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GRADUAL CHANGES IN SNOW PEAKS IN UPPER INDUS BASIN, PAKISTAN: A GOOGLE EARTH BASED REVIEW

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ABSTRACT
The hydrology and climate of mid to high-latitude mountainous areas are significantly impacted by snow cover. Since adding or removing snow cover significantly impacts the snowpack's capacity to operate as a reservoir for water storage, the snowfall-dominated basins of mid- to higher latitudes are anticipated to see the largest shifts in the hydrological cycle because of global warming. By moving the time slider in the historical imagery feature of Google Earth Pro, the Upper Indus Basin study area was examined from the years 1984 to 2020 to track changes in the snow cover. All observations were made with longitude and latitude at 35°, 34', 51.79" N and 74°, 34', 24.21" E, and the eye altitude at 344.46 miles. Google Earth captured pictures of all the observations on December 31st of every year. The data from 1984 to 2020 was examined keenly, and it was observed that as time goes on, global warming is showing its effects and producing climate changes, which has a negative impact on the region's snow and glacier availability. The Landsat images make it abundantly evident that the lower areas of the upper Indus Basin's snow cover are more negatively impacted than the downstream side areas due to the variation in altitude. The authors also referred to the research work by other researchers in the study to compare with their work. The study observed that some areas were utterly showing no snow in 2020 as compared to 1984 as time moved on with an increase in global warming in 36 years.

Key Words: Snow cover, Climate, Global warming, Upper Indus Basin, Google Earth pro.

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INTRODUCTION:

The hydrology and the climate of mid to high-latitude alpine settings are significantly impacted by snow cover. Snow acts as a frozen water reservoir, storing precipitation until it is released by snowmelt runoff. Because it is frequently discharged quickly throughout spring, snowmelt runoff can present a flooding risk [1]. Snow is an essential constituent of the climate system due to its noticeably high ability to reflect in the visible and infrared areas of the electromagnetic spectrum. It modifies the energy exchanges between the atmosphere and the surface of the Earth over regions covered in snow, resulting in lower temperatures there than elsewhere. The majority of the solar radiation that enters is reflected by it. [2]. Snow is an essential aspect of the climate system due to its high reflectivity in the visible and near-infrared areas of the electromagnetic spectrum. It modifies the energy exchanges between the Earth's surface and atmosphere over snow-covered regions, resulting in lower temperatures in these places compared to locations without a snowpack. It reflects the vast majority of solar light. [1]

A significant portion of the freshwater resources of the world comes from snow. It is essential hydrologically not just in mountainous mid- to high-latitude regions [1] but also leads the climate of the mountainous areas over the globe [3]. Nearby, 1/6th of the world's population is getting freshwater through the mountains, which serve as temporary water storage and can actively impact the hydrology. Mountains store snow [4]; [5]; [6]. Snow has an essential contribution to the hydrological response of the complex river basins [7]. Moreover, snow cover and the contribution of snow cover to runoff have been focused on by several researchers worldwide, such as [8]; [9]. The Asian Water Tower, which contains several mountainous glaciers at mid-to high latitudes and significantly impacts downstream hydrometeorological conditions, feeds the Indus Basin, another intricate river basin [10]. Pakistan's agriculture-based economy relies on the Indus basin's waters, 90% of which come from mountain ranges in the Hindu Kush, Karakoram, and the western Himalayas [11]. Depending on the criteria defined, mountainous regions comprise roughly a quarter of the Earth's land area. Mountain rain and snow eventually flow downstream, supplying millions of people with water. While there are many variations over both time and space, mountains have generally warmed between 25 and 50 percent more quickly than the global mean since 1950 (when extensive record-keeping started) [12].

This phenomenon's level is slightly lower than that of Arctic amplification. Additionally, there is mounting evidence that mountain precipitation, which is primarily brought on by air-rising mountain slopes, is not as strong as it once was. Although a warmer world is expected to cause the hydrological cycle to speed up, increasing evaporation and intensifying precipitation episodes, this change so far seems to be more pronounced in lowland areas and less pronounced in mountains. As a result, even though precipitation is rising in many mountains, it is not rising as quickly as would be predicted given a warmer atmosphere. Nearly all mountain glaciers worldwide are receding because of the combined effects of changing temperatures and precipitation (there is also a change from snow to rain). In many areas, this has accelerated over the last 20 to 30 years. Climate zones have also migrated upward, which has resulted in the upslope movement of numerous species and the habitats that support them. This may eventually result in mass extinctions on remote peaks where there is no longer a mountain to climb [12]. Mountain environments are highly complex topographically, with physical and biological processes connected across sharp vertical gradients. The mountain cryosphere, which consists of ice, snow, and permafrost, is essential to these environments and a significant source of freshwater for areas downwind. Mountainous areas receive controlled amounts of water, nutrients, and sediment due to (seasonal) periodic and longer-term variations in the cryosphere. Agriculture, the production of hydropower, drinking water supplies, entertainment, and industry all depend on healthy upstream and downstream ecosystems [13]. Most mountain glaciers worldwide are severely out of sync with the environment and will need to lose up to one-third of their volume to do so [13]. In certain specific places, like the Karakoram, a balanced mass budget during the early part of this century has been observed despite the significant ice mass loss overall mountain ranges worldwide [10], this is probably brought about by modifications to the yearly cycle, changes in air circulation, and increased winter snow deposition on some glaciers. The mountain ranges in the area receive snowfall in the winter, which melts during the summer as the temperature rises. Large rivers receive water from snowmelt used for irrigation, drinking, washing, and energy production for 1.5 billion downstream people. Snow meltwater, glacial meltwater, and rainfall are the three main water sources that keep rivers in the area flowing. However, the third pole of the Earth is also one of the most vulnerable areas to climate change, having warmed by 1.8C over the previous 50 years [14]. Glacier mass balances vary significantly throughout High Mountain Asia. Particularly intriguing is the fact that contrary to the negative mass balances in the remainder of High Mountain Asia, glaciers in the Karakoram as well as Kunlun Shan ranges are in balance or even adding mass. This disparity requires a thorough understanding of the climatic elements that influence the glacier mass balance [15].

According to studies conducted in various parts of the world, the stream-flow regime in river basins where snowmelt predominates is most sensitive to temperature increases during the winter. This is why, in addition to the uncertainty surrounding precipitation forecasts, [4] concentrated on how temperature affects water resources in regimes where snowmelt predominates. Whether it is affected by the natural environment or humans, the amount of snowfall varies each year depending on the climate. Some years have a lot of snow, while others have little. According to [16], Snow is melting earlier in the spring than usual due to the atmosphere warming. As a result, in some cases, there isn't enough water to last throughout the summer. But why is there such a significant change? The burning of coal and other fossil fuels, which contribute significantly to carbon emissions and the increase in global temperatures, is the cause. Snow will melt earlier and earlier in the year as long as carbon dioxide and other greenhouse gases are released into the atmosphere and atmospheric concentrations rise, and that trajectory has negative effects on water resources.

Using a straightforward temperature index model, the monthly snow melt in China for the years 1951 to 2017 was calculated by [17]. After that, data on snow, depth of snow, and snow accumulation level along snow water equivalent were used to confirm the model's predictions. The three primary stable snow cover regions of China—Northern Xinjiang, Northeast China, and the Tibetan Plateau—have average annual melting rates of 0.18, 0.42, and 1.15 m3 per year, respectively. Snowmelt in northern, central, and southern China dramatically reduced between 1951 and 2017, whereas it significantly rose in the Tibetan Plateau. There was a general downward trend in snowmelt across China, although statistically speaking, this was not significant. Third-level basins in West China usually have mean annual snowmelt runoff ratios of more than 10%, those in North China greater than 5%, and those in the South below 2%. [18] have come across which snow-covered mountain packs globally are most "at-risk" from changes in the climate based on regional differences in snowpack melting as temperatures increase. The timing of snowpack clearance is changing more quickly as temperatures rise in coastal regions and the south, while changes are occurring more slowly in the northern interior of the country, according to researchers who examined almost four decades of observation in the Western United States. As a result, snowfall in regions such as the Sierra Nevadas, Cascades, and the southern Arizona mountain is far more susceptible to temperature fluctuations than snowpack in regions such as the Rockies or the mountains in Utah.

The objective of [19] was to simulate climate change forecasts and evaluate possible alterations in snow cover along with runoff due to snow melt across various climate change circumstances. They worked in the Zayandeh-rud River Basin. The IPSL-CM5A-LR, NorESM1-M, and CSIRO-MK3.6.0 cluster models for climate change, as well as the RCP 4.5, 8.5, and 2.6 setups, were used to study how the climate impacts temperature and precipitation in the basin. Temperatures and precipitation total for the four time periods 2021–2030, 2031–2040, 2041–2050, and 2051–2060 under the three scenarios were computed. Utilizing MODIS (MOD10A1) and information on temperature and precipitation, snow cover was also evaluated. The link between the weather, precipitation, temperature, and the area covered in snow was utilized for the prediction of future snow cover. Upcoming snowmelt runoff was simulated using a hydrologic model of SRM using input data for temperature, and precipitation along snow cover. The results show that 3 RCP scenarios result in a rise in temperature as well as a fall in precipitation and snow cover. Snowmelt provides for the majority of the annual runoff, according to investigations of snowmelt runoff throughout the time frame under observation (November 1970 to May 2006). Snowmelt runoff is greatest throughout the winter. According to estimates, meltwater contributes 35 and 53 percent, respectively, to the autumn and spring runoffs. The study's findings can guide water management in making better decisions for their water supply's future.

According to [20], the hydrologic response to each scenario varies, and the resulting solution set establishes boundaries for prospective variations in streamflow, melting snow, snow water equivalent, and the size of annual peak flows. The fact that by the end of the century, late-winter snowfall will have dropped by 50% in all basins with snowmelt-driven runoff is a noteworthy result. [21] dealt with topics relating to the movability of snow cover in time and space, the connection among forms of winter average air temperature, snow cover as well as the climate change impact on Estonia's snow cover pattern. Snow-covered fields are shown as IDRISI raster pictures. The duration of the snow cover was estimated at 100 stations and observation locations and interpolated into the raster cells. Using incremental climate change scenarios (2 °C, 4 °C, and 6 °C of winter warming), the average reduction in snow cover duration in different locations of Estonia is computed. The islands and coastal region of West Estonia will have the highest reduction in snow cover duration, according to model predictions. Probably, over time there won't be any snow cover. In the parts of North-East and South-East Estonia where snow cover lasts the longest, that decline should be somewhat less. A comparison of glaciers was made by [22]. All glaciers have receded, according to data from the SCGI and a revised glacier inventory created from aerial photographs and topographic maps acquired between 1956 and 1983, which is consistent with plateau areas and other mountaintops in western China. The surface area and volume of glaciers have shrunk by 420.81 km^2 (-20.88%) as well as 21.63 km^3 (-20.26%), respectively, over the last fifty years. Those glaciers with areas under 1.0 km2 had the greatest loss in terms of both quantity and size.

The whole demise of the glacier below 4000 m was caused by glacial contraction. A significant longitudinal zone was visible in the Qilian Mountains' glacier fluctuations, with glaciers receding quickly in the east but moderately in the central west. Warming temperatures were primarily responsible for glacier retreat, while increased precipitation only somewhat lessened this effect. [23] employed data from 1995 to 2096 and the regional climate models of Providing Regional Climates for Impacts Studies (PRECIS) to predict the effects of climate change from 2040 to 2050 and 2086 to 2096 compared to baseline (2000 to 2010). The river basin's average temperature increased during the last four decades at a pace of 0.058 °C/year for the greatest temperature and 0.014 °C/year for the lowest temperature, according to the present climate. The amount of flow from snowmelt from non-glaciated areas, the amount of snowfall, and the basin's capacity to hold snow are all anticipated to be adversely affected by the rise in temperature. The model's results showed that the melt from glaciated regions, on the other hand, will increase until the middle of the century before starting to decline. Discharge, Evapotranspiration, along with snowmelt are all sensitive to the impacts of climate change.

METHODOLOGY

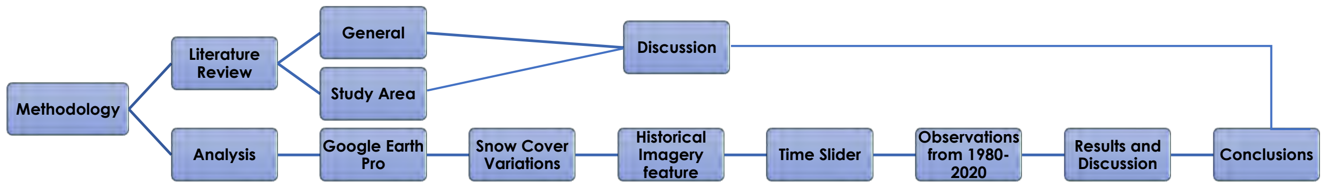

Figure 1. Methodology

The objective of the study was to review and observe the gradual changes in snow peaks in the Upper Indus Basin, Pakistan using the feature of historical imagery by Google Earth Pro by moving the time slider between the acquisition dates from 1984 to 2020. The study area, Upper Indus Basin was examined by using Google Earth Pro from the period 1984 to 2020 to observe the variations in the snow cover areas of the study area by keeping the eye altitude at 344.46 miles and the longitude and Latitude at 35°, 34', 51.79" N and 74°, 34', 24.21" E for all observations. For all the observations, the images were captured by Google Earth on the 31st of December each year.

STUDY AREA

The Upper Indus Basin (UIB) is a catchment area that extends upstream from Tarbela reservoir and is estimated to encompass an area of roughly 206,000 km^2 in northern Pakistan, close to the Chinese border [24] incorporates an extensive variety of topographical and Cryospheric environments from the more warm, low-elevation foreland (Figure 2). The lowest sections of the Indus River basin in the northwest Himalayas get only moderate (1 m/yr) levels of moisture (monsoonal) throughout the summer because they are near the end of the monsoonal conveyor belt which runs from the Bay of Bengal toward the northwest. (e.g., [25]; [26]. In contrast, Westerly Disturbances have a significant impact on the UIB and nearby locations (e.g.,[27]; [28]) resulting in extensive snow cover (over 80%) and snowfall-water storage (above 75 mm) at higher elevations [29]. Snowmelt dominates the UIB's hydrologic budget, while rainfall throughout the monsoon season is significant in lower-elevation locations [24]; [13].

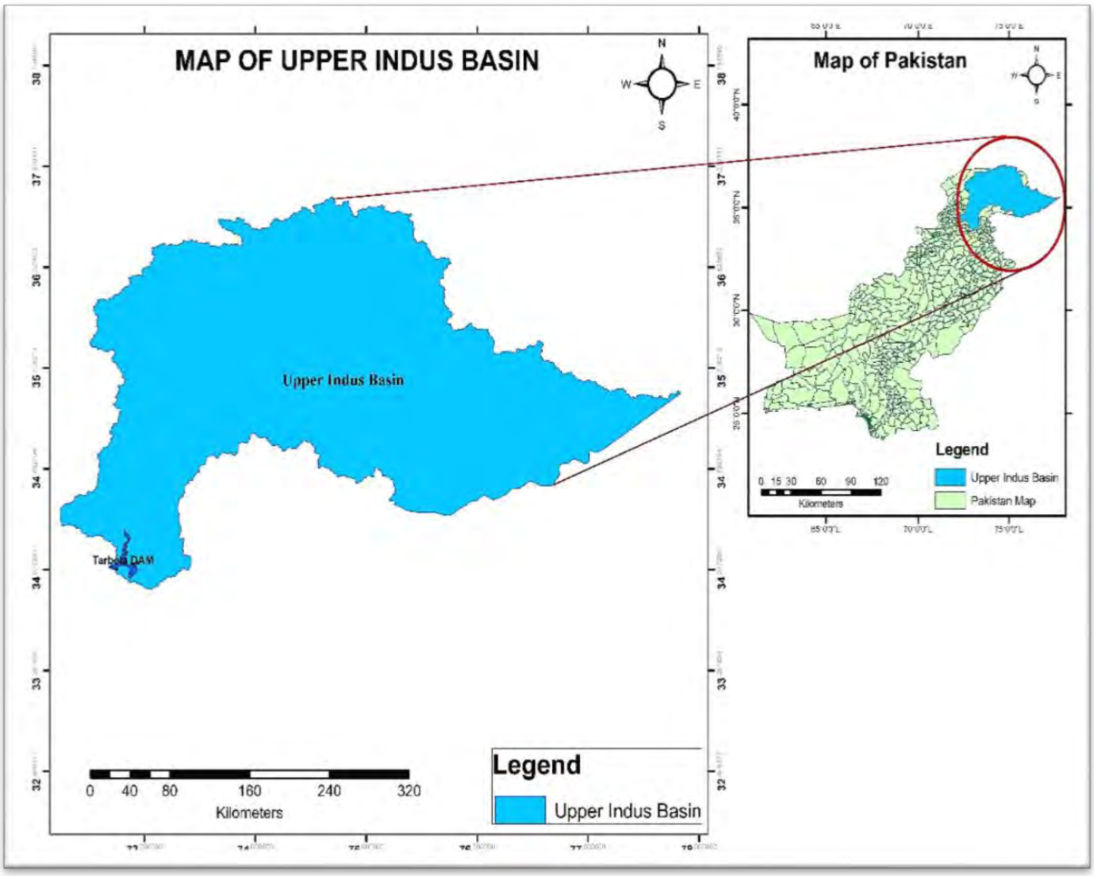

Figure 2: Map depicting the Study Area: Upper Indus Basin

RESULTS:

The results of the observations from 1984 to 2020 with a five-year gap are given below depicting Figure 3 for Google Earth-based Overview of the Upper Indus Basin for the year 1984. Figure 4 for 1989, figure 5 for 1994, figure 6 for 1999, figure 7 for 2004, figure 8 for 2009, figure 9 for 2014, figure 10 for 2019 and figure 11 for 2020. [30]

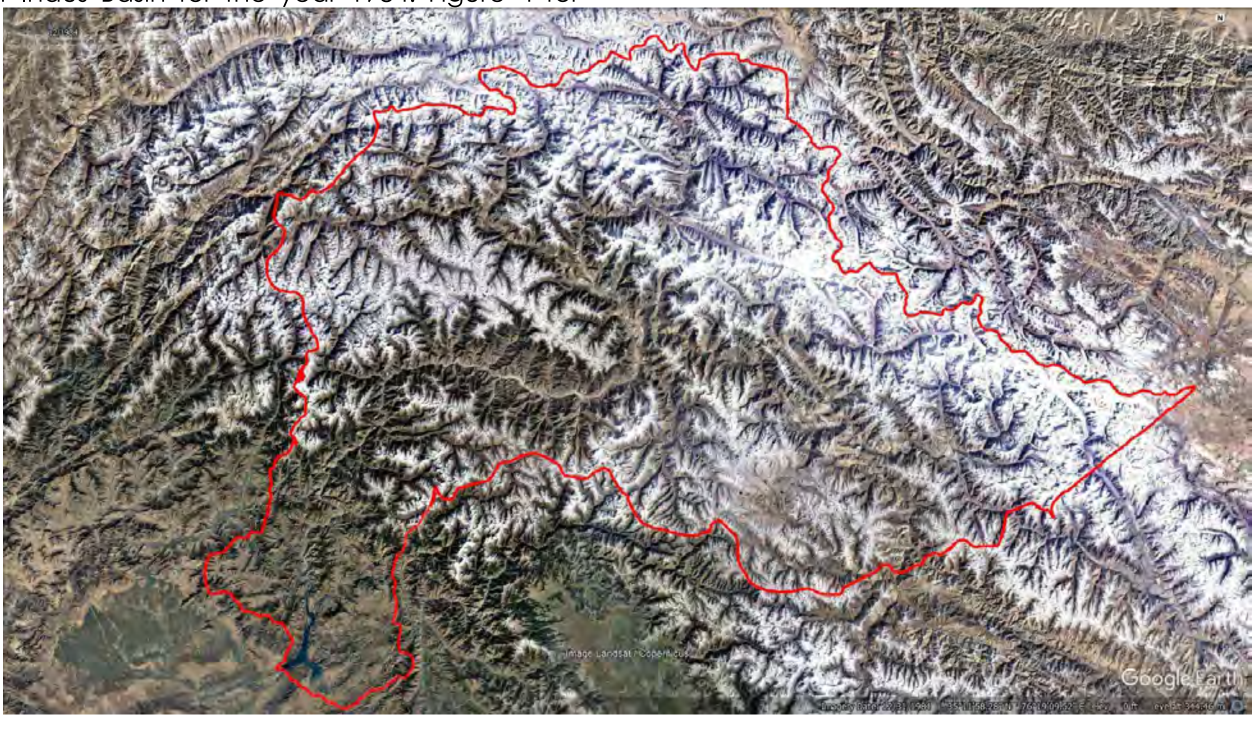

Figure 3: Overview of Upper Indus Basin (Pak) in 1984. [Courtesy: Google Earth]

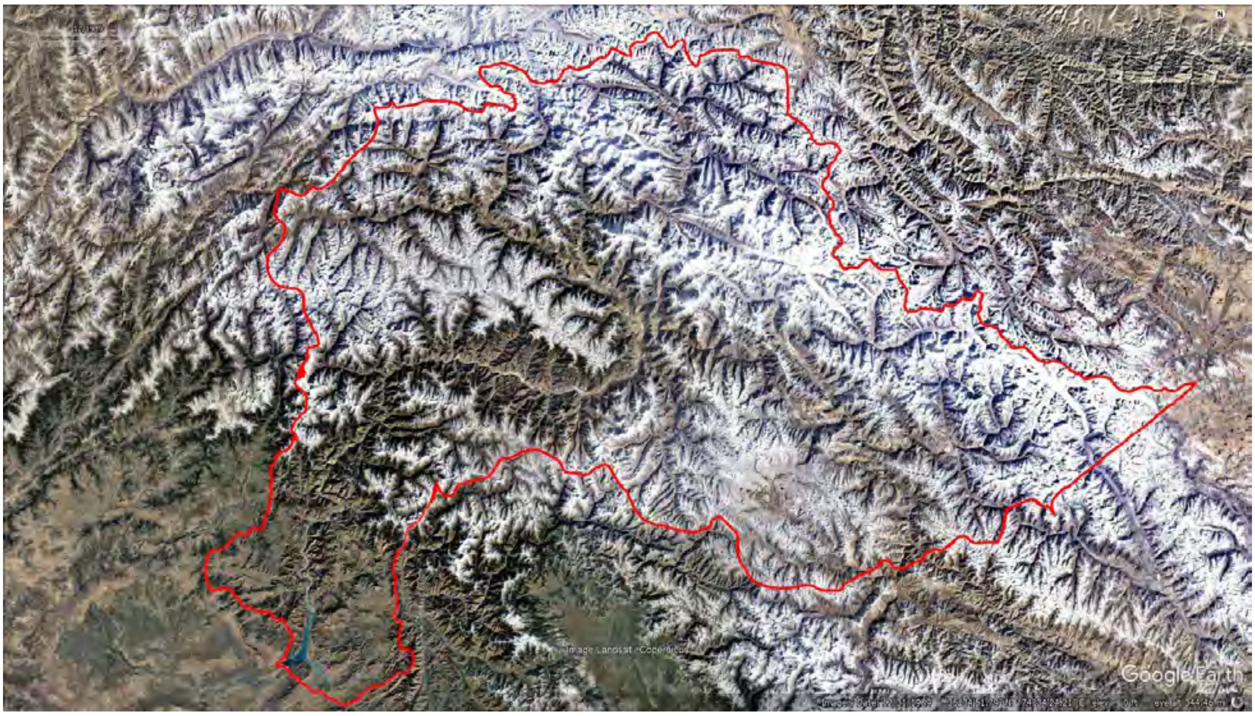

Figure 4: Overview of Upper Indus Basin (Pak) in 1989. [Courtesy: Google Earth]

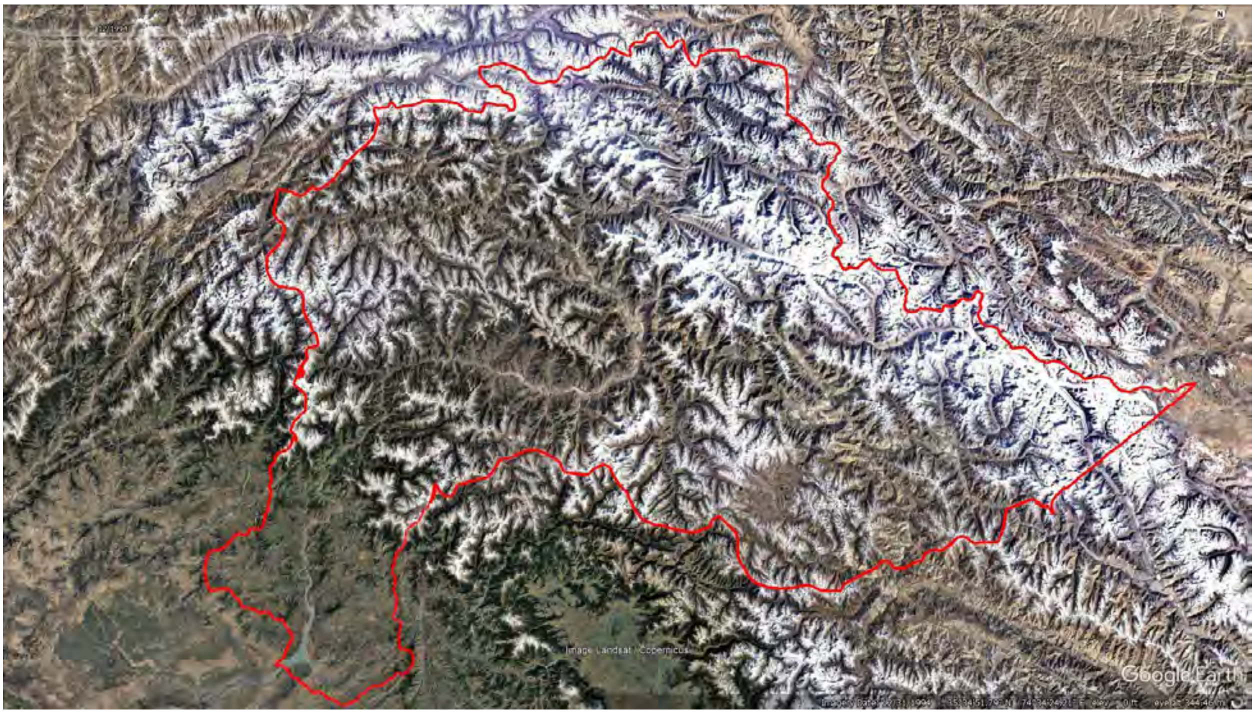

Figure 5: Overview of Upper Indus Basin (Pak) in 1994. [Courtesy: Google Earth]

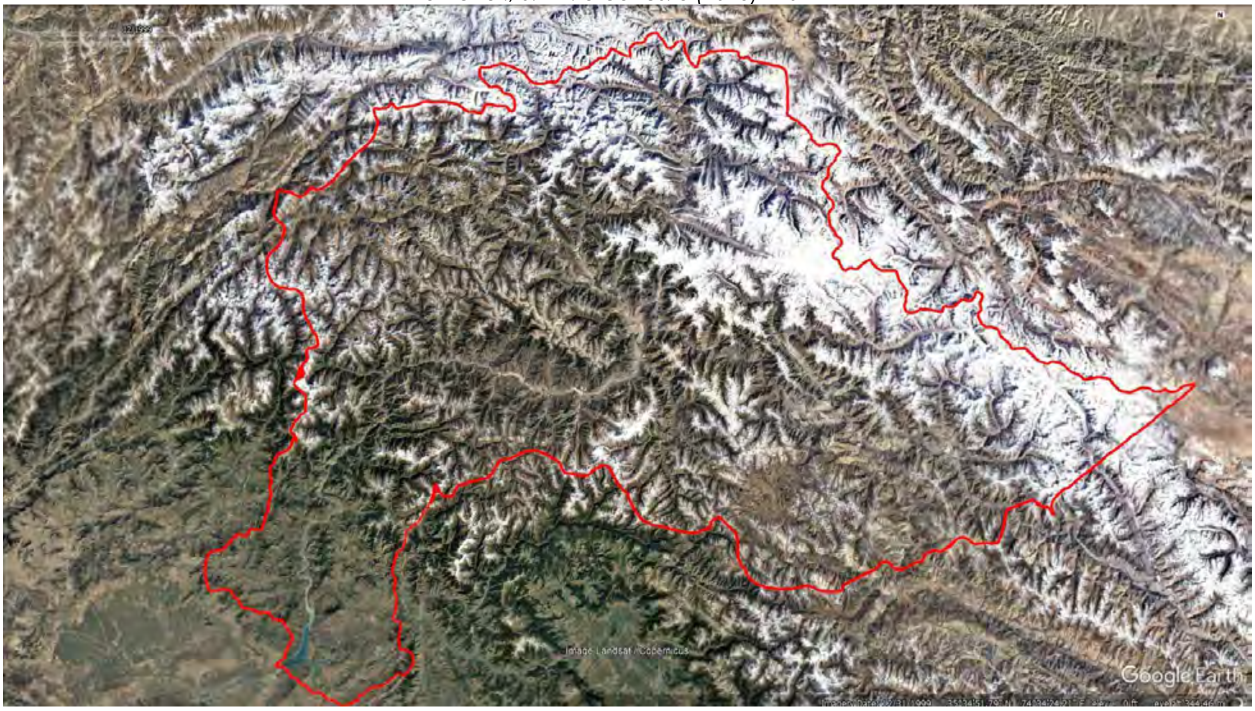

Figure 6: Overview of Upper Indus Basin (Pak) in 1999. [Courtesy: Google Earth]

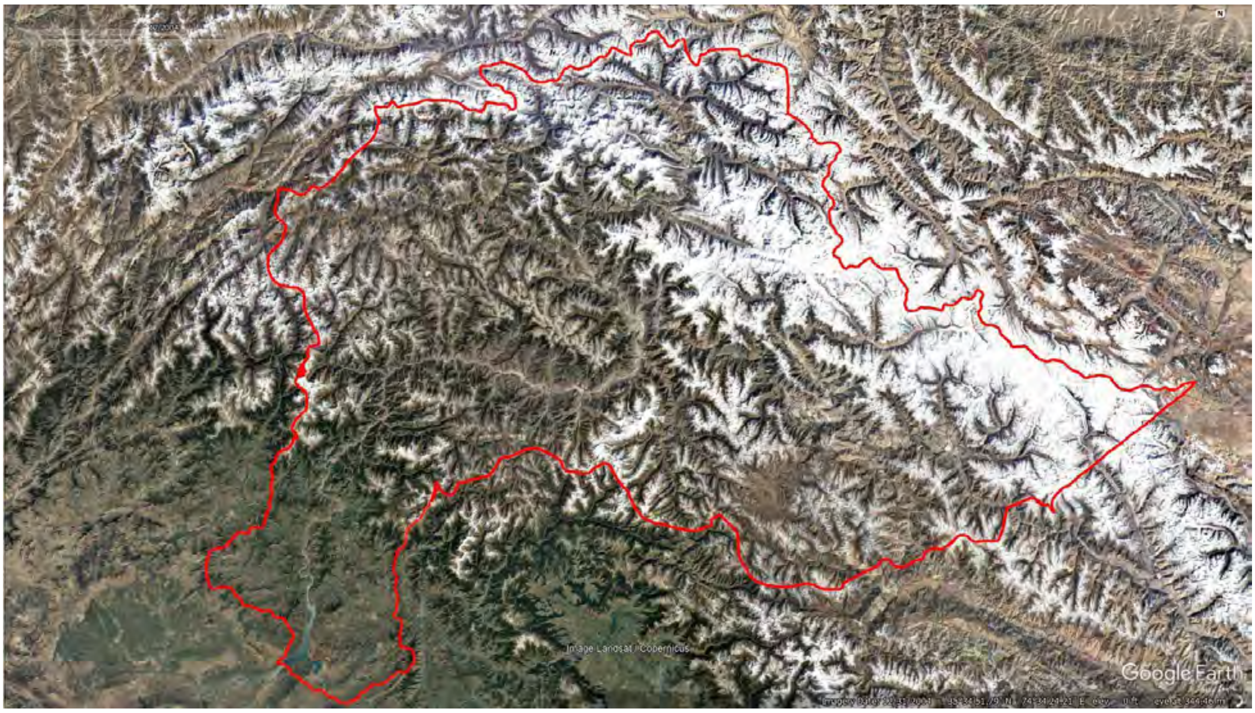

Figure 7: Overview of Upper Indus Basin (Pak) in 2004. [Courtesy: Google Earth]

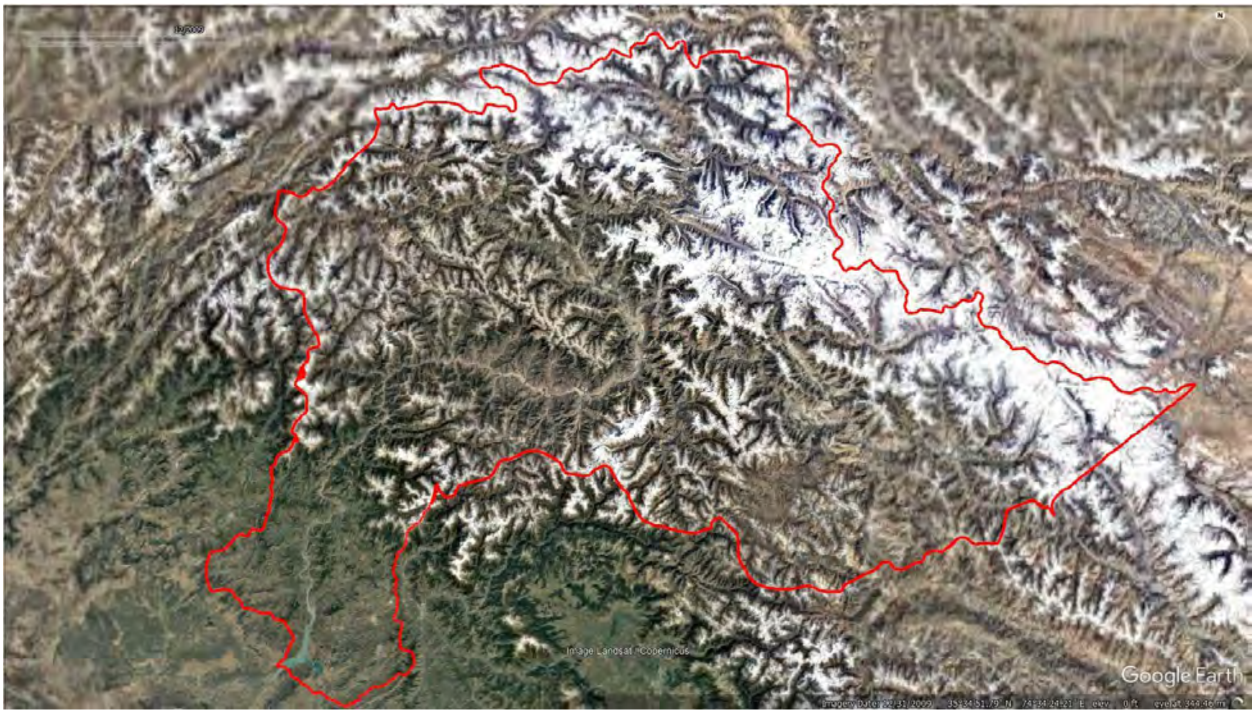

Figure 8: Overview of Upper Indus Basin (Pak) in 2009. [Courtesy: Google Earth]

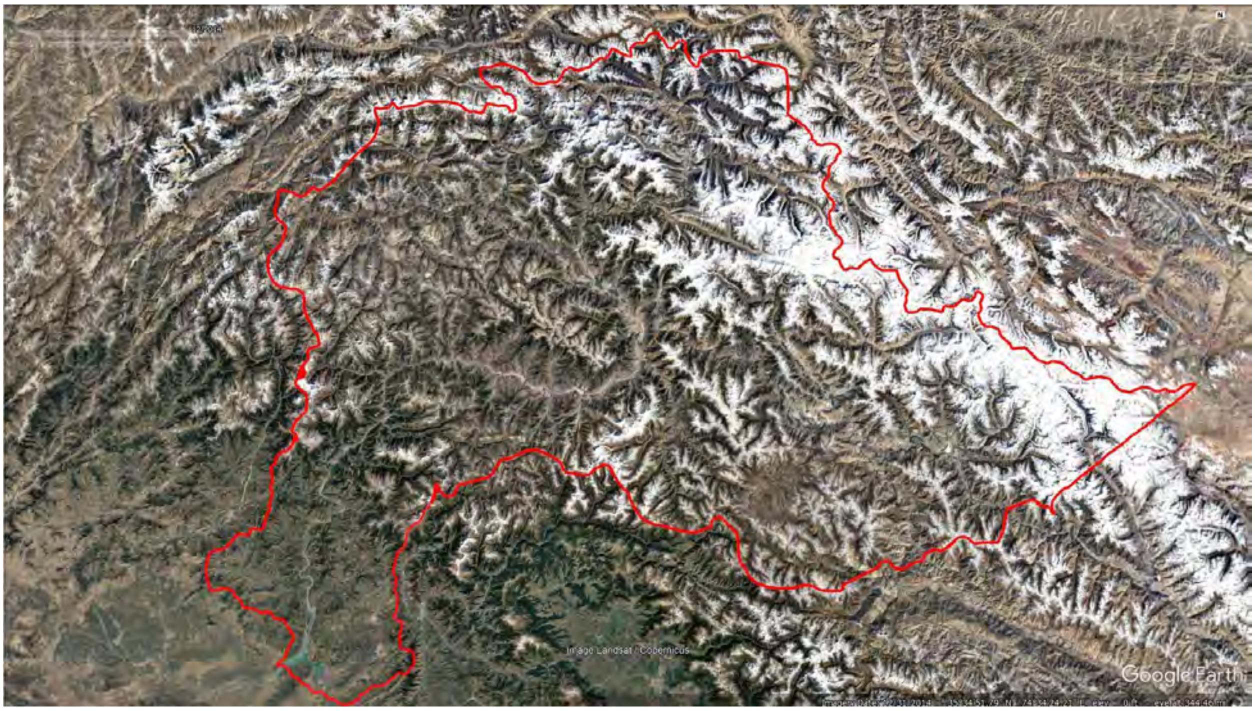

Figure 9: Overview of Upper Indus Basin (Pak) in 2014. [Courtesy: Google Earth]

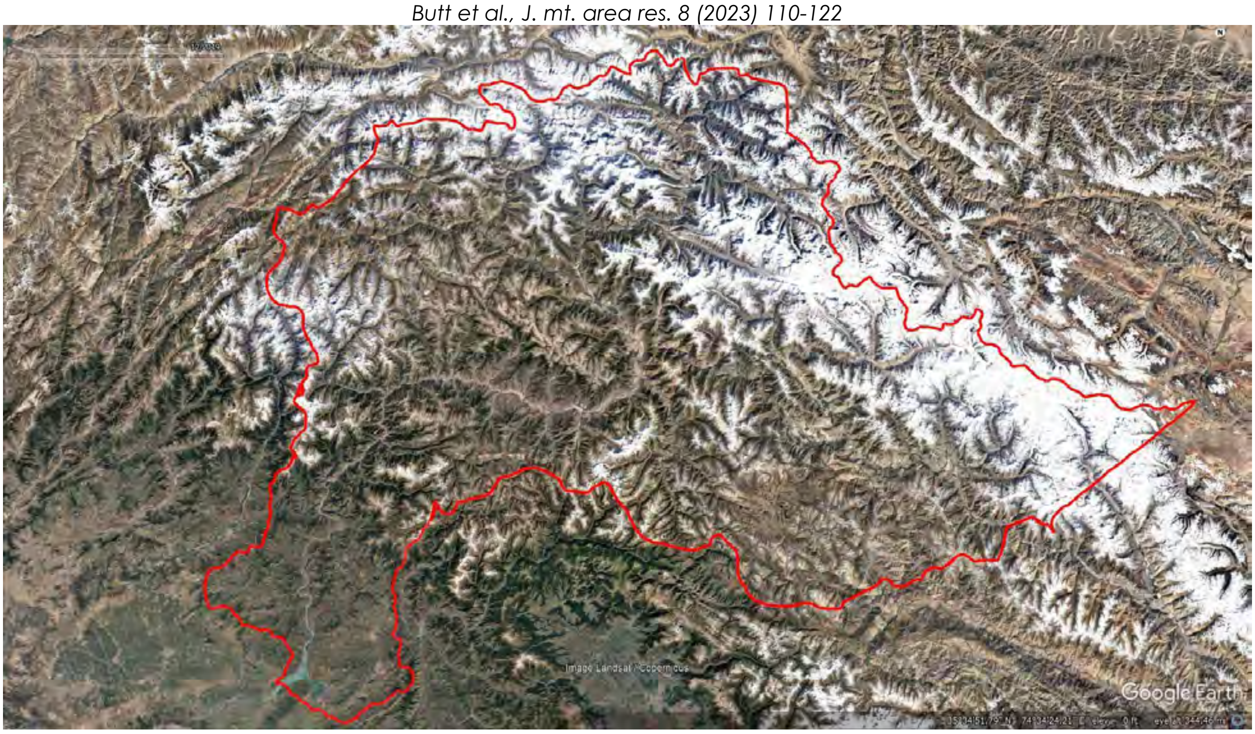

Figure 10: Overview of Upper Indus Basin (Pak) in 2019. [Courtesy: Google Earth]

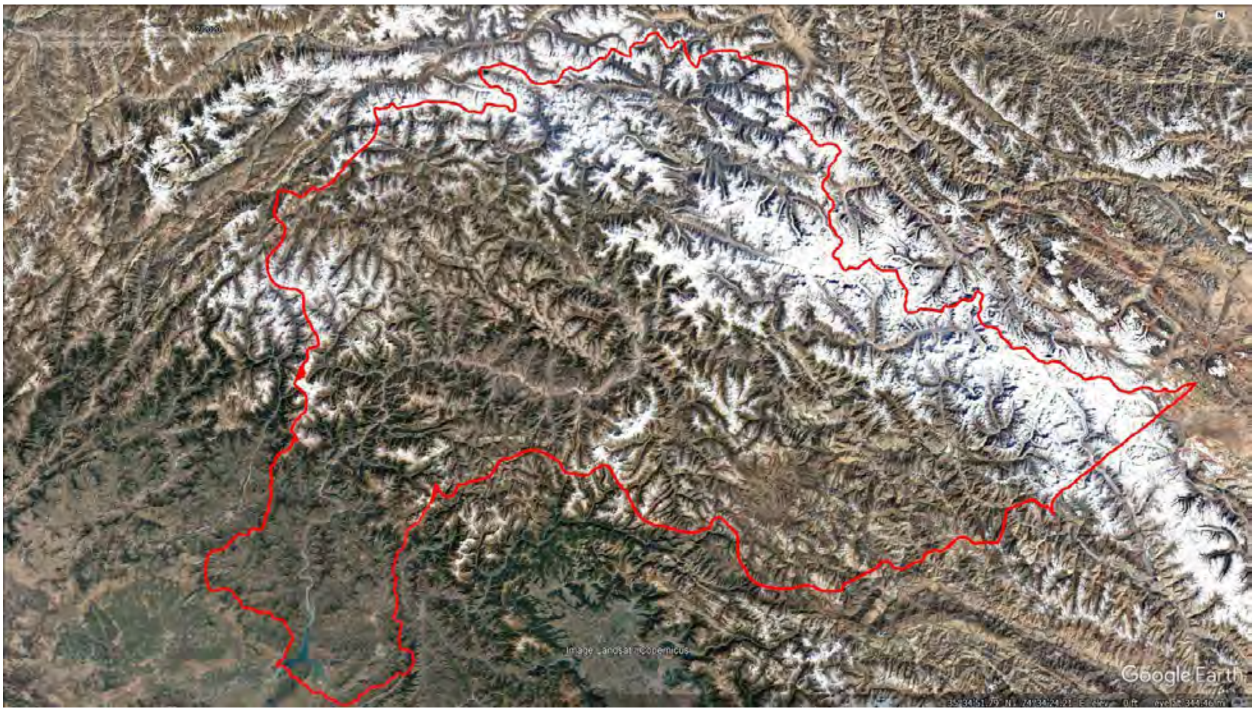

Figure 11: Overview of Upper Indus Basin (Pak) in 2020. [30]

DISCUSSIONS

The results from 1984 to 2020 were observed and it was noted that with time, the increase in temperature is depicting its impacts and causing climate variations, which results in the decreasing trend for the availability of snow/glaciers within the region.

It is due to this delicate relationship that we are facing both temperature rises and more frequent weather extremes and natural disasters as a result of climate change [31]. Higher temperatures cause snow to melt earlier, which in turn affects the timing and availability of water [32]. It is visible from the images that snow cover in the lower regions of the Upper Indus Basin is affected more as compared to the upper region due to the difference in altitudes. The study observed that some of the areas, especially in the areas like

Chilas, Barobas, Babar Shah Harai, Sharang Bar, Darle, Sheosar, Astore, Deosai, Balore, and Khukush etc. were completely showing no snow as time moved on with increase in global warming in 36 years, which were rich in snow in 1984, but almost have no snow in 2020.

As elaborated in Figure 12, figure 13 and Figure 14, [33] used geographic information systems (GIS) and remote sensing to identify temperature, snow cover, and glacier change in the Upper Indus Basin to assess temperature alteration, spatial variations in land surface temperature, and the efficacy of imagery from Landsat for detecting land surface temperature. [33] used the Normalized Difference Snow Index (NDSI) and Landsat pictures from 1993 to 2019 to map the amount of snow cover. The United States Geological Survey (USGS) database was searched for April 1993–2019 Landsat pictures with a 30 m pixel resolution. (http://glovis.usgs.gov/).

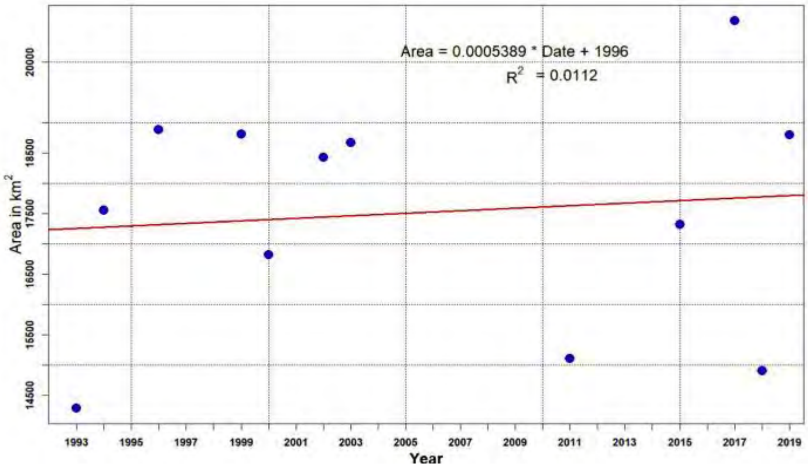

Figure 12: Upper Indus Basin's snow and ice extent (without clouds) for the years 1993-2019 in April. Source: [33]

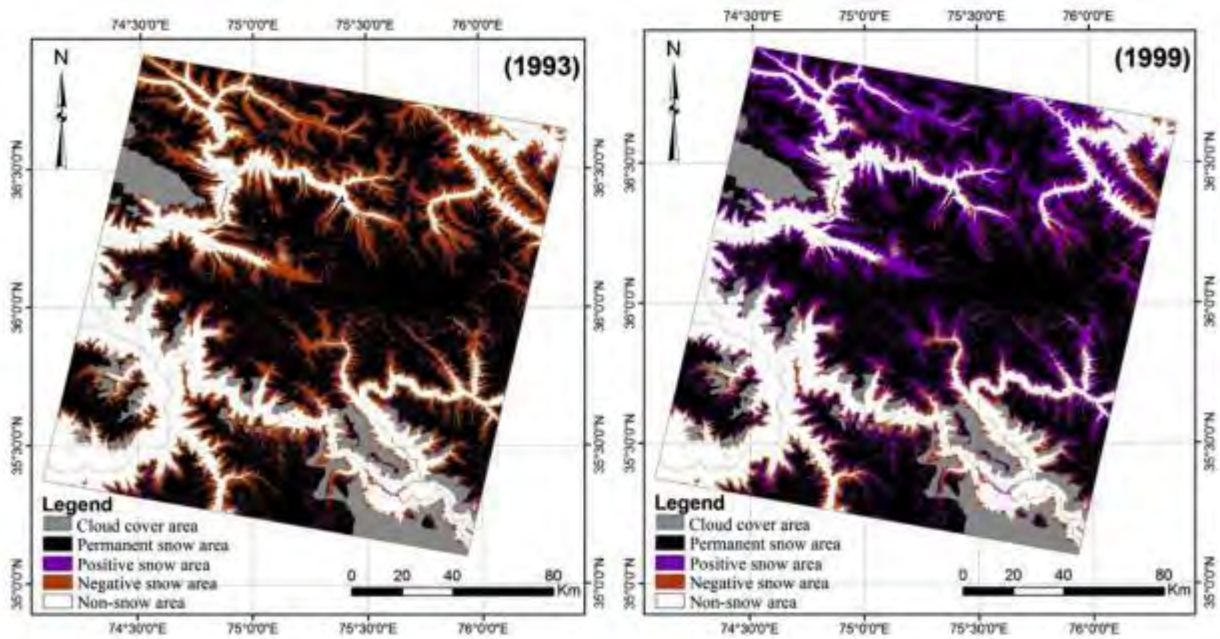

Figure 13: Comparison of snow cover, non-snow cover, Cloud cover, positive and negative snow area between 1993 and 1999. Source: [33]

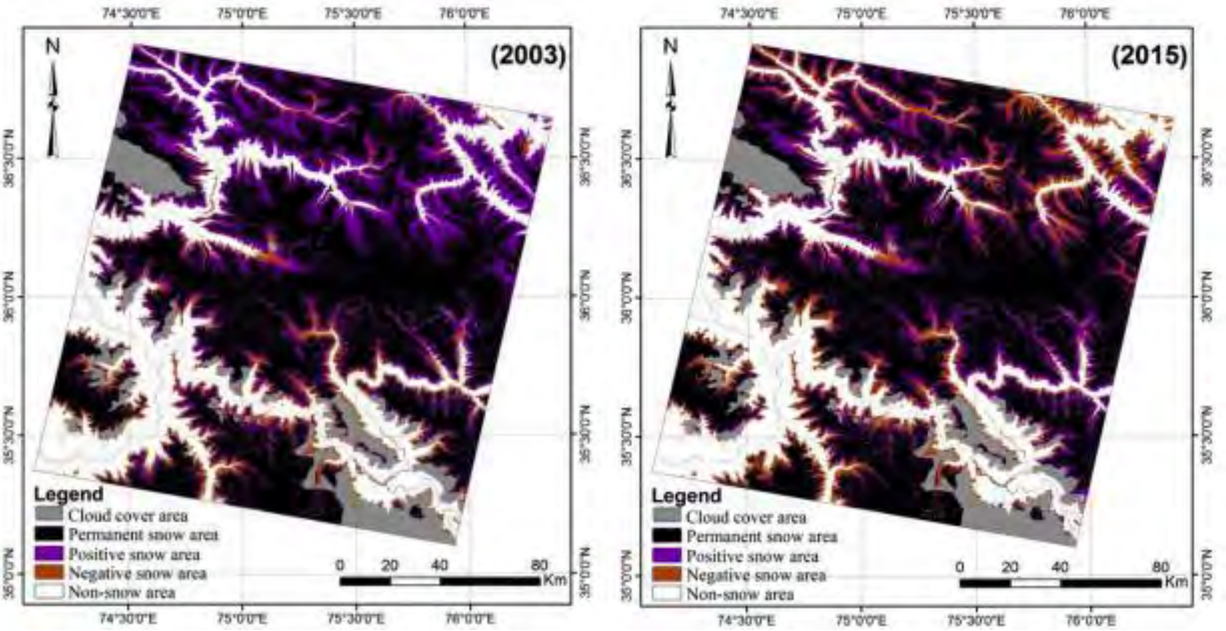

Figure 14 Comparison of snow cover, non-snow cover, Cloud cover, positive and negative snow area between 2003 and 2015. Source: [33]

Using Cloud area masking, Normalized Difference Snow Index (NDSI) threshold selection, Atmospheric correction, Land surface temperature estimation, Classification of the area, ERDAS Imagine, ArcMap, QGIS, ATCOR model, and R Statistical, [33] concluded that the snow cover in the month of April has declined to some extent during 1993–2015. [34] also indicated that Climate change has accelerated the melting of snow in the Himalayas in recent decades, creating unprecedented vulnerabilities that scientists have yet to fully understand. The researcher stated that even a one degree change in temperature can significantly change snow distribution. In places like the Himalayas, where the sensitivity to temperature change is significant, rapid snowmelt is a very critical issue.

CONCLUSIONS

The hydrology and climate of mid to high-latitude mountain environments are significantly impacted by snow cover. Depending on the criteria used to define them, mountainous regions make up roughly a quarter of the Earth's land area. There is a wide variety of topographic and cryosphere settings found in the Upper Indus Basin (UIB). From 1984 to 2020, the Upper Indus Basin was examined using Google Earth Pro to track changes in the study area's snow cover. All observations were made with the eye altitude set at 344.46 miles and the longitude and latitude set at 35º, 34', 51.79'' N and 74º, 34', 24.21'' E. It was observed that as time goes on, global warming is showing its effects and altering the climate, which has a negative impact on the region's snow and glacier availability. The images make it abundantly clear that the lower parts of the Upper Indus Basin's snow cover are more negatively impacted than the upper parts due to the difference in altitudes. The study observed that some of the areas were completely showing no snow in 2020 as compared to 1984 as time moved on with an increase in global warming in the span of 36 years. The effects of rising temperatures are being felt, leading to variations in the climate, which in turn causes a decline in the amount of snow and glaciers in the area. We are experiencing rising temperatures, an increase in the frequency of extreme weather events, and natural disasters because of climate change, all of which are caused by this delicate relationship. Increased temperatures lead to an early melting of snow, thereby influencing the availability and timing of water. It is concluded that there must be a strict policy for a reduction in carbon emissions, which are thinning the ozone layer. Additionally, the importance of reducing the factors that contribute to climate change and global warming should be highlighted.

The study is limited to the review by using Google Earth Pro. The map shows the area of the upper Indus basin within Pakistan only. The study is just covering the review period from 1984 to 2020.

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DECLARATIONS

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Conflicts of interest/Competing interests: The authors declare no conflict of interest/competing interests.

Data availability: Not applicable

Code availability: Not applicable

Authors' Contributions:

Asim Qayyum Butt: Conceptualization, Methodology, Visualization, Writing- Original draft preparation, Donghui Shangguan: Supervision, Funding Acquisition, Da Li: Investigation, Amjad Ali Khan: Writing- Original draft preparation, Writing- Reviewing and Editing, Yulong Tan: Writing- Reviewing and Editing, Muhammad Ahsan Mukhtar: Writing- Reviewing and Editing, Ali Muhammad: Writing- Reviewing and Editing, Muhammad Afzal: Writing- Reviewing and Editing, Faizan Khalid Butt: Writing- Reviewing and Editing, Liaqat Ali: Writing- Reviewing and Editing. All authors have read and approved the manuscript.

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