
	Small businesses (7)	Government jobs (25)	Livestock (92)	Tourism (30)	Private business (20)
		Tourism (20)	Government and private jobs (35)	Private business (20)	Tourism (15)
		Small businesses (15)			
Percent households with out-migrants	6	7	3	nr	nr
Main source of water for drinking	Stream fed by snow melt water and glacier melt water	Streams fed by glacier water (no piping system)	Spring water	Streams fed by snow and glacier melt water	Streams fed by snow and glacier melt water
Main crops#	Wheat, Maize, Vegetables, Fodder	Wheat, Barley, Buckwheat, Peas, Potatoes, Fodder	Wheat, Peas, Potato, Turnip, Fodder	Barley, Potato, Vegetables, Wheat, Pea, Mustard, Apple, Apricot, Fodder	Barley, Mustard, Pea, Potato, Vegetable, Fodder
Main livestock#	Cows, goats, sheep, poultry	Zumo/dzo , cows, sheep, goats, ox (livestock population is declining)	Sheep, goats, zumo/dzo, cows	Cow, dzomo/dzo, donkey, goat, horse, sheep, yak, ox	Cow, dzomo/dzo, Yak, sheep, goat, horse and donkey
Nature of agriculture	Inorganic	Inorganic	Inorganic	Mixed (organic and inorganic)	Organic
Labor shortages faced during critical stages of crop cycle	nr	nr	nr	Yes	Yes
Source of livestock feed (% dependence)	Fodder (100)	Fodder (60) Pastures (40)	Fodder (75) /Pastures (25)	Almost equal dependence on pastures and fodder	Almost equal dependence on pastures and fodder
Dependency of village/cluster on external food supplies (% households partially or fully dependent)	90	100	95	75	100

*Average number of households in the cluster of villages. In brackets, range of number of households across villages is presented. ^For study sites in GB, percentages of those households are reported in brackets who are partially or fully depend on the particular source. For study sites in LL, share (%) of livelihood source in total household income is presented in brackets. #Order of reporting in terms of importance. First one is the most important, and the last one is the least important. Nr, not reported; Source: Field notes.

TABLE 3 Water resources for agriculture.

Indicators	Gilgit-Baltistan			Leh-Ladakh	
	Low altitude (Sundus)	Medium altitude (Tissar)	High-altitude (Hushey)	High altitude site (cluster of villages)	Very high altitude site (cluster of villages)
Source of water for agriculture	Snow melt water (stream originates from Deosai plateau)	Glacier and snow melt water	Glacier and snow melt water (the Hushey river fed by the Gondogoro and other glaciers)	Streams fed by glacier and snow melt water	Streams fed by snow melt water
Any irrigation system in the village	Yes	Yes	Yes	Yes	Yes
Management and maintenance of irrigation system	§ Community level committee for maintenance of channel	§ Community level repair and maintenance of irrigation channel	§ Community level repair and maintenance committee for irrigation channel	§ Community level committee led by the village headman	§ Community level committee led by the village headman
	§ Each household equally contributes a certain amount for need based repair and maintenance works	§ No assistance from government or NGOs	§ Irrigation channels are cleaned and desilted collectively	§ Committee takes care of repair and maintenance of channels	§ Committee takes care of repair and maintenance of channels
		§ Traditional water distribution system regulated by young volunteers	§ Fines are imposed in the case of violation of rules of the committee		
		§ Water distribution based on rotations	§ Fines are deposited to community account		
		§ Violators of local rules are imposed monetary and non-monetary penalties			
Resolution of conflicts on water distribution	Conflicts resolved by community elders	Conflicts resolved by community elders	Conflicts resolved by community elders	Conflicts resolved by village head through discussion	Conflicts resolved by village head through discussion

Source: Field note.

decreasing trends in snowfall and increasing trend in rainfall with the rise in elevation caused due to temperature increase Wang et al., 2016; Ali et al., 2022; Dong and Ming, 2022; Moazzam et al., 2022) and shortening of winter months. In Hushey and study sites in Leh-Ladakhlocal people reported a decrease in average snowfall and rainfall (except rainfall in very high-altitude site in Leh-Ladakh). The decrease in rainfall has been affirmed by the precipitation trends in Chevuturi et al. (2018). In Tissar village of Gilgit-Baltistan and study sites in Leh-Ladakh, local people also reported an increase in the number of dry days per year (Table 4). The observation is validated by the study finding Gilgit-Baltistan to be highly affected by drought (Moazzam et al., 2022).

Overall, water availability for agriculture has declined over time, except Sundus village in Gilgit-Baltistan, which primarily relied on snowmelt for its agriculture needs. In both study sites of Leh-Ladakh, local people reported that they face water shortages during sowing and early phase of crop growth. Some farmers have also abandoned some part of their agricultural land due to frequent water shortages.

The local people reported an increase in the incidence of water related hazards such floods/GLOF, cloudburst and droughts. It clearly indicates that climate change induced erratic rainfall in study sites have increased over time. In Tissar village of Gilgit-Baltistan, cloudburst induced flash flood in 2014 eroded around 20% agricultural land, and nearly 80% of this damaged land is still barren. At least five major flood events have been reported over the last decade in Leh-Ladakh (Ali et al., 2022). Among them, the cloudburst induced flood in 2010 washed away the trees and bridges and damaged the houses. This hazard also had negative impacts on local agriculture, food security and livelihoods.

Local people perceived the increase incidences of crop pest attacks and livestock diseases to be a result of the changes in temperature and precipitation and timing of seasons. In all the study sites except Sundus and Tissar local

TABLE 4 Local people's perceptions of climate change and water related hazards.

Climate change		Changes in climate perceived by the communities compared to situation 15 years before				
		Gilgit-Baltistan			Leh-Ladakh	
		Low altitude (Sundus)	Medium altitude (Tissar)	High-altitude (Hushey)	High altitude site (cluster of villages)	Very high altitude site (cluster of villages)
Climate change indicators						
Average temperature		Increased	Increased	Increased	Increased	Increased
Temperature in summers		Increased	Increased	Increased	Increased	Increased
Temperature in winters		Decreased	Decreased	Decreased	Decreased	Decreased
Average rainfall		Increased	Increased	Decreased	Decreased	Increased
Average snowfall		Increased	Increased	Decreased	Decreased	Decreased
Changes in the timing of seasons	Start of summer	Earlier	Earlier	Earlier	Earlier	No change
	End of summer	Delayed	Delayed	Delayed	Delayed	Delayed
	Start of winter	Delayed	Delayed	Delayed	Delayed	Delayed
	End of winter	Earlier	Earlier	Earlier	Earlier	Earlier
Climate change induced water related hazards						
Number of dry days per year		Decreased	Increased	Decreased	Increased	Increased
Occurrence of floods/GLOFs		nr	nr	Increased	Increased	Increased
Occurrence of cloudburst		nr	Increased	nr	Increased	Increased
Occurrence of drought		nr	Increased	nr	Increased	Increased
Attributed impacts						
Water availability for crops and livestock (from irrigation systems)		Increased	Overall, no change (occasionally inadequate during sowing time)	Decreased	Overall, no change (but shortage during sowing time)	Decreased
Crop productivity		Increased	Increased	Decreased	Decrease	Decreased
Livestock productivity		Increased	Decreased	nr	Decreased	Decreased
Degradation of rangelands and pastures		nr	Increased	Increased	nr	nr
Incidence of crop pests		Increased	Decreased	Increased	Increased	Increased
Incidence of livestock diseases		Increased	Increased	Increased	Increased	Increased

Nr, not reported. Source: Field notes.

people reported a decline in the productivity of crops due to changing climate. Only in Sundus, local people reported an increase in livestock productivity. However, in other sites, they reported a decline in livestock productivity. In Tissar and Hushey villages in Gilgit-Baltistan that rely on pastures as their secondary source of feeding livestock have reported the increase in degradation of rangelands and pastures (Table 4).

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3.4. Local adaptations to climate change and water variability

Local people are taking a diverse range of adaptation measures to cope with climate change induced impacts particularly water variably. They include measures such as changing sowing time of crops, the use of improved seed of crops and adopting new techniques to cope with the changes in timing of seasons and declining productivity. For example, in Sundus village of GB, farmers reported the changes in timing of crop sowing. Instead of waiting for spring (starts from mid-March), they have started cultivating crops in winter months because of the early end of cold spell. Local farmers also improved their farm practices such as mulching and irrigation methods. Most importantly, some local people in Sundus and Hushey villages have introduced microenterprises for crops and livestock in the village, providing good opportunity to farmers for earning reasonable profit.

In Tissar and Hushey villages of Gilgit-Baltistan, local people have introduced improved breeds of livestock and improved seed variety (Table 5) to compensate the declining productivity of agronomic crops and native livestock. However, they are not aware of the fact that improved breeds of livestock require more water and fodder. In Hushey village, local people brought bull (improved breed) for cross breeding with local cows. Currently, 40–45% farmers have crossbreed cattle. It has reduced pressure on pastures because farmers do not send this breed to pasture due to the fear of wildlife attacks. However, it has increased pressure on locally produced fodder production. This breed consumes more fodder and water compared to local breeds. Consequently, livestock farmers have reduced the number of livestock because the situation has forced them to buy expensive fodder from other farmers.

In Hushey village, a local NGO introduced an improved variety of wheat, but it took longer (6 months) to mature, compared to local varieties (5 months). Farmers reported that this improved variety did not respond satisfactorily in the mountain environment and its productivity was also low. Local people also replaced agronomic crops with fruits and trees (for timber) for better economic returns. Among fruits, walnuts are getting a lot of attention. Farmers are selling walnuts and its oil to local markets. They are using manual machines to extract the oil of walnut in the village. For timber, they are cultivating fast growing poplar trees due to its high market demand. Local people have also reported that reviving traditional crops particularly buckwheat in the local agricultural systems due to its resilience to water-stress and suitability to local agro-ecological conditions. During the last couple of years, local community has started cultivating improved variety of buckwheat on commercial scale as second crop. The farmers have signed agreements with a local entrepreneur who collects buckwheat

TABLE 5 Local adaptation measures to cope with climate change and water variability.

Rank of adaptation measures*	Gilgit-Baltistan			Leh-Ladakh	
	Low altitude (Sundus)	Medium altitude (Tissar)	High-altitude (Hushey)	High altitude	Very high altitude
1	Changes in sowing time from spring to winter	Introduction of improved breed of livestock	Introduction of improved variety of wheat	Improved irrigation methods (Community based)	Improved irrigation methods (Community based)
2	Improved farm practices	Shift from agronomic crops to fruits and poplar trees	Introduction of improved breed of livestock	Introduction of improved breed of livestock	Introduction of improved breed of livestock
3	Introduction of microenterprises for crops and livestock	Revival of traditional crops, particularly buckwheat	Start of agricultural microenterprises (including both crops and livestock)	Improved water management (adoption of bore-well pump, ice stupa and artificial glacier)	Shift from agronomic crops to vegetables
4	nr	Change in crop sowing time	nr	Shift from agronomic crops to fruits, vegetables and tree crops	Revival of traditional crops and medical plants, and integrating with tourism.
5	nr	Use of improved seed	nr	Shift to off-farm income opportunities (reported land abandonment)	Shift to off-farm income opportunities (reported land abandonment)

*Adaptation practices are reported in an order with 1 'the most important'. Nr, not reported. Source: Field notes.

grains at household level every season. The entrepreneur, after proper processing, packaging and branding, sells the buckwheat flour in large markets of the country.

In "high altitude" site of Leh-Ladakh local people improved water management practices to cope with the water shortages during crop sowing time in spring. Some installed adopted bore-well pumps. With the help of local NGO, local people have also adopted the method of freezing water for storage such as artificial glaciers and ice stupas. Local people in the area have also improved irrigation methods to use available water more efficiently.

Despite these water management practices, farmers still reported that they are gradually shifting to vegetables, fruits and tree crops from cereals and pulses. They reported that horticultural and tree crops require less water and labor but yield high profit. The District Agriculture Department is also supporting farmers in compost preparation, construction of plastic tunnels and grafting (in fruits only) to promote vegetables, mushroom and fruits cultivation in the "high altitude" study site. In some instance in high altitude site, farmers are abandoning agricultural land and shifting to non-agricultural income sources such as tourism and small businesses (Table 5). It was also reported in 'very high-altitude site' that a small proportion of local people also opted for growing traditional crops (i.e., buckwheat) and are selling traditional dishes in local market/tourism spots to generate income. A very small proportion of local people also reported the cultivation of medicinal and ayurvedic plants in the area.

District level departments of Agriculture and Animal Husbandry working in the area have introduced new breeds of livestock. However, similar to the case in Gilgit-Baltistan these improved breeds are likely to consume more water and fodder. Some people raise sheep to earn from raw material (wool) required for traditional attire, i.e., pashmina, to sustain their livelihoods.

Despite the adaptive strategies adopted, the locals have indicated a decrease in agricultural and livestock productivity which may have encouraged them to shift away to off-farm activities as a coping measure.

3.5. Non- climatic challenges in adoption of local adaptation measures

In addition to climate change induced challenges, there are some non-climatic issues with both positive and negative impacts on local agriculture and livelihoods in study sites (Table 6). Improved access to roads due to construction of Karakoram Highway and link roads has resulted in the adoption of value chains in local food systems. However, in high altitude areas, connectivity to roads and market gets disrupted in winter (December–March). In study sites of Leh-Ladakh, locals also reported improved access to market. However, due to high altitude and heavy snowfalls in winter, local study sites disconnect from distant markets.

As far as extension services are concerned, adequate information on the use of advanced technologies is not being provided to farmers. In study sites of Gilgit-Baltistan, farming practices are mainly based on traditional practices. There are some NGOs providing awareness on value chains development. In the sites of Leh-Ladakh, government institutions are providing awareness and technical support on some technologies such as plastic tunnels for vegetables production. However, most farmers are still not aware of advancement of technologies in agriculture. In all study sites in Gilgit-Baltistan and Leh-Ladakh, farmers' access to financial services is very limited. There are no microfinance schemes for farmers in these difficult mountains. Moreover, access to technology in study sites is also limited to conventional agriculture machinery for tilling, threshing, and transport. Farmers in these study areas have access to mobile connectivity and internet, however there is no institutional mechanism to supply climate services and market information to farmers to tackle climatic and market related challenges. In high altitude site in Gilgit-Baltistan and both sites in Leh-Ladakh, the importance of tourism as livelihood source is gradually increasing. It has negative impacts on agriculture because the local people are gradually leaving agriculture and paying more attention to tourism related income opportunities.

4. Discussion and conclusion

4.1. Discussion

In the study sites, agriculture and livestock are among key livelihood sources (Table 2). This is consistent with findings of preceding studies (Pelliciardi, 2013; Rasul and Hussain, 2015; Hussain et al., 2016, 2021a; Rasul et al., 2019) from other parts of the UIB. Even at the HKH level, around 90% households partially or fully depend on agriculture and livestock for their food security and income (ICIMOD, 2020). Among study sites, three are located in single cropping zone (one in Gilgit-Baltistan and two in Leh-Ladakh) where farmers can cultivate crops during the period from March to October (may change depending on snowfall onset in winter and melting in spring). It implies single cropping zones already face the challenge of harsh weather due to high altitude (Table 1). Study sites in double and marginal cropping zones have long periods for cultivation of crops and are less vulnerable to stress caused harsh weather (Rasul, 2014; Rasul et al., 2014). Livestock is equally important particularly in single cropping zones to sustain livelihoods due to constrained weather conditions for crops, as reported from high altitude areas (Gatlang, Rasuwa district) of Nepal (Merrey et al., 2018).

TABLE 6 Non-climatic challenges in agriculture.

Broader Indicator	Gilgit-Baltistan			Leh-Ladakh	
	Low altitude (Sundus)	Medium altitude (Tissar)	High-altitude (Hushey)	High altitude site (cluster of villages)	Very high altitude site (cluster of villages)
Status of the indicators reported by respondents					
Market access	Good access because the village is located close to district headquarter	Access has improved but still not adequate	Access has improved but during December to March, village disconnects from market due to heavy snowfall	Inadequate access and needs further improvement. Overall it has improved.	Inadequate access due to seasonality. Overall it has improved.
Agricultural extension services	Limited services by the government	Limited services by the government	Limited services by the government	Inadequate services by the government	Inadequate services by the government
	Despite being near to the district headquarter	Provision of services by NGOs and community based organizations		Most farmers are not even aware of extension services. Agriculture mainly based on traditional practices	Agriculture mainly based on traditional practices
	Farmers have partial information on agricultural technology		Agriculture mainly based on traditional practices		
Access to financial services for agriculture	Unaffordable due to high interest rates of micro financing service providers.	Limited information available to the farmers about policies and services of microfinancing institutions.	Limited information about policies and services of microfinance institutions.	Limited access access to financial services	Limited access access to financial services
Access to technology	Limited access to agricultural technology.	Limited access to agricultural technology.	Limited access to agricultural technology. Internet services are available which can be used to learn on agricultural technologies.	Inadequate access to agricultural technology. Subsidized tool and machinery, and 4G internet connection are partially available.	Inadequate access to agricultural technology. Partial access to internet.
Agriculture and Tourism trade-off	Agriculture still remains important livelihood source	Agriculture still remains important livelihood source	Increased focus on tourism based livelihoods.	Increased focus on tourism based livelihoods, i.e. trekking. Improvement in tourism related infrastructure and means for attraction.	Increased focus on tourism based livelihoods (i.e. homestays)

Source: Field notes.

Climate change is adding to the challenges of agriculture and livestock in study sites. Local people reported that climate induced changes in temperature and precipitation patterns, increased hazards, shift in the timing of seasons, and increased incidence of crop pests and livestock diseases have direct negative impacts on the productivity of crops and livestock. Climate change is also indirectly impacting the productivity of crops and livestock through degradation of pastures and rangelands (Table 4) and resulting in water variability in *kuhls*. In almost all study sites (except Sundus village in Gilgit-Baltistan), local people reported that degradation of pastures is negatively impacting the productivity of pasture-dependent livestock. These findings are consistent with those from preceding studies conducted in similar mountain areas (Akramov and Shreedhar, 2012; Bandara and Cai, 2014; Rasul, 2014; Rasul et al., 2014; Bocchiola et al., 2019; Ghahramani et al., 2019; Hussain et al., 2021a; Thapa and Hussain, 2021). Local people also perceived that water variability in *kuhls* is caused by changes in average snowfall in high and very high-altitude sites in Gilgit-Baltistan and Leh-Ladakh. The perceived shrinkage of winter season also supports the reported decline in average snowfall. Climate induced water variability in *kuhls* was also reported by other studies in the UIB (Abbasi et al., 2017; Ashraf and Akbar, 2020). In low and medium altitude sites of Gilgit-Baltistan, local people reported an increase in average snowfall and shrinkage in winter season. Sometimes, erratic snowfall events also lead local people to perceive an increase in average annual snowfall.

To cope with these climatic challenges, local people are taking autonomous adaptation measures. Study sites are agro-ecologically suitable for vegetables, fruits, nuts and traditional crops such as buckwheat, barley and millets. These crops are relatively more resilient to water and cold stresses (Adhikari et al., 2017). In two sites (low altitude site in Gilgit-Baltistan and very high-altitude site in Leh-Ladakh), local people revived traditional crops to cope with water stresses. In the low altitude site of Gilgit-Baltistan – Tissar village – local people developed value chains of buckwheat to take advantage of relatively improved access to market. The revival of traditional crops is a very positive sign for the overall diversity and sustainability of local agriculture. Genetic diversity in agriculture is fundamental to agro-ecosystem resilience and stability in food production (Frison et al., 2011; Matsushita et al., 2016; Rasul et al., 2016). It suppresses pest outbreaks, buffers the impact of climate variability and extreme events and improves income, food security and nutrition (Lin Brenda, 2011; Makate et al., 2016). However, in the HKH, the share of traditional cereals and pseudocereals (barley, oats, millets, sorghum and buckwheat) in overall production of cereals and pseudocereals has declined from 10% in 1990 to 3.2% in 2017, leading to a decline in agrobiodiversity (Hussain and Qamar, 2020). In Tissar village, local people also developed value chains of some fruits such as walnut with the support of local NGOs. In medium and high altitude sits of Gilgit-Baltistan, local people started microenterprises of some selective crops and livestock. In study sites of Leh-Ladakh, the shift from agronomic crops to vegetables is likely to increase the demand for irrigation water. However, local people also reported an improvement in irrigation methods to avoid water losses during field applications. In almost all study sites, local people reported the introduction of improved breeds of livestock. In general, improved breeds of livestock consume more water and fodder. Tissar village of Gilgit-Baltistan had introduction of improved breeds and encountered the challenge of increased need of water and fodder for improved livestock population. They reduced the numbers of livestock due to increased requirement of water and fodder. It is difficult for local people to fulfill the consumptive demand of livestock, particularly when pastures are degrading.

In both sites of Leh-Ladakh, the local people also reported a shift from agriculture-based livelihoods to tourism based economic activities. They mainly attributed this change to climatic induced decline in water availability and labor shortages during critical periods of crop cycle (Table 2). The local people also reported partial abandonment of agricultural land due to labor shortages and variability in available water in irrigation systems (Table 5). This is consistent with other study (Rasul et al., 2019) in the UIB revealing that 41% farming households face frequent labor shortages during critical stages of agricultural activities. It is also important to highlight that study sites have high potential for less water consumptive organic agricultural production. However, currently agricultural practices are dominantly inorganic, except very high-altitude site in Leh-Ladakh. It is also not so much different from the overall situation in the HKH. Only 1.4% (0.80 million ha) of the total cultivated land (≈56 million ha) in the region is under organic agriculture (Wester et al., 2019; ICIMOD, 2020). Overall, climate induced variability in *kuhls*, dominance of inorganic agricultural practices, degradation of rangelands, agricultural land abandonment and shift to non-agricultural income activities (in case of complete shift) are posing challenges to future sustainability of agriculture (including livestock) in the UIB.

4.2. Conclusion

In study sites of subregions – Gilgit-Baltistan and Leh-Ladakh– in the Upper Indus Basin (UIB), climate change induced challenges are almost similar. In study sites, water resources, agriculture and livelihoods are highly vulnerable to climate change induced risks and hazards. Despite the rising importance of non-agricultural economic activities, agriculture still remains the main source of food security and livelihoods. Agriculture in study sites mainly depends on traditional irrigation systems fed by glaciers- and snow-melt water. Climate induced changes in precipitation patterns, temperature rise, changes in timing of seasons, increased incidence of pest attacks and water related hazards are impacting agricultural practices, productivity and sustainability. Dominance of inorganic agricultural practices in most study sites, and land abandonment and shift to non-agricultural income sources in study sites of Leh-Ladakh are also posing challenges to suitability of agriculture. Despite inadequate water availability from *kuhls* and degradation of rangelands, a shift toward water consumptive crops (i.e., vegetables) and improved breeds of livestock is also likely to increase the chances of water stresses in future. Revival of less water consumptive traditional crops, start of enterprises and value chain development in some study sites of Gilgit-Baltistan, improvement in irrigation methods and integration of traditional agricultural products (products prepared from traditional crops and medicinal plants) with tourism in Leh-Ladakh are likely to contribute positively toward productivity and sustainability of local agriculture. Improved water management practices including the adoption of bore-wells and ice stupas in Leh-Ladakh are also important solutions to cope with the climate induced water variability in *kuhls* and stresses caused by dry spells.

Based on findings of this study, it is understood that there is need of almost similar type of solutions in both subregions – Gilgit-Baltistan and Leh-Ladakh – corresponding to similar nature of challenges. There is a need to establish a cross-border learning mechanism for local communities.

In this regard, collaboration of local institutions from both sides of border and people to people connections are very important to share the good practices and learn from both experiences. The study also reiterates the importance of the Upper Indus Basin Network for cross-learning among scientists and researchers from all four UIB nations to discuss and support the implementation of the most viable local solutions.

4.3. Future research

This study was initially designed as quantitative research with the aim to conduct household surveys based on robust sampling design. However, due to COVID-19 cased restrictions, the study relied mainly on qualitative community level data. It could not conduct quantitative assessment of the role glacier-/snow-fed irrigation systems on agriculture and livelihoods. Therefore, it is suggested to conduct more robust quantitative assessment on the subject by selecting a few villages as cases from study sites of this research. It is also suggested to conduct quantitative assessment of the trade-off and synergies between agriculture and tourism through the lens of sustainability.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not provided for this study on human participants because as we are intergovernmental organization the standard we follow depends on the partner we work with and the country we are researching in. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Informed verbal consent was taken prior to any participation.

Author contributions

AH and ABS conceived the idea. ST and AH analyzed and prepared the manuscript. ST, SB, AA, MS, TA, and APD collected and compiled the data. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1012363/full#supplementary-material

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