THAWING TREASURES: CLIMATE CHANGE AND ITS TOLL ON THE UPPER INDUS BASIN'S CRYOSPHERE

TALHA AFZAL KOHISTANI*

Abstract

The Hindu Kush-Karakoram-Himalaya (HKH) region is strongly impacted by climate change, particularly the Upper Indus Basin (UIB). This study evaluates the effects of global warming on the cryosphere by looking at data on glaciers, snow cover, and permafrost. The HKH glaciers are melting more quickly than expected, possibly losing 80% of their mass by 2100. The longer melting season is reducing UIB snow cover, while permafrost is also thawing. This may have implications for Pakistan's crucial Indus River. The water input of UIB may increase until the 2060s before decreasing as a result of glacier mass loss. Flood frequency may increase due to increased melting and severe monsoons. Glacier melt may also increase the probability of glacial lake outburst floods (GLOFs), while river sedimentation exacerbates all these problems. Permafrost thawing, besides causing the landslides, may affect lowland soil fertility, and water quality. Dependence on existing data might lead to limitations, resulting in potential biases or research gaps. The study makes important recommendations in light of these challenges. Developing effective early warning systems, implementing nature-based adaptations, increasing research and data collection, integrating local

* Mr Talha Afzal Kohistani is a graduate of Government and Public Policy from National Defence University, Islamabad.

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populations in decision-making, and engaging in climate diplomacy stand out as essential measures.

***Keywords**: cryosphere, permafrost, hydro-met changes, Upper Indus Basin (UIB), glacial lake outburst floods (GLOFs), adaptation actions, elevation-dependent warming (EDW)*

Introduction

Global warming is impacting every part of the planet, extending its impact as far off as the Hindu Kush-Karakoram-Himalaya (HKH) region, especially the Upper Indus Basin (UIB). In the recent past, the UIB has been faced with a relatively more intense hike in temperature than before.[1] The HKH is home to the biggest reserves of ice outside the polar regions and that is why it is also termed as the third pole of the world. The HKH feeds 12 river basins that flow through 16 different countries and serve 240 million people living in the HKH region and about 1.6 billion others living downstream.[2] In contrast to the eastern river basins in the HKH, which rely mostly on rainfall, the western river basins in the region depend more on glaciers and snowmelt water. Amu Darya is the most melt-dependent river in the HKH followed closely by the River Indus.[3] This dependence of the River Indus on the meltwater defines the paramount importance of the cryosphere for Pakistan, provided that most of the population of the country and its agriculture-based economy rely heavily on water from the Indus. The HKH has been declared as the climate change hotspot due to the extreme levels of hydro-met changes expected in the area throughout the 21st century.[4] Studies have found that the temperatures in the HKH have risen at the average rate of +0.28^{o}C per decade during the period from 1951 to 2020.[5] These increasing temperatures are seriously affecting the cryosphere of this region. The three major components of the cryosphere in the HKH are glaciers, permafrost, and perennial/seasonal snow.

This study investigates how the aforementioned three significant cryosphere components are affected by the rising global temperatures and what expected hydro-met disasters can it potentially cause. The focus, however, will be on hydrological extremes expected in the near term, i.e., in the timeframe ranging from 2050 to 2070. Historical data on glacier melt rates and temperature rise in the HKH region has significant discrepancies due to a number of factors, including the use of different methodologies, restricted access, and the lack of modern and precise technology. Given the aforesaid gap in the available literature, this study mainly relies on the most recent data from the most reliable sources only. The significance of this study is rooted in its distinct contribution to bringing together fragmented data on different cryosphere components to produce a comprehensive perspective that is uniquely customised to the Upper Indus Basin. This also serves as a crucial addition to the existing body of knowledge on the subject that is mostly focused on the individual components of the cryosphere. Methodologically, the research is qualitative and aims to provide a thorough analysis and synthesis of the data that has already been published in reliable research papers and reports across the globe. The recommendations detailed as the conclusions of this research are directed at enhancing state capacity to develop informed strategies for the sustainable management of the region's water resources and environmental resilience.

Methodology

In this study, the effects of global warming on the melting of the cryosphere in the UIB are examined. The first phase of data collection included establishing a databank of the most pertinent information from a variety of reputable research papers and international reports. These resources were chosen to guarantee a thorough representation of the most recent research on the UIB cryosphere melting and its connection with increased global warming. The end goal during the said phase was to compile a wide range of expert ideas and discoveries to provide a comprehensive understanding of the subject. The content's applicability to the research question, the sources' credibility and repute, and the timeline of the publications consulted were some of the major determinants in choosing the data sources. The sources chosen cover a wide historical period and offer a balanced representation of different points of view. In the second phase, to analyse the data gathered for this study, a qualitative synthesis approach was used. While no particular data analysis methods were employed, a thematic analysis was carried out to locate recurrent patterns, important discoveries, and noteworthy insights that were evident throughout the data collected from various sources. This procedure made it easier to gather important data which forms the basis for the ensuing discussion. Utmost precision and attention to detail were accorded to ensure accurate attribution of sources throughout the entire data collection process. To credit the original authors and uphold academic honesty, thorough citations and references were used. It is noteworthy to mention the aforesaid since this methodology depends on already-collected data, it is vulnerable to the constraints imposed by primary sources. The absence of precise data analysis procedures and the lack of direct participation in data collection could lead to biases or gaps in the research. Nevertheless, this study's validity is preserved by the meticulous selection of reliable sources and the triangulation of data from various angles.

Geography of the HKH

The Hindu Kush-Karakoram-Himalaya (HKH) cover an area of around 4.2 million km^2. It stretches around 3,500 kilometres in length from Afghanistan in the west to Myanmar in the east, covering parts of Pakistan, India, China, Nepal, Bhutan, and Bangladesh. The region is home to mountain peaks higher than 7,000 metres. The HKH feeds a total of 12 river basins, including the ten biggest rivers of Asia, i.e., Amu Darya, Brahmaputra (Yarlung Tsangpo), Ganges, Indus, Irrawaddy, Mekong (Lancang), Salween (Nu), Tarim, Yangtse (Jinsha), and the Yellow (Huang He) River. This is why the mountain ranges located in the HKH region are known as the *water towers* of Asia. This study, however, is more focused on the Indus River Basin, particularly, the Upper Indus Basin (UIB). The Indus Basin itself consists of three river basins which are the Kabul Basin, the UIB, and the Panjnad Basin. Within the wider HKH region, the UIB is an important hydrological area. It includes the upper reaches of the Indus River and its tributaries and involves sections of China, India, and almost all of northern Pakistan. All of the area north of the Tarbela Dam in Pakistan is included in the UIB. There are eight sub-basins in the UIB which include Gilgit, Hunza, Shigar, Shyok, Zanskar, Shingo, Astor, and the Upper Indus sub-basin.

Cryosphere of the Upper Indus Basin

The cryosphere is defined as the part of the earth where frozen water exists. This frozen water can exist in many forms such as glaciers, seasonal snow, continental ice sheets, sea ice, river ice, permafrost, and aufeis. Every location's cryosphere has a different combination of components and the composition of the cryosphere changes from region to region. The UIB has three major components that come together to shape its cryosphere including glaciers, perennial/seasonal snow, and the permafrost.

Glaciers

Overall, the number of glaciers found in the HKH region is around 52,252, covering an area of 60,052 km^2 and holding ice reserves of 61,126 km^3.[6] Out of this, 18,495 glaciers belong to the Indus Basin, which span around an area of 21,192 km^2 and contain ice reserves of approximately 2,696 km^3.[7] Out of the three basins of the Indus, the UIB has by far the largest number of glaciers and ice reserves. There are 11,413 glaciers in the UIB alone, which is 61 per cent of the total number of glaciers in the Indus Basin. Similarly, about 71 per cent (15,061 km^2) of the total glacier area and about 80 per cent (2,173 km^3) of the ice reserves of the Indus Basin are also held by the UIB.[8] The Siachen, which is the largest glacier in the HKH covering an area of 926 km^2, also lies in the UIB.

Perennial Snow

Perennial or seasonal snow is the second major component of the cryosphere of the UIB. This is different from the glaciers as most of it melts away during the spring and summer seasons and is then replenished by the winter snowfall. About 33 per cent of the area of the UIB receives seasonal snow.[9] The average seasonal snow cover across the HKH stays for a little more than 100 days every year before melting away.[10]

Permafrost

Permafrost is the third and seemingly a rather understudied component of the UIB's cryosphere. Permafrost is a term used to describe a form of ground that is constantly frozen for long periods, usually for at least two years in a row. The permafrost is made up of several different elements, including ice, soil, and other materials such as gravel, sand, and organic materials. It also holds large amounts of greenhouse gases, such as CO_2 and CH_4. It is the ice that holds all these components together to form this entity of the cryosphere. However, the amount of ice in this part of the cryosphere varies from region to region, with some having a far higher amount than others. It is estimated that the permafrost in the HKH stretches over an area of more than 2 million km^2.[11] A recent study showed that this part of the cryosphere covers about 38 ± 3 per cent of the total area of the UIB.[12]

Changes Observed in the Cryosphere

Anthropogenic carbon emissions are causing global temperatures to rise, but the albedo effect and Elevation-dependent Warming (EDW) are making it especially hot in high-elevation areas.[13] The term 'albedo effect' in the context of the cryosphere describes the phenomena where the amount of solar radiation absorbed or reflected into space depends on the reflective qualities (albedo) of ice and snow surfaces. As the surface of glaciers is white, their albedo is high, which means they absorb little solar energy and reflect most of it and this is the reason behind low temperatures in the higher altitude and snow-covered areas. As the glaciers melt away due to global warming, the darker surface is exposed which causes the overall albedo of the area to decline as the dark-coloured surfaces tend to absorb more energy and reflect little. This in turn leads to relatively more intense warming of the areas with higher altitudes and the phenomenon is known as elevation-dependent warming (EDW).

It has been found that the difference in the warming between the highest and lowest altitudes of the UIB can be as significant as 1°C under RCP[14] 4.5 and 2°C under RCP 8.5 by the end of this century.[15] An average temperature increase of +0.28°C has been observed across the HKH region from 1951 to 2020 with an explicitly higher trend across the UIB and some other basins.[16] It is this rise in temperatures that is causing the glaciers to melt at faster rates. According to studies, the average rate of glacier loss in the HKH was -0.19 m w.e.f. 2000 to 2009, but it accelerated to -0.28 m w.e.f. 2009 to 2019, a 65 per cent hike in the rate of melting within one decade. Even under the most optimistic projections of global mean temperatures staying between 1.5°C and 2°C, glaciers across the HKH are expected to lose anywhere between 30-50 per cent of their mass by the year 2100 with the number going as high as 60-80 per cent loss of mass under more realistic projections of temperature rise by 3-4°C.[17]

The second important component of the cryosphere in the HKH is seasonal snow cover which is also affected by global warming. The average duration of perennial snow cover over the HKH is found to be 102 days per year between the years 2002-2017 and it is dwindling at the pace of 0.844 days per year.[18] It is declining due to an increase in the overall duration of the melting season, owing to the late start of snowfall and the early onset of the melting season. There is a probability of the melting season shifting backwards by as much as two months from June to April, by the end of this century.[19] The decline in snow cover can be partly attributed to the diminishing annual rate of snowfall over the UIB and it is expected that the annual rate of snowfall in the area can deteriorate by 30-50 per cent under the projected climate change pathway RCP 8.5.[20] Additionally, the overall snow depth across all the mountain regions is expected to decline inevitably by 25 per cent by 2050 under all projected climate scenarios.[21]

The third significant part of the UIB's cryosphere is the permafrost. Studies suggest that permafrost lies anywhere between 1,190,000 km^2 to 2,090,000 and 2,250,000 km^2 across the HKH region.[22] The mean temperature for this part of the cryosphere is found to have risen by 0.19±0.05°C.[23] Research on this component of the cryosphere has been very limited so far and there are very few studies suggesting how much damage has been done to it across the HKH. One of the studies conducted in the Indian Himalayas shows a loss of 8,340 km^2 of permafrost area in the last few decades.[24]

Potential Consequences of the Changes in Cryosphere and Threats in the Near Term (2050-60)

It is anticipated that the input of water to the River Indus from the UIB will increase in the near term till 2050-60.[25] However, in the long term, i.e.; 2080-2100, it will begin to decrease because a significant portion of the glaciers would have been exhausted by then and their contribution to river flow will start decreasing. Along with that, relatively more melt-dependent sub-basins of Kabul and Jhelum are also expected to contribute higher amounts of water to the Indus until 2050. This contribution can go up as much as 26 per cent and 71 per cent under the climate projections of RCP 2.5 and RCP 8.5, respectively, by the end of this century.[26] All of the climate prediction models agree that there will likely be heavier precipitation during the monsoon season in the more rain-dependent eastern rivers of Chenab, Ravi, and Sutlej, even though future total precipitation rates will vary widely.[27]

High river flows due to the rising melting rates combined with the expected high monsoon precipitation rates during the 21st century may lead to more frequent hydro-met extremes, such as floods and other compound events. One of the examples of such events was the devastating flood of 2022 in Pakistan, where high precipitation rates teamed up with the heatwave to create havoc.[28] Other than that, when glaciers retreat, they leave behind glacial lakes which occasionally burst to create the so-called glacial lake outburst floods or GLOFs. There are about 3,044 glacial lakes across the Pakistani section of the HKH with 36 being critical in terms of the GLOF hazards.[29] There is a possibility that the frequency of GLOF events in the area can go up threefold by the end of this century. The risk of GLOFs further exacerbates the already minacious probability of increased hydrological extremes across the River Indus.

An increasing number of slope failures and landslide events across the UIB is expected during the 21st century, attributable to the thawing of permafrost. About 22 per cent of all the landslide events in northern Pakistan in the last 20 years can be attributed to climate change.[30] Besides triggering such events, the destruction of this entity of the cryosphere may also create environmental and public health challenges. It may not only release massive amounts of CH_4 stored in it to the atmosphere, but also other substances such as heavy metals, pollutants, pathogens, and various other chemicals into the River Indus.[31] Furthermore, the soil fertility across the low riparian zones may rise but the overall quality of water is expected to decline, creating health problems for the general public because of the aforesaid as well.

Permafrost thawing, together with the GLOFs will lead to the problem of extensive sedimentation of rivers across the UIB. The suspended sediment load across the High Mountain Asia

(HMA) was found to have increased by 80 per cent within the last 60 years and is expected to double by 2050 under RCP 8.5.[32] Moreover, the fluvial sediment has also been found to have been on the rise across the HKH Rivers. Studies have shown that for every 10 per cent increase in precipitation, the fluvial sediment goes up by 24% ± 5%, while for every 1^{o}C increase in temperature, the sediment load soars up by 32% ±10%.[33] This extensive sedimentation of the rivers will also play its part in degrading the water quality of rivers. Along with that, hydropower projects like Tarbela will be threatened by issues such as turbine abrasion and decreased reservoir capacity.[34] The menace of floods is also intensified by the fluvial sediment which is capable of progressively increasing the bedload of rivers, decreasing their water-carrying capacity and escalating the prospect of overflowing.

The Karakoram Anomaly

While the glaciers across most of the HKH began to retreat due to rising global temperatures a few decades ago, those in the Karakoram region showed a different behaviour. These glaciers exhibited a strange resilience to climate change and their mass either increased or stayed unaltered.[35] Different studies show several scientific and meteorological circumstances as drivers of this anomaly, but a consensus is yet to be reached. The anomaly itself, however, is coming to an end. According to the latest research studies, some glaciers in eastern Karakoram show the glaciers losing mass at the rate of 0.09 ± 0.04 m per year.[36] With the rise in global temperatures, a faster rate of melting is to be expected in the near term.

Conclusion

The future of Pakistan is dependent on the status of the cryosphere in many ways. It is the biggest source of water for the Indus River which is the lifeline of Pakistan. From fresh drinking water to the water required for agriculture, from groundwater recharge to the massive hydropower projects, the cryosphere serves 230 million people of Pakistan and its economy in many direct and indirect ways. It is, therefore, an invaluable asset that is under severe threat from climate change. Global warming is disproportionately affecting the cryosphere of Pakistan, progressively increasing its rate of melting. The faster melting rates and longer melting seasons in the UIB as well as high monsoon precipitation rates over the eastern rivers of Pakistan may keep pouring increasingly high amounts of water into the river Indus throughout the first half of this century. This may lead to a massive increase in the frequency and intensity of floods and other hydro-met disasters in the near term, with long-lasting impacts on the socio-economic conditions of the country. The menace of GLOFs and extensive sedimentation of the rivers due to permafrost thawing will further foment the hydro-met threats. The misery, however, does not end here as most of the cryosphere would have melted by the end of this century, leaving nothing to feed the mighty Indus. A long and agonising period of droughts can be expected thereafter. It is, therefore, of immense importance to take timely and effective adaptation actions to secure the future of both the cryosphere and the country.

Recommendations

The following adaptation actions are recommended for Pakistan in light of the above-mentioned environmental hazards.

1. Pakistan urgently needs to improve its water storage due to rising water flows from melting glaciers and higher precipitation. Building new dams and reservoirs, even at a smaller scale, is essential since the current capacity of the country is only 30 days, which is well below world standards. In addition to that, hilly areas must adopt both traditional water-storage practices like Zing and Kanda and cutting-edge ones like Ice Stupas.
2. Nature-based adaptations are an effective solution for Pakistan in mitigating cryosphere-related hazards. These

adaptations include actions like reforestation and afforestation for slope stability and avalanche barriers, wetland creation to absorb excess water to curb floods and conserve resources, as well as prioritising riparian buffer upkeep to prevent erosion, enhance habitats, and boost biodiversity.

3. Steps towards advanced research and accurate data collection are of utmost importance to assess current damage and predict future outcomes for effective adaptation. These steps include: building more weather stations in remote HKH areas and upgrading already existing 30+ stations with advanced tech like Doppler's Radars, UAVs, and Lidar. Also, funding and incentives for cryosphere research in northern Pakistani universities are critical.
4. Pakistan desperately needs a robust early warning system in the UIB to prepare for looming disasters. The GLOF II project in Gilgit-Baltistan is effective but has limited coverage. Expanding the scope of GLOF II and launching similar projects is important for informed decision-making.
5. Inclusion and input from the local and indigenous people while deciding the adaptation measures are necessary for more effective action.
6. More projects like WEP's Strategic Plan (2023-27) and UNDP's GLOF II are urgently required for the development and implementation of an effective disaster risk reduction strategy involving measures to reduce the socio-economic and other kinds of vulnerabilities and exposure of the people to the high number of expected disasters in coming years.
7. The use of platforms like COP for more aggressive climate diplomacy and advocacy to push the world, especially the high emitters of GHGs, into bringing down their carbon emissions is also of paramount significance at the moment.

8. A “Third Pole Dialogue Forum” needs to be established, initially involving the governments of China, India, and Pakistan. The forum would be specifically dedicated to coordinating regional state-level strategies for saving the HKH cryosphere among its member states.

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