PROCEEDINGS OF THE

International forum on cryosphere and society

The voice of the Hindu Kush Himalaya

28–30 August 2019 | Kathmandu, Nepal

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Abbreviations and acronyms

BC Black carbon
BCM Billion cubic metre
CAS Chinese Academy of Sciences
CH_4 Methane
CO_2 Carbon dioxide
ECV Essential climate variable
EWS Early warning system
GCOS Global Climate Observing System
GHG Greenhouse gas
GLOF Glacial lake outburst flood
GW Gigawatt
HKH Hindu Kush Himalaya
HMA High Mountain Asia
ICIMOD International Centre for Integrated Mountain Development
IPCC Intergovernmental Panel on Climate Change
KU Kathmandu University
MW Megawatt
PDGL Potentially dangerous glacial lake
PPA Power purchase agreement
SDGs Sustainable Development Goals
SKLC State Key Laboratory of Cryospheric Sciences
TP Tibetan Plateau
WHO World Health Organization

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Executive summary

The health of the Hindu Kush Himalaya (HKH) – its cryosphere, hydrosphere, and biosphere – serves as an indicator of the general health of the planet. Being at the "top of the world", changes occur in this region before anywhere else, and the beat of the place reverberates across the globe. The HKH thus represents the pulse of the planet.

On 28–30 August 2019 the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu University (KU), and the State Key Laboratory of Cryospheric Sciences (SKLC) of the Chinese Academy of Sciences (CAS) organized the "International Forum on Cryosphere and Society in the HKH: The Voice of the HKH" – the first event of its kind in the region. The event brought together 120 leading experts, practitioners, stakeholders, and representatives of local communities from across the HKH and beyond to share their insights and perspectives on the intersections of the cryosphere and society and to articulate a collective voice for the HKH.

At the core of this forum was an exploration of the concept of "cryosphere contributions", a comparatively new lens through which the cryosphere is viewed at its intersections with humanity. This "cryosphere contributions" concept strives to contextualize risks or services, without imposing antiquated resource-based thinking on them. The main components of the cryosphere in the mountain environment are glaciers, snow, and permafrost. As these are sensitive to climate change, the cryosphere affects every aspect of high mountain life in the HKH, including its people and the environments downstream.

The voice of the HKH, as articulated in the forum, underlines the need to find contextual and pragmatic solutions to the challenges induced by cryosphere changes and their impacts. It emphasizes that there is enough actionable data to address these challenges and it calls for action in the following areas:

Key messages

- Improved communication among scientists, decision makers, and diverse groups of communities, as well as enhanced regional and inter-regional dialogue on cryospheric change and its impacts on society.
- Close collaboration with diverse groups of high mountain communities to integrate indigenous knowledge with scientific research, ensuring that indigenous peoples can use science for the benefit of their communities; and that this integrated knowledge is reflected in the decision-making process.
- Adopting a transdisciplinary approach to understanding and managing change and its impacts, and protecting natural resources, people, and their livelihoods.
- Employing transformative strategies for integrated risk assessment and management to protect the people of the HKH and their livelihoods from cryosphere hazards, such as glacial lake outburst floods (GLOFs), landslides, rockfall, and ice and snow avalanches.
- Identifying and addressing the knowledge gaps and needs of diverse stakeholders at all levels; these include gaps in terms of scientific data, people's awareness about the impact of cryosphere change, gaps between scientific findings and policy uptake, and gaps at the interface of physical and social sciences.

Section A

The high mountain environment: A shared heritage

The opening session of the forum on cryosphere and society established the focus of the event: to better understand the importance of mountains, especially through its interactions and intersections with society. The HKH has the third-largest repository of ice and snow, with over 54,000 glaciers storing more than 6,000 km^3 of freshwater. These components of the cryosphere serve as a vital source of water for as many as two billion people, particularly in the dry seasons.

The region is undergoing tremendous alterations, heavily impacted by climate change and other anthropogenic activities, and these changes are becoming rather challenging to manage. Temperatures rise faster in the mountains than in the plains, and the changes in terms of glaciers, permafrost, and the monsoon add different complexities and new dimensions to the prevailing challenges.

It is now time to set a new agenda for addressing the impacts of climate change on glaciers, mountains, and people. Any policy or action focused on mitigation needs to shift its attention away from the symptoms and address the actual causes.

Economics of the cryosphere

The cryosphere lies at the source of many major rivers in South Asia. Glacier- and snow-fed rivers originate in the upstream areas and flow across national boundaries, sustaining surface and groundwater irrigation, livestock production, fisheries, and hydropower, as well as fulfilling domestic and other needs of the mountain and downstream populations. The populations in the high mountain areas are dependent on meltwater from the snow and glaciers for domestic use and irrigation. The glacier- and snowmelt-fed springs are also major sources of water in the high-altitude areas of the HKH. In addition, many of the major cities in the region depend on glacier- and snow-fed surface water for their municipal water supply. Even further away from the mountains, large irrigation systems in South Asia depend on water from the HKH cryosphere systems.

A recent comprehensive assessment of glaciers in the HKH concluded that the trend of glacier changes – i.e. thinning, retreating, and losing mass – in the Himalayan region is increasing at a higher rate and this trend is expected to continue in the future and, by 2100, the HKH could lose one-third of its glacier volume. The economic and social costs of cryosphere change could be massive and its ramifications can extend beyond the mountain region and affect the densely populated river basins of the HKH region. It is thus important to understand the role of cryosphere in the realm of society and economy in order to facilitate actions to mitigate the impacts and undertake adaptive actions in the region.

The economies of some HKH countries depend considerably on cryosphere resources. In the Indo-Gangetic Plain, millions of farmers depend, directly or indirectly, on glacier and snowmelt water for irrigation, food security, and livelihood. And within the Indus and Ganges basins, about 129 million farmers depend on snow and glacier melt for their agriculture, livelihood, and food and nutritional security.

The major economic impacts of cryosphere change will manifest through the changes in hydrological regimes and water availability, as all the major rivers in South Asia originate from the mountains of the HKH, flowing across national boundaries and draining into the ocean. These rivers are lifelines for the downstream populations. As well as sustaining agriculture, livestock, fisheries and hydropower, a large number of cities and towns are situated along the banks of the three main rivers – the Indus, Ganges, and the Brahmaputra – and their tributaries. The changes in the cryosphere are likely to affect water availability, in terms of quantity, quality, and timing, thus fundamentally impacting food, energy, and human security. In order to prevent such a scenario, timely and appropriate adaptation measures and investment in development of infrastructure are very much required.

Hydropower contributes 16 per cent to global electricity. The changes in the cryosphere will affect the quantity and seasonality of the water available for energy production in the HKH. Meanwhile, GLOFs are posing threats to the hydropower infrastructure in the mountain regions. Cryosphere changes affect hydropower and the consequent impacts on streamflow direction are unpredictable. As a coping strategy against unpredictable water input in the wake of hazards such as GLOF, water storage reservoirs, for instance, need to have adequate capacity.

Moreover, the disasters unleashed by avalanches and GLOFs have resulted in huge economic losses to the countries of the region. When GLOFs destroy hydropower facilities, it cannot be perceived as a one-time loss, as the impacts are long-lasting and multiply over time. The destruction costs include value of the damaged infrastructure, loss of royalty from electricity sale, loss of revenue, loss of capacity, royalties on installed capacity, the investment required for environmental and socioeconomic development, and reinvestment in the hydropower plant (if repaired or replaced). The potential for economic losses and damages due to GLOFs are increasing as hydropower and other infrastructure are developing fast along the river valleys.

In this regard, geohazards like GLOF need to be studied from a multi-hazard perspective in order to estimate the loss from associated impacts, including bank undercutting, landslides, and debris flows.

Importantly, effectual adaptation to cryosphere change is essential to avoid irreversible damage to the economy and society of the HKH region. The current adaptation measures related to cryosphere change in the region are not adequate or well planned. Most responses are short term, autonomous and sector-specific. And these adaptive actions face multiple challenges, including inadequate scientific data and financial resources; low technical capacity; and weak institutional and policy support. Limited data on glacier changes in the region remains one of the main hindrances in making informed decisions while attempting to understand the economics of the cryosphere. While data on the physical science of the cryosphere change is improving, due to ever-increasing adoption of remote sensing techniques, information on its socio-economic impacts and on livelihood aspects remain limited or non-existent. It is time to acknowledge the economic value of the storage services provided by the cryosphere to the regional hydrological regimes. It is also important to consider the non-economic benefits of the cryosphere, such as its cultural and religious services as well as the collaborative regional mechanisms that are in place for adapting to cryosphere change.

In the HKH, most economic infrastructure is dependent on glaciers and snowmelt water.

- Agriculture and food security: Glaciers and snowmelt contribute to 60 to 90 per cent of the water supply for agriculture and irrigation in the high mountain areas, particularly in the western Himalaya. Besides these high mountain areas, lowland agriculture and sources of food security rely considerably on glacier and snowmelt water. The Tarbela Dam on the Indus River, for instance, stores about 14 billion cubic metres (BCM) of water, with 70 per cent of this water coming from glacier and snowmelt. The water from the Tarbela Dam irrigates about nine million hectares of agricultural land, generates 3,478 MW hydropower, and supports the livelihoods of millions of people. Similarly, in the Indus River Basin, many large irrigation systems rely on glacier and snowmelt water, such as the Bhakra-Nangal Dam in Himachal Pradesh, India.
- Hydropower: The energy generated from glacier and snow-fed rivers makes significant contributions to the economies of Bhutan and Nepal and, to a lesser extent, India and Pakistan. In addition to large hydropower systems, Himalayan tributaries also support many small-scale hydropower projects that supply electricity to the rural areas.
- Drinking water: Glaciers and springs are the main source of drinking water in the high mountain areas of the western Himalaya. In the Indian Himalaya, 50 per cent of the springs have dried up. A number of municipalities depend on glacier and snowmelt water for supplying water to the urban populace. In the Ganges basin, several drinking water projects are sourced from the mountainous regions; in the upper Ganges basin, about 12 per cent of the water comes from glacier melt and 9 per cent from snowmelt, and this contribution increases up to 25 per cent during February and March.

Cryosphere shrinkage and the associated environmental changes may affect agriculture, food security, energy, and drinking water supply in the HKH region and the downstream areas. Besides these direct impacts, cryosphere changes can also increase economic burden through the enhanced risk of disasters such as floods, avalanches, landslides, and forest fires, resulting in damage to property and human resources. The additional costs of maintaining and repairing economic infrastructure and facilitating community relocation owing to environmental and livelihood shocks/risks from cryosphere change add even more burden on the economy.

KEY MESSAGES

- Further research is needed to quantify the potential long-term effects of cryosphere change on upstream–downstream areas in the contexts of economies, societies, and the environment.
- Partnership and regional cooperation are key to success in the HKH to adapt to the adverse impacts of cryosphere change and minimizing the damages and effects of cryosphere-related hazards. Institutional mechanisms need to be developed to coordinate responses across sectors and across the HKH countries.
- Adequate financial resources and increased investment in water-related infrastructure will be necessary to adapt to future economic challenges. Investment in building and improving physical infrastructure such as irrigation channels, flood control dams, and water storage facilities is necessary to cope with water stress as well as the impacts of the changes in the cryosphere.
- Future research needs to assess the economic value of the storage services provided by the cryosphere in the hydrological regime and also study the long-term effect of cryosphere change on water, agriculture, food security, hydropower, and livelihoods in the HKH region.

Cryosphere contributions and sustainable development

The cryosphere contributes to and has impacts on societies in ways that can be perceived positively, negatively or neutrally. The impacts can vary, depending on the stakeholder experiencing or perceiving them. As a positive, aspects of the cryosphere services can be categorized by following a framework similar to that of ecosystem services, by including social/cultural services and regulatory and supporting services. Then there's the factor of the impacts of cryosphere hazards, which are typically perceived as having a net negative or potentially deleterious effect. The dynamics and perceptions about cryosphere contributions need to be better understood. The importance of cryosphere contributions has to be conceptualized in the context of both space (upstream–downstream) and time (i.e. season, year). The contributions, as well as their importance, vary considerably depending on who, where and when aspects of the stakeholders.

The different components of the cryosphere – glaciers, snow, permafrost, lake and river ice, and glacial lakes – have varying significance for climate systems and environment, and their dynamics are complicated, especially when the interlinkages with other spheres in the Earth system are considered. These connections become ever more complex when the cryosphere is connected with societies – through its contributions or impacts on the society as well as how human activities influence it.

Moreover, the cryosphere is sensitive to climate change, which continues to affect and influence its systems, and subsequently, other interconnected systems. The changes are reflected by the increase in the frequency or scale of cryosphere-related hazards in some areas or deterioration of cryosphere services that had been positively perceived. Subsequently, the changes ultimately impact humanity.

In fact, the cryosphere contributes significantly to innumerable societies throughout the HKH region. But there are two aspects to this – while the cryosphere protects the well-being of the region's peoples, it also induces hazards that affect health and livelihoods. So, a deeper understanding and integrating cryosphere contributions with policy and societal benefits could be the key to strengthening sustainable development in the region.

KEY MESSAGES

- The dynamics and perceptions about cryosphere contributions need to be better understood and conceptualized in the context of both space (upstream–downstream) and time (i.e. season, year); they should also be informed by the views of the stakeholders.
- The cryosphere plays a critical role in strengthening sustainable development and can contribute significantly towards achieving the Sustainable Development Goals (SDGs).
- Establishing risk management approaches can provide effective pathways to maximize the benefits and minimize the adverse impacts on sustainable development in the HKH.
- Scientific findings must be translated into intelligible and relevant language. Resources should be mobilized to amplify the voice of the HKH region in order to improve understanding and facilitate the communication of knowledge and the concerns of the region to the global community, including scientists, decision makers, local communities, and other public audiences.

The cryosphere under a changing climate in the HKH: Findings from *The Hindu Kush Himalaya Assessment* and linkages to global policy processes

The Hindu Kush Himalaya Assessment report revealed that even if global warming is limited to 1.5°C by 2100, there will be an estimated 1.8°C rise in temperature across the region, and up to 2.2°C in the mountains. Given such a situation, about one-third of the glaciers in the HKH region will melt by the end of this century. And if global warming goes unchecked, potentially two-third of the glaciers in the region will disappear by the same time. The snow-covered areas and snow volume, too, will decrease, while snowline elevations will rise. As for the snowmelt-induced run-off peak, it will be stronger and will occur earlier in the year.

Mountains are a hotspot of climate change in part because temperature fluctuations, exacerbated by greenhouse gas (GHG) emissions, are amplified with elevation. Thus, when global temperatures rise, the temperatures across the HKH have and will continue to rise at a higher rate. At current emission trends, the average temperatures in the HKH are expected to rise by about 5°C by 2100. The higher rates of warming in the mountains will lead to changes in upstream water resources in the form of increased glacial melt and decreased ice reserves.

Glacier volume loss and retreat has also been responsible for glacial lake expansion. Accelerated glacier wasting and degradation of permafrost, in response to rising global temperatures, are expected to increase the number and/or magnitude of GLOF events in the future. Presently, glacial lakes are expanding and increasing in number. In Nepal, although monitoring and risk assessment methodologies need to be critically discussed and unified, around 20 lakes have been identified as potentially prone to outburst. A transnational management strategy and a monitoring framework are urgent requirements in order to provide a concrete set of solutions and actions to tackle the GLOF issue.

The permafrost temperatures increased significantly in the last decades, at a rate of approximately 5 per cent per decade between the 1960s and the 2000s. In particular, the “cold type” of permafrost, i.e. with a mean annual temperature between -6.5 and -8.5°C, was subject to the strongest degradation, at a rate of about 16 per cent per decade. Whilst research has been conducted across the high-altitude plains of the Third Pole, especially under the initiative of

China in the Tibetan Plateau (TP), there is a need for routine permafrost monitoring in the mountains of the HKH.

Black carbon (BC), which can be considered as a fingerprint of human activities, is also a major player in glacier and snow wasting. BC refers to particles with a core composed of carbon, and results mostly from the incomplete combustion of petroleum products and plant-derived biomass. Due to their dark optical properties, these carbonaceous aerosols have the particularity of capturing and absorbing sunlight energy, thereby enhancing snow or ice melt at the surface of the glaciers. This phenomenon provides one of the best examples of how the quality of air, particularly in cities and industrial regions, can impact the fate of glaciers, even those located in the far distance. Meanwhile, air pollutants originating in and near the HKH amplify climate change and may contribute as much as carbon dioxide (CO_2) to radiative forcing.

KEY MESSAGES

- Even 1.5°C is too hot for the HKH, and will be amplified by elevation-dependent warming. If global warming goes unchecked, the loss will amount to two-third of the number of existing glaciers. This will adversely impact the lives of nearly 250 million people living in the mountains and hills and nearly 2 billion people living in the river basins downstream.
- The changes in the HKH region affect more than a quarter of humanity, as the region is considered the Third Pole with more than 54,000 glaciers. The glaciers, both directly and indirectly, supply hundreds of millions of people with food, energy, clean air, and income.
- There are areas where knowledge gaps still exist in the region, but there is also enough data to take action. Better knowledge together with better communication will mean better action.

Section B

Cryosphere contributions to society and the environment: Supply and regulating contributions; the role of the cryosphere in the hydrological cycle

Mountain ranges act as barriers for moisture transportation, influencing where and when solid and liquid precipitation occur. The highest temperature increases within the HKH have been observed across the Hindu Kush, Pamir and Karakoram regions, with evidence of strong elevation-dependent warming. When looking at the water balance component, glacier melt is projected to increase through to the 2040s, and subsequently decrease as regional glaciers degrade, decreasing the overall ice volume and resulting in the limited remaining ice being restricted to higher elevations. Even though annual total precipitation may increase in the future, due to climate change, glacier and snow contributions to the water balance are likely to decrease. Seasonal shifts in the contributions from precipitation are also anticipated.

Glaciers and snow act as water reserves, which attenuate water transportation from upstream to downstream. Glaciers are heterogeneous by nature, with different lengths, areas and masses in different regions. However, changing patterns in climate regimes, increasing population and pollution are all impacting the different components of the hydrological cycle. The impacts of climate change are also heterogeneous, with disparate impacts and manifestations across affected regions, even down to the valley or even city-scale. The HKH has experienced major glacier mass loss (except in the Karakoram region) on an accelerated scale due to climate change. And to add to the complication of scientifically understanding the issue, the study of glaciers has been limited by the inaccessibility of many ice masses in the region.

On an average, the HKH region is losing 150 kg/m^2 per year. However, it is difficult to measure glacier retreat on the ground due to the rugged topography of the region. Not even a quarter of the approximately 54,000 glaciers in the HKH region are monitored. The Pamir and Karakoram regions have been experiencing positive glacier mass balance due to high increase in precipitation and cooler summers, leading to the so-called “Karakoram Anomaly”.

The three major climate change impacts on glaciers can be seen in: i) glacier retreat or elongation; ii) glacier area expansion or contraction; and iii) positive or negative mass balance. One of the major impacts that has still not been studied properly is mass wasting of glaciers. The uncertainties in the glacier volume estimates and the rate of glacier melt projections further complicate the impact on future hydrological flows and their components. This uncertainty can be reduced by the integration of the collected data from the field with remote sensing and modelling. Such integration can be used for future projection of changes in the snow and glacier dynamics.

There is a need for adaptation policies on climate change impacts on water availability, and such policies should be supported by vulnerability assessments of climate change impacts on the communities. The vulnerability factor itself is contingent upon the degree of dependence of the local people on glacier and snowmelt throughout the year for domestic use and irrigation.

There is also the fact that the contributions of snow and ice melt vary from basin to basin, with higher contributions going to the immediate vicinity of the glaciers, while the downstream areas receive less. In the case of agricultural produce, the proportions of contributions from the cryosphere vary from crop to crop and season to season. Meanwhile, the projections are that events of hydrological extremes are set to increase. As regards groundwater, it is expected to deplete due to the combination of increasing demand – mainly from domestic and industrial quarters – and population growth.

KEY MESSAGES

- The region is experiencing an acceleration in glacier mass loss, except in the Karakoram region, due to climate change. That said, the capacity to monitor glaciers is rather limited owing to the difficulty in accessing these terrains in the HKH region.
- The three components that entail the monitoring of glacier change need greater integration so as to reduce any degree of uncertainty; the three components are – field data collection, remote sensing, and modelling for the purpose of forecasting .
- Policies to enhance adaptation in order to limit climate change impacts on downstream water availability need to be informed by vulnerability assessments. The aspect of vulnerability is influenced by the degree of dependence of the local people on a glacier.

Climate modulation with a focus on particulate pollution and its impact on the cryosphere

The issue of air pollution in the HKH is one that needs to tackle with the concerted aid of regional collaboration. The HKH is not a major source of GHGs, but the impact of the GHGs produced elsewhere is evident across the region. So, global action is needed to reduce GHG emissions and thus their impacts. Stricter regulations, policies, and enforcement measures would be a good starting point.

The precipitation patterns in the HKH vary from east to west. The precipitation originating from the Indian Ocean is deposited over the central and eastern Himalaya in the summer months, whereas the western Himalayan precipitation is fed predominantly by the Mediterranean Sea and the North Atlantic Ocean during the winter. Studies show that while there has been an increase in the mean and extremes of precipitation, there has been no significant change in summer monsoon depressions.

As regards the state of precipitation and temperature across all seasons in the region, it is predicted that they are bound to rise. However, presently, snowfall has been on the decline in the eastern and central Himalaya. While precipitation changes in the western reaches of High Mountain Asia (HMA) will most likely dictate cryosphere health in the future, temperature fluctuations are anticipated to be the key driver of change in the eastern HMA.

In terms of climatic modulation of the cryosphere processes, it is occurring through intricate interactions with particulate pollutants such as black carbon. Light-absorbing particulate matter decreases the albedo and subsequently amplifies the melting of glacier, snow, and ice. Modelling work, ice core archives, and satellite data show that glacier, snow and ice melt are significantly influenced by light absorbing impurities. They can also potentially degrade the water quality. This is a transboundary problem and requires regional and global collaboration to address the knowledge gaps in the field.

In the case of aerosols, apart from their importance in the formation of clouds, they can also act as a coolant and have a role in the precipitation process. However, aerosols can also have less favourable impacts, such as on visibility, radiative forcing, and albedo. Within the HKH, the south side of the Ganges and south-east China are hotspots of aerosol production.

The major sources of BC in the region are coal and the burning of other fossil fuels and biomass, as well as transportation and household emissions. To understand the presence and impact of BC in the region, its samples have been collected from the Karakoram region (western Himalaya), Yala Glacier (central Himalaya), and eastern China. Through these samples, it has been observed that across the region, BC and other particles deposited in the cryosphere have reduced the albedo effect by between 0.3 per cent to 27.6 per cent.

BC and particle deposits were found in higher concentration in the Karakoram region compared to the central and eastern Himalaya. Concentrations of ambient black carbon are the highest during pre-monsoon and the lowest during monsoon. Hotspots of black carbon emissions, atmospheric processes such as monsoon depression, the western disturbances, precipitation, and the entire hydrologic cycle of HMA need to be well studied and parameterized. Through long-term field measurements, remote sensing techniques, and integrated earth modelling systems that incorporate the unique features of HMA, it may be possible to reliably project the complex interactions between the changing climate, particulate pollution, and the cryosphere.

For mitigation measures to be effective, vulnerabilities need to be identified, and adaptive and mitigation actions ought to be tailored for the purpose. This is further achieved through policy changes that range from the local to global levels.

Regionally impactful phenomena such as forest fires are a major source of pollution in South Asia and the HKH; so, to meaningfully address this vulnerability, national-level mitigation measures can be adopted wherein the use of clean energy is encouraged and the reliance on fossil fuel is reduced; this will weaken the emission sources. At the same time, investment has to grow in the area of scientific research.

In terms of communication, the scientific information conveyed through the media needs to be customized to better resonate with the target audience. Media personnel should be included in research expeditions and field work, while science communication must rely on clear and compelling graphics, narratives, and visuals. This is ever more relevant in this era of the social media, which has become a major source of information for the general population.

KEY MESSAGES

- The people in the HKH region are broadly exposed to air pollution levels much higher than WHO recommendations. Air pollution not only has a negative impact on glacier integrity, it is also a health hazard. Moreover, it reduces crop yield, thereby affecting nutrition and livelihood. Air pollution is a transboundary problem and requires regional and global collaboration to address the knowledge gaps and reduce GHG emissions and their impacts. Overall, the HKH is not a major source of GHGs, but the impact of GHGs is evident across the region.
- The transport, dispersion, and seasonal variation of aerosols should be simulated by state-of-the-art chemical transport models of high reliability and less uncertainty.
- As communities are the first to bear the brunt of climate change impacts, any mitigation measures and policy changes (from local to global scales) should seek and integrate community voices.
- Climate change impacts are transboundary in nature and require regional and even global collaborations to develop solutions and address the gaps.
- The media is an important collaborator in scientific communication, in raising awareness, and encouraging regional collaboration. However, communicating scientific research and its outcomes to the public remains a major challenge. There is a need to collaborate more with media personnel, to better integrate them in scientific projects, and promote creative ways to communicate science.

Cryosphere and hydropower sustainability in the HKH region

Exploring the future of hydropower development under changing cryosphere conditions should consider three questions:

1. How much hydropower potential can be harnessed in an environmentally sustainable way?
2. What is the role of local benefit sharing in hydropower development?
3. Will hydropower be competitive at the marketplace?

There are four aspects of sustainability in relation to hydropower: environmental, financial, social, and technical. Environmental sustainability encapsulates elements such as flow variation, geohazards, sedimentation, ecosystem viability, climate change, and extreme events. Financial sustainability relates to price, market trade, unit cost, power purchase agreements (PPAs), and financing. Social sustainability encompasses benefit sharing, resettlement, and inclusiveness. And technical sustainability includes siting, design, quality assessment, quality control, and modelling.

Environmental risks pose serious threats to the sustainable operation of hydropower and energy production generally. Technically feasible hydropower potential in the HKH is estimated at more than 500 GW. However, it is uncertain how much of this potential would be environmentally sustainable, in the context of climate change impacts like streamflow variability, sediment load changes, and GLOF risk; and in turn, what these impacts would mean for the hydropower potential itself. The higher the environmental risks, the higher the costs of generation and the return required by investors in power projects, lowering the competitiveness of hydro-electricity in the marketplace. Several mitigation measures need to be developed against the factors that impact hydropower in the HKH, such as glacier retreat that leads to higher variability in streamflow, sedimentation, and erosion.

Recognizing the above threats and the need for judicious investment, it is important to commission detailed basin-scale multi-hazard risk assessments to evaluate the level of threat, all the way through to the worst-case scenario. It is critical to consider the cascading nature of the hazard phenomenon during assessment. Ultimately, the assessment outputs need to be tied up with the design of infrastructure, leading to more resilient hydropower and appurtenant structures. In the context of geophysical hazards like GLOF and flooding influenced by climate change, a comprehensive understanding of changing climate and the consequent impacts on downstream infrastructure needs to be developed through research.

As sediment dynamics are directly related to water flows, cryosphere changes are likely to contribute to increased suspended sediment transport during dry seasons, and transport of higher volume, larger sized sediment during extreme floods. These effects will create major problems for hydropower plants during the implementation and operational stages. To mitigate the impacts of cryosphere changes on sediment dynamics and the subsequent problems for hydropower plants, the following key measures should be taken:

a) Install a flood early warning system (EWS) upstream of the hydropower station to reduce potential damages to lives of project personnel and communities in the riparian areas of the project sites. This will also lessen the damages to both natural and man-made structures;

b) Create a robust design for river hydraulic structures to handle and bypass extreme floods;

c) Optimize a settling basin design to trap higher percentages of finer materials than can be done by conventional designs;

d) Incorporate the provision of sediment bypass tunnels and bottom outlets wherever feasible to prevent excessive sediment load;

e) Reduce fine sediment load on turbines to lessen equipment abrasion; and

f) Design and implement effective emergency preparedness plans in case of dam failure or damage to headworks.

There are numerous measures that can be taken to mitigate the risks that hydropower projects can encounter; some of them are: flow regulation; data collection and projection; smart site selection, micro hydropower; basin-scale multi-hazard studies; installation of EWSs; regular impact and safety assessments; building of resilient projects with robust designs; and development of risk management plans. Incorporating these measures will help sustain hydropower projects in the long run.

Partnerships also play an important role – partnerships between the government, the private

KEY MESSAGES

- In the context of geophysical hazards like GLOFs and flooding influenced by climate change, a comprehensive understanding of changing climate and the consequent impacts on downstream infrastructure needs to be developed through research.
- Risk assessments are required to understand how hydropower can be sustainable from environmental, social, and financial angles.
- Local benefit sharing is an evolving process. Lessons need to be learnt from the current practices and proper mechanisms should be developed.
- For hydropower to be competitive at the marketplace, partnerships between the government, the private sector, and civil society are essential; such partnerships reduce the generation cost by managing the risks and distributing responsibility.

sector, and civil society could reduce generation costs by managing the risks and distributing responsibility. Another important facet that needs to be looked at is incorporating the idea of local benefit sharing into the scheme of things; the types of such benefit sharing mechanisms in Nepal include royalty mechanisms, equity investment, support for local livelihoods, and community development.

Similarly, the governments in the region should be encouraged to invest in mini and micro hydropower schemes, which are less susceptible to streamflow variability. As for the knowledge gaps existing in the areas of cryosphere changes, infrastructure vulnerabilities, and natural hazards, they can be addressed by investing more in research activities.

Supply and regulating contributions: Irrigation, agriculture, and domestic use

The basins of the Indus, the Ganges and the Brahmaputra are home to 900 million people. Within the Indo-Gangetic Plain, 45,000 sq. km are overlain by glacier ice, which irrigates as much as 500,000 sq. km of land. Snow and glacier meltwater is extremely important within the Indus basin, contributing to 60 per cent of the total irrigation during the pre-monsoon season. The availability of meltwater during the pre-monsoon period is particularly important and enhances crop production by 11 per cent. Contributions from snow and glacier meltwater to the downstream discharge is about 10–20 per cent in the Ganges.

Glacier meltwater is also an important source for irrigation in the northern areas of Pakistan, constituting as it does about 65.8 per cent of the total irrigation water. However, with incidences of glacier downwasting on the rise here, the villages in the mountains are expanding their irrigation systems to higher elevations.

Site-specific water management options can be adopted in both upstream and downstream areas to address the impacts of downwasting. In this regard, hydro-dynamic analyses need to be conducted to understand the repercussions of climate change in terms of the availability of snow and glacier meltwater in the future.

Many mountain communities are dependent on glacier meltwater for domestic use. Water mills for processing wheat flour are common in the upper Mustang region of Nepal. But with the number of development projects on the rise and growing tourism, there is an increased demand for water in the high-altitude areas, and this has led to scarcity when it comes to the use of water for domestic purposes. Meanwhile, in the last 10 years, glaciers throughout Mustang have visibly changed and acute water shortages have ensued. This scarcity has forced communities to abandon historical settlements and migrate to new sites. Such migrations have the greatest impacts on women and children.

However, snow and glacier melt in the higher elevations also open up opportunities. With the change in climate and increase in temperature, snow lines in the higher elevations, on an average, have shifted upwards, creating space for agriculture. Due to this snow line shift, possibilities have arisen for crop diversification and for the upward migration of perennial tree lines, thereby providing the mountain people with alternative avenues to improve local economies and livelihoods.

Social, economic, and cultural contributions – changing cryosphere and tourism: A sustainable tourism development agenda

The cryosphere is indispensable for humans and their well-being. In particular, the services and functions derived from the cryosphere are important for the sustainable development of tourism in the HKH. Tourism, particularly mountain tourism, as a recreational activity takes place usually in scenic destinations and, in the HKH, relies on snow cover, glaciers, water, etc., which are highly influenced by weather variability and climate change. In order to establish sustainable tourism development agendas and build destination resilience as well as protect the overall well-being of the tourism sector, it's important to understand the changing cryosphere and its interlinkages with tourism.

The changes observed in the cryosphere have deleterious effects; they reduce cryosphere services and their functionality, triggering cascading effects on tourism destinations and overall business. However, even in this context, there remain many knowledge gaps in understanding the interlinkages and the dynamics of the cryosphere–tourism nexus. Research at the tourism and cryosphere interface can create synergies cutting across the disciplinary boundaries of natural and social sciences, and between scientific and applied knowledge – and for this, collaboration among the different stakeholders (e.g. scientists, practitioners, policymakers, and local communities) is important so that data is jointly generated to help validate scientific findings.

KEY MESSAGES

- Snow and glacier meltwater plays an important role in irrigation, agriculture, and domestic life. In the Indus River basin, it contributes to around 60 per cent of the water for irrigation during the pre-monsoon period.
- Increased cryosphere melting is not all about risks – it also creates opportunities. Tapping these opportunities and preparing for the risks are key ways to adapt to cryosphere changes.
- Development activities and growing tourism are adding pressure to the already scarce water resources in the mountain areas.
- The drying up of mountain irrigation systems due to cryosphere changes is leading to changes in the pattern of land use in high-altitude agriculture.

KEY MESSAGES

- People play an integral role in assisting both science and practice (tourism) to improve the quantity and quality of data that can be analysed in order to help contribute to make better and informed policies and decisions.
- Tourism and the cryospheric services are inherently interlinked with destination resilience and the well-being of the broader tourism society that includes the government, the private sector, local communities, development organizations, and researchers.
- The links between the cryosphere and tourism development need to tackle three core issues: inter-sectorial integration to address issues like climate change adaptation, disaster risk reduction, and sustainable tourism development; knowledge integration to develop tourism services; and institutional integration to strengthen collective responsibility and forge effective partnerships.
- Climate science can come to the aid of the tourism sector by providing prior information on weather, road conditions, and settlements. In this regard, there should be developments in the following areas: user-friendly frontline technology; citizen-centric research approaches; and knowledge customization and dissemination through apps, maps, and digital stories.

The links between tourism and the cryosphere should be seen through three core lenses – thematic/inter-sectoral integration, knowledge integration, and institutional integration – in order to address the following aspects: disaster risk reduction and sustainable tourism development; integration of interdisciplinary scientific and local knowledge for evidence generation; alternative approaches that transform scientific research using frontline technology; and multi-stakeholder/multi-level collaboration among decision makers for strengthened partnerships.

Climate science can play a complementary role in the tourism sector by providing prior information on weather, on road conditions, and settlements. The experiences from Nepal, where ICIMOD is working on tourism, have demonstrated the benefits that inter and transdisciplinary research can bring by promoting collaborative partnerships in order to promote a safer tourism sector and a better travel experience. The idea of integration and partnership between scientific agencies and the tourism stakeholders (local communities and the tourists themselves) needs to be emphasized and synergy must be created to ensure customized and relevant knowledge production and effective communication. The relationship between the cryosphere and tourism also has spiritual aspects as many communities living in the Himalaya consider mountains as sacred environments.

It is vital to adapt to the changing cryosphere. So, it is important to not only adopt frontline technologies that are user-/community-friendly, but also to disseminate localized/customized knowledge specific to the stakeholders' needs. The relevance of information is crucial to building resilience. Therefore, alternative approaches must be explored in conducting research and disseminating knowledge; they could be through citizen science, digital mapping, and storytelling. This will not only engage the local communities in scientific research, but also pave the way for developing discourses related to sustainability, the changing cryosphere and its interconnectivity with tourism.

Climate change has put pressure on landscapes and infrastructure. So, tourism destinations need to be wary of exacerbating the impacts of climate change. Bhutan provides a striking example in climate change mitigation; it is committed to remain carbon neutral and should be acknowledged for having created an environment trust fund to conserve its protected areas; it also promotes green initiatives such as low carbon travel and eco-hotels.

In terms of developing adaptation plans, it is important to incorporate in them traditional and indigenous knowledge to address local issues. It is also necessary to use relevant technology to create awareness about the impacts of climate change on mountain communities; this will not only help change perceptions but also enable the emergence of fresh perspectives on people, places, and culture.

Here it is important to once again underline that tourism and cryosphere services are inherently interlinked; and that destination resilience and the overall well-being of the broader tourism society – consisting of government and the private sector, as well as local communities, development organizations, and researchers – depends on the right synergy being created on the ground.

Cryosphere contributions to spiritual, symbolic, cultural, and religious perceptions

The linkages between the cryosphere and spiritual, symbolic, and cultural aspects are vital to the HKH region. Yet, they have not been explored in depth. The mountains and lakes are revered as the abodes of the gods. So, when glacier melt and natural disasters increase, they are perceived by the mountain communities as signs of the gods departing. In the harsh Himalayan environment, culture and indigenous knowledge are kept alive by people sticking to traditions and native adaptive techniques.

However, in the present times, this indigenous knowledge and culture are under threat. So, there is a need to re-examine the narratives of cultural services and the research on indigenous knowledge in order to understand how the mountain communities have built their resilience. Developing such insights also provides an opportunity to engage with the youth so that they don't migrate.

That said, whilst underdeveloped, there is an increasing recognition of the importance of traditional knowledge in science. In this regard, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has called for due attention to be given to traditional knowledge in order to deal with the forces of climate change. Similarly, the Sustainable Development Goals (SDGs) have also underscored the linkages between traditions, humans, and ice.

The mountain communities are struggling to shift from the traditional trading systems of exchanging goods and services (i.e. barter) to the market-based economy. In order to adapt to the market economy, highland indigenous people have to learn new ways of providing services and goods for money. Tourism, horticulture, and organic farming provide opportunities for these communities to adapt and integrate.

Meanwhile, mountaineering has become increasingly commercialized, leading to an apparent improvement in the living standards of the mountain communities. However, this has often come at the cost of their traditions and culture. The ways of modern culture are increasingly permeating these communities, and indigenous cultures and belief systems seem to be fading away. This inflow of mass tourism has also worsened the situation of ecological degradation, pollution, and littering.

The increase in the frequency of disasters and casualties among the mountaineering communities is often perceived as due punishment from the gods. So, scientific research should focus on explaining and contextualizing to the mountain communities so that they can make sense of the changes happening in their immediate environment.

Not so long ago, the mountain communities in Gilgit-Baltistan in Pakistan used to practise shamanism, a centuries' old practice, as a way of communicating to fairies, to whom these societies looked to solve their daily problems. Rocks, snow, lakes, water channels, etc. were considered to be the abodes of these fairies and it was prohibited to pollute them. (Juniper trees played an integral part in such rituals and were protected.)

The disintegration of traditional world views and adapting to a globalized world view have had adverse impacts on the local environment. More people place higher value on economic benefits than following traditional cultural practices. And these changes in value systems have wiped out, in the past 40 years, entire forests throughout the region as economic incentives overcame indigenous values.

The Langtang community in Nepal is still recovering and rebuilding in the wake of the disastrous earthquake in 2015. Moreover, the Langtang community was devastated by a disaster within a disaster, wherein a massive avalanche was triggered by the earthquake, killing over 300 people and virtually wiping out the community.

Resilience is not an inherent quality. It takes a lot of hard work and should not be taken lightly. Recovery from even recent disasters (i.e. the 2015 Gorkha Earthquake) is a lengthy and ongoing process. And in this, there is a need to assemble both indigenous as well as modern knowledge. In Langtang, it helps

KEY MESSAGES

- The cryosphere is a foundational component of the mountain communities' identity, culture, and heritage. The continuous erosion/drift of certain values has added to the pressure that these communities face. Human interactions with the cryosphere are a strong feature not only in the Himalaya but all over the world.
- Indigenous knowledge and culture have been ignored at all scales of development and are at risk of disappearing. There is a need to re-examine the narratives of cultural services and indigenous knowledge; and the methods of resilience of the local community should be taken as an opportunity to prevent the youth from migration.
- Frequent disaster events and the increasing impacts of climate change are causing a confluence of forces that leave limited time for the mountain communities to develop or inherit resilience. Interventions are needed to help build resilience.

that there is a strong sense of ownership among the community members in terms of the environment and its protection.

Cryosphere and livelihoods in high mountain communities: Understanding from a socio-ecological systems perspective

Mountain communities have been experiencing different drivers of changes, including climate change. The early findings of a social vulnerability study conducted by ICIMOD in the Langtang Valley reveal that there are complex interlinkages between the cryosphere and socio-economic systems. The nuances and details of the complex systems need to be understood for developing adaptation plans and strategies.

The settlements of the Langtang Valley, comprising of a population of 456 people, are located close to glaciers and snow-covered mountains. The local communities are dependent on glacier and snowmelt water for domestic and agricultural purposes. Glaciated and snow-covered mountains are also the abodes of local deities. Agriculture, animal husbandry, and tourism are the major income sources of the local communities. In recent years, the mountain communities have been witnessing shrinking of glaciers, changes in the timing and intensity of snowfall, increases in river discharge, and hazards like avalanches, blizzards, and landslides.

Untimely heavy snowfalls have partly caused major avalanches, killing a large number of domesticated yaks. After the 2015 earthquake, the majority of the households in the Langtang region have shifted from agriculture and livestock herding to tourism. The communities have converted agricultural land for construction of guest houses to accommodate the growing number of tourists in the area. Further, the inflow of tourists has also increased demands on water and energy, while the use of wood as fuel has led to deforestation. Other environmental issues such as solid waste and water pollution are also emerging.

Himalayan communities traditionally rely on subsistence agriculture and animal husbandry for their livelihoods. Throughout the 21st century, the mountain communities have witnessed rapid occupational and demographic shifts. People are shifting away from traditional livelihood practices and opting for non-agricultural income sources such as tourism. These shifts in local livelihood practices, from farm to non-farm–based income sources, have gradually led to a disconnection of the mountain communities with glaciers, snow, and the mountains they inhabit. And the growing transnational connections have triggered outmigration, leading to a decline in local population which has social implications.

Tourism is extremely vulnerable to localized factors like natural hazards, and external factors like global economic patterns. Climate change and the over-reliance of the mountain communities on tourism increase the physical and social vulnerabilities of the mountain communities. Considering the complex social and ecological systems in the high mountains, an interdisciplinary approach is necessary to address the problems faced by the high mountain communities. The scientific community needs to engage the local communities in their research activities, and understand their indigenous and traditional practices; they should also share their research findings and knowledge with the local communities.

KEY MESSAGES

- The physical and social vulnerabilities of the high mountain communities have increased due to climatic and socio-economic changes.
- There is a growing disconnection between the mountain communities and nature, particularly glaciers and snow, due to the ongoing changes in the mountains and increased globalization.
- An interdisciplinary approach is needed to understand the complex interlinkages between the cryosphere and the socio-economic systems in the high mountains and to develop adaptation plans and strategies.
- Collaboration among scientists and the local people are a must to address emerging issues in the high mountains. There should also be exchange of indigenous and scientific knowledge between the scientists and the local communities.

Section C

Cryosphere hazards and their impacts

Glacial lake outburst floods: From risk to community's approach

Over the past two decades, countries throughout the HKH region have seen increases in glacial lake formation and the expansion of existing lakes fed by rapid glacier melt. GLOFs are the result of increased pressure on unstable moraine walls and unprecedented rock or ice fall on lakes. GLOFs can have catastrophic impacts on landscapes, human settlements, agricultural lands, hydropower plants, and other infrastructure. Their impacts are often transboundary in nature. It is important to understand how GLOFs originate and about their impact on the livelihoods of people living both upstream and downstream, and accordingly devise risk management and mitigation strategies.

The frequency of GLOFs is increasing in Afghanistan, Bhutan, India, Nepal, and Pakistan, and these countries are also seeing increases in the number of potentially dangerous glacial lakes (PDGL). Current records indicate that 35 glacial lakes in Bhutan are PDGLs. In Pakistan, 33 glacial lakes are categorized as "High Risk Category Areas". Following the devastating impact of GLOF on Pangshir Valley in 2015, Afghanistan has also started carrying out GLOF risk assessments.

Glacial lakes need to be identified and ranked in accordance with the parameters of PDGLs. Risk assessments need to be carried out to understand the magnitude of the potential hazard and the exposures need to be highlighted. In Sikkim (India), sensors that transmit data to the control rooms have been successful in alerting the communities ahead of a GLOF event. In Bhutan and Nepal, mitigation works to reduce lake--water levels have helped reduce the potential risk. EWS and mass texting (short message service, or SMS) systems have also been adopted as "community-based control measures" to alert the people of any imminent danger.

There is also a need to improve the identification criteria of PDGLs. Parameters like the source of the lake water, dam height, crest width, etc., need to be taken into account and greater number of lakes need to be studied to understand the overall dynamics.

KEY MESSAGES

- It is important to understand how GLOFs originate and about their impacts on the livelihoods of the people living both upstream and downstream, and accordingly devise risk management and mitigation measures.
- There is a need to expand the PDGL identification criteria to include elements such as source of lake water, dam height, crest width, the potential contributions of snow/ice avalanches, earthquakes, rockfalls, and the surge of the source glacier. A greater number of lakes need to be studied to understand the overall dynamics.
- Early warning systems and community engagement are vital to mitigate GLOF risks and to reduce the potential exposure of the upstream and downstream communities.
- Greater clarity is needed during collaborative work with the stakeholders. The role of the government should be to help with installation and proper functioning of EWSs. If the policy does not comply with risk mitigation strategies, there will be unforeseen challenges.

The other parameters that should be taken into consideration are the potential impacts of snow/ice avalanches, earthquakes, rockfalls, and the surging of source glaciers. If all these aspects are taken into account, better study models can be developed.

As GLOFs have a major impact on the downstream areas, there ought to be active engagement and cooperation amongst communities, relevant stakeholders, and government agencies in order to bring about positive changes; such partnerships will also give a boost to mitigation measures and limit the potential and/or impacts of GLOFs.

However, despite many ongoing efforts, the current available data reveal that more research is needed to understand the status and potential hazards associated with glacial lakes. Further studies and understanding would help inform risk mitigation activities as well as help educate community members on the effects of climate change on glaciers in their vicinity.

That said, gaining access to many glaciated areas across the HKH remains physically challenging; so, it necessitates a broad reliance on satellite monitoring. By capturing and analysing high resolution images, coupled with refined modelling approaches, the efforts to mitigate the impacts of GLOFs can be improved appreciably.

Permafrost degradation and GHG emissions

Permafrost is defined as ground that remains at or below 0 degrees Celsius for at least about two consecutive years. Permafrost monitoring in the high mountain regions is hindered by several factors, including the complexity of the thawing–freezing processes and because it is not readily visible on the surface. However, despite permafrost being considered an essential climate variable (ECV) within the Global Climate Observing System (GCOS), it remains a neglected (albeit critical) research topic in the high mountains of Asia. Accordingly, greater efforts need to be made to understand the distribution of permafrost throughout the region in order to develop an understanding about its impacts on hydrology, ecosystems, hazards, and livelihoods.

The Tibetan Plateau has the largest areas of permafrost terrain in the mid- and low-latitude regions of the Earth. In fact, permafrost covers more than 1 million sq. km in the TP and the HKH, which exceeds the combined areas of snow and glaciers in the region. The areas covered by permafrost act as storehouses of organic matter which remain in a frozen state for centuries.

KEY MESSAGES

- Permafrost is frozen ground material, invisible on the surface, which traps organic carbon; it covers larger areas than a combination of snow and glaciers. Only a few studies have been conducted within the HKH region on permafrost although it is a central component of the global carbon and hydrological cycles.
- The thawing of permafrost leads to an increase in active layer thickness, thereby supporting more soil moisture, nutrients, and plant growth. More research is needed to determine the source and sink components of the permafrost regions.
- Permafrost stabilizes soils, slopes, and rock walls in high mountain regions. The kinematics of rock glaciers in particular need to be studied properly for a detailed assessment of the lower limits of permafrost and the evolution of the periglacial areas.
- Permafrost is considered an ECV for the understanding of the global climate system. Active layer thickness and the thermal state of permafrost are key parameters for long-term permafrost monitoring.
- Advanced technology like remote sensing and mathematical modelling, as well as aspects such as physical expertise, and ground validation are essential components of the monitoring chain for a proper understanding and documentation of the permafrost processes which impact both local and global environs.

Permafrost consists of an active layer at the surface that freezes and thaws each year. Perennially frozen ground is found below this active layer. Therefore, the top of a permafrost sits at the base of the active layer. As a result of climate change, the active layer increases in depth over time, leading to gradual top–down thawing of the upper permafrost and to an increase in soil moisture. This increasingly rapid thawing phenomenon leads to a reactivation of the organic matter that was previously frozen, and to the so-called "carbon decay", whereby gaseous carbon, such as in the form of carbon dioxide (CO_2) or methane (CH_4), is released into the atmosphere from the melted ground. The net carbon balance in the permafrost regions are currently not well known as both the carbon sources and sinks are difficult to estimate in these newly wet conditions with a lengthened thawing season. For instance, at the Qinghai Lake on the TP, the water level has been observed to be rising over the past decades due to the thawing of permafrost, with profound impacts expected in terms of carbon exchange and hydrological cycling.

Moreover, permafrost can be viewed as a stabilizing agent for soils, mountain slopes, and rock walls. It is also a natural barrier to water penetration from the surface to the soils. With the thawing of permafrost, debris and rocks become increasingly exposed to the elements and to the action of erosive processes. This can result in rockfalls, debris flows, and a variety of soil mass movements and other cascading hazards. These processes have already been observed and studied in the Alps over recent decades and, with ongoing changes in regional climates, are likely to start occurring in the HKH and across the TP.

Optical remote sensing, together with geospatial analysis and mathematical modelling, are all important approaches to aid in the production of permafrost distribution maps. In this regard, a better understanding of rock glacier distributions, topographical attributes and the dependence on climate variables is paramount, as rock glaciers are indicative of the lowest limit of permafrost occurrence.

In summary, permafrost studies in the HKH are sparse and suffer from serious knowledge gaps in terms of distribution, thermal state, organic content, mass dynamics, etc. However, it has a great impact on the carbon and hydrological cycles, as well as on the steadiness of the mountain ground. This calls for detailed and expanded studies applying in situ monitoring and cutting-edge modelling.

Section D

Cryosphere contributions to the biosphere

The HKH region includes all or part of four biodiversity hotspots – the Himalaya, Indo-Burma, the mountains of south-west China, and the mountains of Central Asia. These hotspots are determined by exceptional biodiversity richness with significantly high levels of threats. The Himalaya biodiversity hotspot has about 10,000 species of vascular plants, with one third of it being endemic. It supports over 60 different ecoregions and is experiencing many physical changes. Climate change and anthropogenic activities, including unplanned development, over-exploitation of resources, and land-cover change are the main drivers of this transformation.

The impact of climate change is observed in high mountain forest ecology and in alpine ecosystems and their biodiversity. Rising temperatures at higher elevations are triggering upward migration of treelines, coupled with increasing growth rates of trees and changes in flowering and fruiting seasons. This impacts endangered species with a specific habitat range, such as the snow leopard who depend on the ecozone overlap between the cryosphere-dominated areas and the biosphere. The snow leopard and its prey are threatened by the fluctuating treeline which is a response to changes in thermal balance and temperature sensitivity, coupled with forest fragmentation.

The mountain communities are vulnerable to climate change impacts and their lives depends on their ability to adapt to these changes. High mountain communities are seeing increased warming and precipitation, and more rain in place of snow; the snowfall is also irregular while the glaciers are receding. The drastic changes in temperature and precipitation are having a huge impact on high mountain livestock. For example, due to continuously heavy snowfall from January to March 2019, the Mustang region of Nepal reported a loss of over 4,600 in livestock, equivalent to NPR 100 million. More particularly, Kobang, one of the last villages in Nepal to grow apples, is struggling as the climatic condition is no longer favourable for growing the fruit. Shorter winter periods and the emergence of new diseases have affected the production of apples, which is forcing the villagers to use pesticides. Under such circumstances, value addition services such as weather forecasting mechanisms, insurance schemes, crop diversification, and encouraging the farmers to stockpile fodder and other supplements could reduce the burden of loss.

As is only too well known, birdlife has been affected by the changes in the cryosphere. Climatic changes are driving the birds that are usually found in the lowlands to migrate to higher elevations. The impact is greater on the rarer bird species than on the more common ones. For example, the enigmatic Himalayan wader, which breeds mostly in the glacier valleys of the HKH and Central Asia, is losing its habitat due to retreating glaciers. But the extent of the impact on the Himalayan wader is unspecific as there has been only limited research on the issue. Similarly, snow cocks feed in glaciated areas and are thus highly dependent on glaciers. Overall, studies show that of the 888 bird species found in Nepal, 168 of them are threatened while 22 species are directly affected by climate change.

The so-called “mountain islands” (examples of “ecological islands”) are areas wherein micro-habitats have developed and where uniquely adapted species exist in an isolated patch in the midst of a different, larger ecosystem. They provide vast and varied ecosystem services, but these are hampered by both human- and climate-induced changes. The mountains above 3,000–4,000 masl remain under snow cover throughout the year and maintain the ecosystems that thrive in the high mountains. But these ecosystems are not protected. Human interference, such as harvesting non-timber forest products (i.e. cordyceps), hunting, and development projects contribute to changing the landscape and the entire ecosystem.

In Nepal, the protected areas system is exceptionally good for conservation of biodiversity. However, most of the protected areas are either at extremely high or low altitudes. The middle Himalayan range is not represented in the national protected areas system, and this is impacting many species in the diverse and extensive ecosystems of the mid-hills of Nepal.

KEY MESSAGES

- More research is needed to understand the dynamic interlinkages between the biosphere and the cryosphere. The approaches need to be long term, comprehensive, and holistic.
- Communication channels ought to be established to provide weather forecasts and also to encourage the farmers to stockpile fodder and other needed supplements. Insurance schemes and crop diversification methods ought to be introduced in order to reduce the burden of loss arising out of extreme weather conditions and changing temperature.
- Glacier valleys are important habitats for birds. The shrinking of regional glaciers could have a negative impact on the breeding and feeding grounds of certain bird species like the snow cock.
- Conservation gaps have been created by biases in the protected areas in Nepal, which are also threatening endangered species. As there are very few protected areas in the mid-hills, these are not well represented or integrated within the national protected area network. This lack of representation makes it difficult to understand the vulnerabilities of mid-hill ecosystems and its resident species.
- Habitat fragmentation is high in the HKH region, especially in the mountains. The cryosphere is degrading, impacting humans and ecosystems both upstream and downstream. While there has been some research on flagship species, like the snow leopard, a lot remains unknown, especially relating to microorganisms, rangelands, and the nutrients that directly connect the cryosphere and the biosphere.

Section E

Exploring bridges to the Andes

Studies on three glaciers in Bolivia – Illimani, Sajama, and Mururata – using modelling and remote sensing data to monitor glacier changes reveal that these glaciers have been consistently losing mass since the 1950s. In the Andes, glaciers are referred to as "white sponges" which release water little by little, whereas high-altitude wetlands are referred to as "green sponges" from which water is available more readily. Glacier recession is recognized as a global problem, and while it is challenging and vital to mitigate this phenomenon, it is also critical that strategies are developed to preserve high-altitude wetlands in an effort to enhance regional water integrity and security. Wetlands have important buffer qualities; for example, during the winter season, they can store the same amount of water as in the monsoon.

The resilience strategy adopted in Bolivia and in other locations in the Andes covers four cornerstones: strengthening knowledge sharing; strengthening human resources; strengthening organizations and institutions; and strengthening networks. In the case of strengthening human resources, it has been achieved by engaging in dialogues with the communities about the impacts of climate change, sharing scientific finding with those communities, and enhancing the value of local knowledge by exchanging perceptions and experiences.

Bolivia has taken several steps to strengthen its conservation activities; first, by monitoring its wetlands using modern techniques such as drones, and second, by accepting the technical know-how of the indigenous communities. An example of such conservation activities lies in the construction of small dams using locally available materials in order to collect and store water for the dry seasons. Biocultural programmes have also been introduced to promote an alternative vision of development and translate it into concrete practices so as to increase climate change resilience. Bolivia is also nurturing networks throughout the Andes and is collaborating with other countries, such as Peru and Ecuador, to develop transboundary strategies focusing on integrated economic and social development. The fundamental role of women in ensuring food security and community integrity is recognized

KEY MESSAGES

- In both the South American Andes and the HKH, there is an urgent need to recognize how the impacts of climate change on the cryosphere will affect water resources and, consequently, the local communities and biodiversity.
- Developing strategies for enhancing community resilience requires a multilevel approach, including strengthening knowledge sharing, strengthening human resources, strengthening organizations and institutions, and strengthening networks at various levels.
- Bolivia's policy of developing adaptive strategies clearly emphasizes the need to promote, support, and strengthen indigenous organizations and institutions at various levels. Bolivia's model and experience can be useful for the HKH and there should be a bridge of networks of indigenous communities between the Himalayas and Andes.
- The role of women at the community level and beyond has been clearly recognized and strategies have been developed to create societal spaces for gender equity in terms of decision-making and access to property rights and economic resources.
- Social media is a powerful tool to strengthen networks, educate the young people about climate change and its impacts, share experiences and learnings, and also to implement traditional communication strategies.

and emphasized by promoting the participation of women in leadership activities and in achieving equal access to property rights and economic resources. Social media is another example of an effective tool being used to inform and educate the younger generations about climate change impacts.

The Bolivian model shows that local and scientific knowledge needs to be fully integrated in the development phase of strategic decision processes, and should be purposefully facilitated by dialogues between communities. Bolivia's model and experiences using local resources to adapt to climate change can be very useful to the HKH. As the South American Andes and the HKH are experiencing similarly drastic changes in terms of the cryosphere, there is a need for greater exchange of knowledge and collaboration between these two regions.

Section F

Decision and transformative strategies in the high mountains: Building resilience and capacity – community voices

The scientific community needs to change the space it provides for the mountain communities in research, and how knowledge brokers could fill in the gaps between the scientific and local communities. Twenty-first century mountain communities are more heterogeneous and mobile than ever as they have transnational connections. Considering these new realities, the scientists and the local communities need to enter into collaborations in order to tackle the challenges of cryosphere changes.

The mountain communities are direct witnesses to glacier degradation, the increasing frequency of snowstorms and other erratic weather patterns that are adversely affecting their agriculture and livestock production. These communities need forewarning systems and sufficient information about incoming weather conditions and potential disasters so that they are better prepared to deal with these challenges.

However, cryosphere changes in the HKH have not been fully covered by research. With limited scientific data available, it remains a challenge to understand the trends of these changes and to forecast their implications. In order to identify the fingerprints of climate change, at least 30 years of data is needed to understand trends and to make long-term forecasts. Remote sensing tools have been used to record cryosphere changes, but they are of relatively coarser resolutions and are better suited for analysing regional trends. In such a context, the perceptions of the local communities about cryosphere changes play a vital role in filling the gaps. Moreover, there is a growing realization amongst the scientific community that local and indigenous knowledge can serve as huge repositories of information, particularly where scientific data generation from in situ measurements have been only available recently.

There is a gap between scientists' work and community needs. Therefore, there is a need for knowledge brokers like ICIMOD to tailor appropriate scientific information for the local communities, and communicate local knowledge and needs to the scientists. Existing university curricula are more appropriate for lowlands, thus less relevant in the mountain context. Knowledge interfaces between the scientists and the local communities should start with access to actionable information in order to improve the mechanisms of disaster preparedness and effective knowledge transfer. Besides, inputs and services should be tailored as per the requirements of the high mountain communities, especially in the case of the agriculture and livestock sectors. Provisioning the right level of service and physical infrastructure in the mountains can address the issues faced by the local communities. Also, ensuring access to the market for mountain products can decrease outmigration from these regions.

Journalists, tourists, school students, local leaders, and scientists can be knowledge brokers. In order to ensure communication of the correct information to the targeted audience, editing and proofreading of publishing materials need to be carried out by

KEY MESSAGES

- Science can provide information on the processes and environmental conditions but the inclusion of local knowledge is essential for effective designing and implementation of programmes and policies. There is a need to communicate local knowledge to the policymakers as well as policies to the local communities.
- Knowledge brokers can be the bridge between the local and scientific communities by tailoring scientific information as per the needs of the community and transforming local needs to scientific inquiries.
- In order to address the issues and challenges of the high mountains, university and school curricula should incorporate high-altitude knowledge.
- Bridging knowledge gaps will require transdisciplinary and interdisciplinary approaches so as to engage multiple stakeholders – the local community, researchers, institutions, and policymakers – at different scales.
- Collaboration between the local community and the scientific community will help in enriching scientific knowledge and bridging the gaps between local and scientific knowledge systems.

the relevant institution or community. An inclusive stakeholder engagement involving governmental institutions is also essential in knowledge brokering and production. In this regard, the scientific findings should be shared with the local communities and not limited to publication in peer-reviewed journals.

Cryosphere contributions: Gender and social justice perspectives

The discussions on gender and social justice highlighted relationship inequalities and hierarchies, and the marginalization and exclusion of certain groups of men and women in the region which affects the access to and control over resources. They explored how existing gender disparities in access to resources are further exaggerated by the impact of cryospheric change, especially in the areas of water, energy, and food security.

Mountaineering in the HKH is still associated with masculinity, and only a handful of women have managed to break this glass ceiling. Being a women mountaineer is challenging, as it goes against the established norm of mountaineering as a “man’s job”. Mountaineering, however, has created new opportunities to travel globally as ambassadors of climate change, thereby changing gender roles and women becoming role models for younger generations.

As for irrigation in the upper reaches of the Himalaya, it is dependent on glacier melt and is both labour and capital intensive as irrigation channels need to be repaired several times in a year. A case study from Nepal’s Upper Mustang highlights the complicated social aspects of water user rights, which is based on a two-class system of upper class and the marginalized class. Their irrigation system follows the head-tail water amount distribution, whereby the upper class, with its higher landholding has greater access to water and exercises influence over the irrigation decision-making body. Meanwhile, the marginal class contributes labour. In the long run, if the current practice is continued, it could give rise to disputes, increased outmigration, and the considerable risk of the entire system collapsing. To address this inequality, a principal-agent bargaining model, wherein both communities work out a fair exchange of labour and capital for irrigation, has been recommended. Such systems are expected to increase the combined benefits for both classes and maximize the best use of water for the community at large.

The impacts of climate change on water resources manifest in different social issues and are complicated by the dimension of poverty. For instance, women in Gilgit-Baltistan do not own property and have no control over resources. Men are increasingly migrating for jobs, leading to women taking on additional responsibilities. More research is needed to understand this changing role of women in water governance and the impacts of men's outmigration.

Women and children are at the forefront of dealing with climate change impacts. As women struggle to engage in tasks spanning the fields and households, their burden is often shared by children, who are enlisted to undertake chores like fetching water. Involving the children in such chores, which can be time consuming, has resulted in high school dropout rates among the high mountain communities. All of this also adds new dimensions to mountain poverty. Women are overburdened in the context of climate change; therefore, research should focus on ensuring equal access and control over such resources for both women and men.

Capacity building and promoting gender-friendly water-sourcing technology are ways to address this gap. As communities in the HKH depend on remittance, using this source of funds to create jobs and improve banking facilities for women and those belonging to different classes, castes, ethnicities, and geographical regions need to be considered.

Cryosphere, society, and risk management

Climate change threatens to reverse development gains and reinforce structural barriers to development, thereby pushing mountain communities back into poverty.

Risk management strategies should address the issue of exposure of people to climate change. Countries should strengthen their absorptive capacity in order to deal with one-off and low-magnitude climate change impacts; they should also augment their adaptive capacity in order to deal with frequent and higher magnitude climate change impacts. Besides, transformative capacity should also be shored up so as to deal with situations where climate change undermines livelihood strategies.

The risk management strategies that contribute to these absorptive, adaptive, and transformative capacities include:

KEY MESSAGES

- Women bear the brunt of climate change impact in the high mountain communities; more research is needed to understand the changing role of women in water governance and the impact of men's outmigration.
- The impacts of climate change on water resources manifest into a different dimension of poverty; they influence food production and also trigger outmigration of men, resulting in additional pressure on women and children. Capacity building and promoting gender-friendly water sourcing technology are key to addressing this gap.
- Women and men have a different level of access and control over resources; the talks on resources need to ensure equal access and control over such resources for both women and men.
- Women are increasingly challenging their traditional roles as homemakers to take up tasks such as mountaineering and portering, which were previously considered men's jobs. This shift in gender roles needs to be recognized and promoted in research and decision-making processes.
- Mountaineers are the knowledge forgers who intimately deal with the mountains and the cryosphere. So, researchers and mountaineers must work together.

KEY MESSAGES

- A sense of ownership among the local community helps in creating sustainable, effective, and successful early warning systems
- Including women and other vulnerable groups in disaster risk reduction plans will go a long way in building their capacity to cope with disasters
- There is a strong need for long-term data sharing in order to reduce complexity and uncertainty in risk management decision-making
- Use of satellite data to analyse past trends and predict future scenarios helps a lot in reducing disaster risks
- Long-term impact assessment and management involving recovery, the economy, social systems, the environment, and local livelihoods should be part of any risk reduction strategy.
- Regional cooperation is essential for managing risks, developing inclusive solutions, and building resilience among the mountain community

- Investment in climate-resilient infrastructure
- Investment in climate smart technology – such as climate information services to help anticipate and manage climate change impacts
- Climate smart institutions – for community mobilization in the area of disaster preparedness and management; systems to integrate traditional and modern science to manage the risks; collective institutions to improve decision-making; and policy and regulatory instruments to incentivize behavioural change for sustainable production and consumption of goods and services.
- Financial services – to scale up climate action

Regional collaboration and cooperation can contribute to maximizing the benefits and minimizing the losses from climate change impacts; this can be done in the form of increasing awareness through data sharing and strengthening the multi-stakeholder networks of communities, the media, government, the academia, and the funding bodies.

The keys to any early warning system and risk reduction are the realization of the risk, monitoring, communication, dissemination, and building the capacity of the local communities. The community should be involved in capacity building as well as in developing policy and disaster management plans. In this regard, satellite data can be used for hindcasting and forecasting. The findings of studies, tailored to the community and its needs, can bolster community engagement and preparedness.

As for the issue of gender parity, women are not usually given equal access to resources and that has made them vulnerable. Women need to be involved in all stages of risk management planning; their capacities ought to be strengthened; and training programmes ought to be held for them so that they are better prepared when it comes to natural disasters.

Climate change can have various impacts on societies; it can stir and affect them. It can also drive political change, alter and provide new roles for women, and create resilience.

Typically, the mountain communities rely on subsistence farming, mostly on agriculture and livestock, which are both water intensive. So, access to sustainable water sources is a challenge wherein alternative sources need to be explored to reduce the dependence on increasingly unpredictable precipitation.

Wrap-up panel: Voices of the HKH – youth, scientists, practitioners, communities, media

There are innumerable groups conducting research on a diverse range of issues throughout the HKH region. However, despite this profusion of teams and research, too many are working in isolation. Adding to this, there is a prevailing attitude of protectionism, wherein the data that is generated remains with the gatherer or his institution and is not necessarily utilized (perhaps due to time or financial constraints); this hinders consequent actions. So, open access principles, where data sharing is key, must be more widely adopted and adhered to. Presently, the institutional imperative of peer-reviewed publications is hampering the process of sharing data with those who need and want to use it.

Knowledge is also being lost in the high mountain communities, as younger generations have lost their connections with their ancestral homes, mother tongues, and site-specific intergenerational indigenous knowledge. In addition, there is insufficient engagement or consultation with the local peoples by the researchers. Meanwhile, the spectre of climate change is worsening the situation as it poses a threat to entire ecosystems. But too little is being done to lower the local communities' vulnerability index. In order to protect these communities, solutions need to be co-created with inputs and insights from the community members. Further, where data is gathered and researchers are able to enhance their understanding of the conditions on the ground, it is vital that the local communities are subsequently updated on the progress and findings, as they are the end users of this information. There are also other challenges that impede substantive climate action, adaptation, and mitigation. While many things are known about climate change and its many manifestations, there are very many unknowns – in terms of data and knowledge gaps, and inconsistencies – that hamper the quality, efficacy, and, all too often, the willingness to pursue solutions. Such a situation makes it difficult to convince the general population and its elected representatives to push for action. Therefore, more communication and engagement by scientists is required, to help people understand the reality and inspire them to act.

Opportunities for bringing together specialists help in increasing awareness and interest in the cryosphere; they also foster intersectional, intersectoral, interdisciplinary, and international collaborations. If the policymakers are to be convinced, the challenges faced in the cryosphere context need to be conveyed in terms of consequences which will resonate with them.

Annex

Annex 1: Programme schedule

Day 1 (Wednesday, 28 August 2019) at ICIMOD Compère: Ashmita Shakya	
09:00–09:30	**Registration**
09:30–09:45	**Session A – The high mountain environment: A shared heritage** **A.1:** Towards a sustainable, resilient, and inclusive HKH Introductory remarks by David Molden, ICIMOD **Rapporteurs:** Kripa Shrestha and Binu Maharjan
09:45–10:00	Welcome remarks by co-organizers: Subodh Sharma, Kathmandu University, Nepal; Xiaoming Wang, State Key Laboratory of Cryospheric Sciences (SKLC), CAS, China **Rapporteurs:** Kripa Shrestha and Binu Maharjan
10:00–10:20	**A.2:** An urgent call to protect the world's "Third Pole" TED Talk screening **Rapporteurs:** Kripa Shrestha and Binu Maharjan
10:20–10:40	**A.3:** Keynote speaker: Samina Baig, High Altitude Mountaineer, UNDP Goodwill Ambassador, Pakistan **Rapporteurs:** Kripa Shrestha and Binu Maharjan
10:40–11:00	**A.4:** Economics of cryosphere **Keynote speaker:** Golam Rasul, ICIMOD **Rapporteurs:** Kripa Shrestha and Binu Maharjan
11:00–11:30	*Tea break, group photo, and unveiling of photo exhibition*
11:30–12:00	**A.5:** Cryosphere contributions and sustainable development (a presentation) **Presenters:** Anna Sinisalo, ICIMOD; Xiaoming Wang, SKLC, China **Rapporteurs:** Amrit Thapa and Sabarnee Tuladhar
12:00–13:00	**A.6:** The cryosphere under a changing climate in the HKH: Findings from the Hindu Kush Himalaya Assessment and linkages to global policy processes (wrap- up and moderated group discussion) **Host:** Philippus Wester, ICIMOD Presenter: Denis Samyn, ICIMOD **Rapporteurs:** Udayan Mishra and Sanhita Sahasrabudhe
13:00–14:00	*Lunch break*
14:00–15:15	**Session B – Cryosphere contributions to society and the environment** **B.1:** Supply and regulating contributions **B.1.1:** Role of the cryosphere in the hydrological cycle (panel) **Co-hosts:** Rijan B. Kayastha, Kathmandu University (KU), Nepal; Santosh Nepal, ICIMOD **Panellists:** Rijan B. Kayatha (Chair), Arthur Lutz, FutureWater; Farooq Azam, Indian Institute of Technology Indore (IITI), India; Rajesh Kumar, Central University of Rajasthan, India; Miriam Jackson, Norwegian Water Resources and Energy Directorate (NVE); Shresth Tayal, The Energy and Resources Institute (TERI), India; Firdos Khan, National University of Sciences and Technology (NUST), Pakistan Rapporteurs: Saurav Pradhananga and Nisha Wagle

15:15–16:30	**B.1.2:** Climate modulation with a focus on particulate pollution and its impact on the cryosphere (panel) **Co-hosts:** Kundan L. Shrestha, KU, Nepal; Arnico Panday, ICIMOD; Inka Koch, ICIMOD **Panelists:** Kundan L. Shrestha (Chair); Aurora Elmore, National Geographic Society; Moetasim Ashfaq, Oak Ridge National Laboratory, Pakistan; Chaman Gul, Nanjing University, China; Arnico Panday, ICIMOD; Mukesh Rai, Northwest Insti- tute of Eco-Environment and Resource, China **Rapporteurs:** Praveen Kumar Singh and Tenzing Sherpa
16:30–17:00	*Tea break and unveiling of posters*
17:00–18:15	**B.1.3:** Cryosphere and hydropower sustainability in the HKH region (panel) **Co-hosts:** Ramesh A. Vaidya, ICIMOD; Nirjan Rai, Policy Entrepreneurs Incor- porated (PEI), Nepal **Panelists:** Ramesh A. Vaidya (Chair), Arun Bhakta Shrestha, ICIMOD; Arthur Lutz, FutureWater; Deo Raj Gurung, Aga Khan Agency for Habitat (AKAH); Pratik Man Singh Pradhan, Butwal Power Company, Nepal; Sanita Dhaubanjar, ICIMOD **Rapporteurs:** Karen Marie Oseland, Nisha Wagle, and Nabina Lamichhane
18:30–20:30	*Reception dinner at ICIMOD*

Day 2 (Thursday, 29 August 2019) at ICIMOD

09:00–10:15	**Session B.1: Supply and regulating contributions** **B.1.4:** Irrigation, agriculture, and domestic use (panel/interaction) **Host:** Abid Hussain, ICIMOD **Panelists:** Arjumand Nizami, Helvetas, Pakistan (Chair); Santosh Nepal, ICIMOD; Arshad Ashraf, Pakistan Agricultural Research Council (PARC), Pakistan; Sujata Manandhar, University of Saskatchewan, Canada; Narendra Lama, National Trust for Nature Conservation, Nepal **Rapporteurs:** Lipy Adhikari and Sandhya Thapa
10:15–10:45	*Tea break and start of poster competition (voting begins)*
10:45–12:00	**B.2: Social, economic, and cultural contributions** (parallel sessions)

	B.2.1	B.2.2
	B.2.1: Changing cryosphere and **t**ourism: A sustainable tourism development agenda (panel)	**B.2.2:** Economics of cryosphere change in the HKH Region
	Co-hosts: Anu K. Lama, ICIMOD; Denis Samyn, ICIMOD	**Co-hosts:** Golam Rasul, ICIMOD; Nilhari Neupane, ICIMOD
	Panellists: Lisa Choegyal, Tourism Resource Consultant (Chair); Dandu Raj Ghimire, Department of Tourism, Nepal; Sonam Dorji, Association of Bhutanese Tour Operators; Saurav Dhakal, StoryCycle; Laxmi Gurung, Yac Donald Hotel and Restaurant, Kagbeni; Aurora Elmore, National Geographic Society Rapporteurs: Nabina Lamichhane, Sunayana Basnet, and Reeju Shrestha	**Panellists:** David Molden, ICIMOD (Chair); Jelle Beekma, Asian Development Bank; Miriam Jackson, NVE; Narendra Khanal, Ttribhuvan University (TU), Nepal; Golam Rasul, ICIMOD **Rapporteurs:** Abid Hussain and Abhijit Vaidya

2:00–13:15	**Session B.2: Social, economic, and cultural contributions** (parallel sessions)	
	B.2.3: Cryosphere contribution to spiritual, symbolic, cultural, and religious perceptions (panel/ interaction) **Chair:** Hon. Chakka Bahadur Lama, Member of Parliament, Humla, Nepal **Co-hosts:** Kosar Bano, ICIMOD; Rajan Kotru, ICIMOD **Panelists:** Pasang Lhamu Sherpa, independent mountaineer; Aziz Ali Dad, Aga Khan Rural Support Programme (AKRSP); Austin Lord, Cornell University **Rapporteurs:** Serena Amatya and Chimi Seldon	**B.2.4:** Cryosphere and livelihoods in high mountain communities: Understandingfromasocio-ecological systems perspective (human library) **Co-hosts:** Arabinda Mishra, ICIMOD; Binaya Pasakhala, ICIMOD **Panelists:** Smriti Basnett, Future Earth; Christie Lai Lam, University of Osaka; Pasang Yangjee Sherpa, University of Washington; Amina Maharjan, ICIMOD **Rapporteurs:** Lipy Adhikari, Sabarnee Tuladhar, and Karen Marie Oseland
13:15–14:15	*Lunch break*	
14:15–15:30	**Session C: Cryosphere hazards and their impacts** **C.1:** Glacial Lake Outburst Flood (GLOF): From risk to community's approach (panel) **Co-hosts:** Finu Shrestha, ICIMOD; Arun B. Shrestha, ICIMOD **Panellists:** Finu Shrestha (Chair); Aisha Khan, Mountain and Glacier Protection Organization (MGPO), Pakistan; Sonam Lhamo, National Center for Hydrology and meteorology (NCHM), Bhutan; Shresth Tayal, TERI, India; Deepak KC, UNDP, Nepal; Nie Yong, Institute of Mountain hazards and Environment (IMHE), CAS, China; Hedyatullah Arian, Kabul University, Afghanistan **Rapporteurs:** Reeju Shrestha and Yathartha Dhungel	**Session D: Cryosphere contribution to biosphere** **D.1:** Cryosphere contribution to biosphere **Host:** Sunita Chaudhary, ICIMOD **Panellists:** Ghana S. Gurung, WWF- Nepal (Chair); Roshan Sherchan, Green Governance Nepal; Hem Sagar Baral, Zoological Society of London; Prakash K. Paudel, Kathmandu Institute of Applied Science (KIAS); Achyut Tiwari, TU, Nepal **Rapporteurs:** Sunita Ranabhat and Pradyumna Rana
15:30–16:00	*Tea break and end of poster competition (voting concludes)*	
16:00–17:00	**C.2:** Permafrost degradation and GHG emissions (panel) **Co-hosts:** Denis Samyn, ICIMOD; Dorothea Stumm, independent researcher **Panelists:** Dorothea Stumm, Tingjung Zhang, Lanzhou University; Prashant Baral, NIIT University **Rapporteurs:** Tika Gurung and Kabi Raj Khatiwada	Special breakout session on scoping the HIMAP Climate Change, Cryosphere and Water Outlook **Co-hosts:** Philippus Wester, ICIMOD; Anna Sinisalo, ICIMOD
17:00–17:45	**Session E: Exploring bridges to the Andes** (panel/Interactive) **Chair:** David Molden, ICIMOD **Hosts:** Danish Samyn, ICIMOD **Rapporteurs:** Kripa Shrestha and Binu Maharjan	

Day 3 (Friday, 30 August 2019) at Kathmandu University	
09:00–09:30	**Registration**
09:30–10:45	**Session F: Decision and transformative strategies in the high mountains F.1:** Building resilience and capacity – community voices (moderated panel) **Co-hosts:** Amina Maharjan, ICIMOD; Arabinda Mishra, ICIMOD **Panellists:** Son Norpu Lama, Community member, Langtang, Nepal; Chewang Norphel, "Ice Man of India"; Arjumand Nizami, Helvetas, Pakistan; Lobzang Stanzen, Shoolini University, India; Xiaoming Wang, State Key Laboratory of Cryospheric Science (SKLCS), CAS, China; Miriam Jackson, NVE; Anna Sinisalo, ICIMOD **Rapporteurs:** Binaya Pasakhala and Tenzing Sherpa
10:45–11:15	*Tea break*
11:15–12:30	**F.2:** Cryosphere contribution: Gender and social justice perspective (Variety – panel, poster, sharing experiences) **Co-hosts:** Suman Bisht, ICIMOD; Rajan Kotru, ICIMOD **Panelists:** Pasang Yangjee Sherpa, University of Washington, USA (Chair); Samina Baig, UNDP Goodwill Ambassador, Pakistan; Nilhari Neupane, ICIMOD; Pasang Lhamu Sherpa, independent mountaineer; Aditya Bastola, ICIMOD **Rapporteurs:** Sijal Pokharel and Chimi Seldon
12:30–13:30	*Lunch break*
13:30–15:00	**F.3:** Cryosphere, society, and risk management (moderated panel) **Co-hosts:** Neera Shrestha Pradhan, ICIMOD; Sanjeev Bhuchar, ICIMOD; Nanki Kaur, ICIMOD **Panellists:** Xiaoming Wang SKLCS, China, (Chair); Aisha Khan, MGPO, Pakistan; Narendra Khanal, TU, Nepal; Deo Raj Gurung, AKAH; Kosar Bano, ICIMOD **Rapporteurs:** Serena Amatya and Anushilan Acharya
15:00–15:30	*Tea break*
15:30–15:45	**Closing remarks from the co-organizer**
15:45–16:45	**Wrap-up panel – Voices of the HKH: Youth, scientists, practitioners, communities, media** **Vote of thanks** **Host:** Arun B. Shrestha, ICIMOD **Rapporteur:** Sam Inglis

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