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A review on the implications of changing climate on the water productivity of Himalayan glaciers

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Abstract

The Himalayas are one of the important and highest mountain ranges of the world spread over several countries. The region is rich in biodiversity and water resources. It is known as the third pole because of the largest glacier and ice reserve outside the two poles. This complex zone is highly critical and sensitive to the temperature fluctuations which is clearly visible in the changing dynamics of the glaciers present in the Himalayan region. Glaciers are an ideal sensor in this highly glaciated region to detect the causes and impacts of global warming. They form the backbone of this ecosystem especially the economy which makes the studies of the glaciers and climate change more important. This paper reviews the changing climatic scenario of the region with emphasis on the impacts on the glacier reserves. Various research findings have been put forth such as changing stream flows, decreased precipitation, increased frequency of extreme climate events, glacier shrinkage, expansion of glacier lakes and the glacier lake outburst floods. This detailed review of the previous studies will help in formulating the required strategies and management practices in the Himalayan region especially the water resources.

Keywords: Climate Change; Dynamics; Glaciers; Himalayas; Indus; Rivers; Runoff; Temperature; Water Security

INTRODUCTION

The Himalayas are one of the important mountain ranges of the world having a diverse ecosystem making it more fragile and critical in the changing climatic scenario. It contains the largest snow and ice reserves after the two polar regions, hence famously known as 'third pole' (Schild, 2008), about 15000 glaciers storing more than 12000 km^3 of freshwater are present in it. Himalayas are home to World's biggest and extensive river systems; the Indus basin and the Ganga-Brahmaputra basin; a substantial portion of runoff in these rivers is contributed by the snow and glacier melt. The region is also associated with hundreds of lakes spread throughout the different Himalayan ranges; Sivaliks in the south, lower and greater Himalayas in the center and the Tibetan Himalayas in North. The anthropogenic activities have caused the global temperature to rise by about 0.8^{o}C to 1.2^{o}C, and it is expected that this rise will increase up to 1.5^{o}C by 2030 (IPCC, 2018). This warming is more on land than the oceans. Also, the change in the climate factors especially the temperature rise is responsible for changes in the precipitation, increased frequency and magnitude of extreme precipitation events, increased drought frequency, etc. (Barnett *et al*., 2005; Cruz *et al*., 2007; Xu *et al*., 2009). These changes are clearly visible

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throughout the globe with their magnitude and intensity varying with the region, its biotic and abiotic components, their interaction, biodiversity, human population and their living conditions and standards. But, on a larger time scale, some changes may lead to a more disastrous condition such as global sea-level rise.

Glaciers are an integral component of this critical region and are an indicator of the changing dynamics due to the climate change. The studies have reported the increased sea-levels and attributed it to the rising temperatures and the associated acceleration of glacier and ice melting. Since 1880, global mean sea level rise of 8-9 inches has been reported with about 1/3rd of it in last 2.5 decades. Global mean sea level rise was 3.4 inches in 2019 above the 1993 average; during 2018-2019, the global sea level rose by about 0.24 inches. These pose a risk for the environment and human lives both; and depend on the rate of temperature increase, geography of the area, development status of the region, urbanization, vulnerability of a region, and adaptation and mitigation policies. Average loss of glaciers is increasing; from 6.7 inches of liquid water in 1980s to 33 inches for 2012-2016 (Lindsey, 2020).

The shrinking of the glacier and ice mass has led to the negative impacts on the food security, water resources, water quality, livelihoods, health, well-being, infrastructure, tourism, culture, etc. The abundance of water resources and a critical set-up in the structure and functioning of the Himalayan region puts the terrestrial and freshwater ecosystems at higher risk of change and loss. IPCC (2019) recommended that the increase in global temperature must be retained well within 2°C above industrial levels and efforts must be taken to limit temperature rise to 1.5°C above pre-industrial levels. The sustainable development in the world can well be achieved if this temperature rise is contained within the set limits.

The shrinking of the glacier and ice reserves in this region since the 20th century has led to predominantly negative impacts on food security, water resources, water quality, livelihoods, health and well-being, infrastructure, transportation, tourism and recreation, as well as culture of human societies (IPCC, 2019).

The purpose of the present work is to exhaustively review the work conducted in the region pertaining to glaciers, climate change and its effects on the water productivity in the region. It is necessary to formulate an extensive inventory of the trends and results of the research conducted till date to form a basis on which the future course of action for a sustainable development of the resources in the region can be adopted.

CLIMATE CHANGE

The Himalayas have generally showed warming over the past century but, the rates vary with the region, seasons and the human living conditions and activities. The Himalayan and Tibetan Plateau region have shown warming in the last few decades at a rate higher than that in the last century (Diodata *et al*., 2011). The western Himalayas showed 0.9°C rise for 1901-2003 (Dash *et al*., 2007); and the rise was more after 1970s. The northwest Indian Himalayas reported 1.6°C warming in the last century (Bhutiyani *et al*., 2007). The same increase in max temperature and seasonal average for all seasons except monsoons was reported over the northwest Himalayas constituting the lower Indus basin (Singh *et al*., 2008). The upper Indus basin also showed increase in winter temperature for 1961-2000 at rates of 0.07-0.51°C/decade in annual mean temperature and 0.1-0.55°C/ decade in maximum temperature (Fowler and Archer, 2005), the increasing trend was observed in winter maximum temperatures as well (Khattak *et al*., 2011). Studies on the eastern Himalayas are scarce but references about the north east India are made by the various researchers and similar warming trends have been confirmed, Dash *et al*. (2007) reported rise of 1°C in maximum temperature over the whole of northeast India for 1901-2003. Of the researchers suggest the warming trends, Jhajharia and Singh (2011) showed 0.2-0.8°C/decade increase in average temperature, 0.1-0.9°C/decade in maximum temperature and 0.1-0.6°C/decade in minimum temperature, Immerzeel (2008) reported basin-wide warming trend in average temperature like global average for 1901-2002 for the Brahmaputra basin in the eastern Indian Himalaya and Tibetan Plateau. Significant increase in annual maximum and minimum temperature for reported by many researchers in the Kashmir Valley of the Himalayas (Bhutiyani *et al*., 2008; Shekhar *et al*., 2010; Romshoo *et al*., 2015; Zaz *et al*., 2019; Romshoo *et al*., 2020a)

The warming trend was also reported for the Nepalese Himalaya in the last century (Shrestha *et al*., 1999) with the high Trans-Himalayan region showing the highest and the lowland region showing the lowest; these findings were found same for those concluded by Tse-ring *et al*. (2010), also rise of 0.5°C in non-monsoon season for 1985-2002 was reported. The warming trends were reported for eastern Himalayas in China as well (Liu and Chen, 2000; Yunling and Yiping, 2005; Liu *et al*., 2006; Wang *et al*., 2008; Xu *et al*., 2008; You *et al*., 2008; Yang *et al*., 2011). The warming was more in the higher altitudes in China (Thompson *et al*., 2003; Liu *et al*., 2009; Qin *et al*., 2009); same was reported for Nepal (Shrestha *et al*., 1999) and upper Indus basin in Pakistan (Khattak *et al*., 2011). Winter season has showed higher rates of warming in most of the Himalayas (Bhutiyani *et al*., 2007. 2010; Shrestha *et al*., 1999; Shrestha and Devkota, 2010; Ali *et al*., 2019). This seasonal trend was also observed for the Tibetan Plateau (Liu and Chen, 2000; Du *et al*., 2004; You *et al*., 2008). In the Himalayan region, the highest warming rates were exhibited in the Yarlung Zangbo River basin at a rate of 0.29°C/decade followed by the northern Mt. Everest region at a rate of 0.234°C/decade) for 1971-2004; these rates are higher than the Chinese average (0.226°C/decade), the global average (0.148°C/decade) for the same period and the Indian average (0.22°C/decade) for 1971-2003 and the average for Tibetan Plateau (0.24°C/decade) for 1971-2000 (Kothawale and Rupa Kumar, 2005; Yang *et al*., 2006; Wu *et al*., 2007; You *et al*., 2007).

The projections of the temperature in the Himalayan region indicate the expected rise higher than the global average. IPCC AR4) project a median increase of 3.3°C by 2100 for the A1B SERS scenario for South Asia (Nakićenović *et al*., 2000), although these projections by GCM lack regional information, such as orographic features and summer monsoon considered extremely important in the Himalayas (Kumar *et al*., 2007; Lucas-Picher *et al*., 2011). Regional Climate Models (RCMs) refine the spatial scale and are better suited for more realistic projections in daily climatic extremes (Christensen *et al*., 2007), but the computational costs involved in RCMs are too high (Rummukainen, 2010) because of which the Himalayan region lacks a dedicated program like other regions around the globe. One of the commonly used climate models in the region is the PRECIS (Providing Regional Climates for Impacts Studies), which is based on the Hadley Centre's regional climate modeling system. The simulation shows an all-around warming over the Himalaya including Tibetan Plateau and the Indian subcontinent. The warming seems to be more pronounced over high-altitude areas in the northern parts of India, Nepal and Bhutan. Shah *et al*. (2020) concluded warmer climate in the upper Indus basin with expected projections of 2.36 degrees and 3.5 degrees under RCP4.5 scenario for 2041-2070 and 2071-2100 respectively and 2.92 degrees and 5.23 degrees increase under RCP8.5 for the two time zones.

Most of the studies (Tayal, 2019) reveal considerable warming in the whole Himalayan region especially for the later part of 21st century, with higher rates for the winter season, and greater warming in the higher altitudes; also, the most affected area was the Yarlung Zangbo river basin. The results are same for the projections as well.

CLIMATE CHANGE IMPACTS

The rising temperatures have affected the globe adversely and these are more amplified in a diverse and a critical region of the Himalayas. The impacts of the global warming have been felt on all the aspects of this complex ecosystem especially the water resources. The changes are reflected in the disrupted precipitation patterns, increased extreme climate events such as droughts, floods, altered stream flows, rapid melting of glaciers, increased glacial lakes, GLOFs etc. In this paper, the focus remains on the glaciers and their related events, as discussed in the following sections.

Precipitation

Precipitation does not show a consistent trend over a longer time frame and has inconsistencies on spatial and seasonal levels as well. This may be attributed to the influence of local thermodynamic and orographic processes (Dimri and Dash, 2011).

Bhutiyani *et al.* (2010) observed significant downward trend in monsoon and average annual rainfall in the northwest Indian Himalaya for 1866-2006, similar trend was observed for 1960-2006 over the western Indian Himalaya region (Sontakke *et al.*, 2009). A general trend of decreasing precipitation was observed in most of the regions (Guhathakurta and Rajeevan, 2008; Dimri and Dash, 2011) especially J and K and Uttarakhand while as increasing trends were observed in winter precipitation during 1961-1999 in the upper Indus Basin (Pakistan) but no long-term trend was observed for 1895-1999 period (Archer and Fowler, 2004; Fowler and Archer, 2005).

Generally, precipitation shows decrease in the western Himalayas except for J&K where, monsoon and annual precipitation is increasing. Also, winter precipitation is decreasing in the western Indian Himalaya, but it is increasing in the upper Indus Basin (Pakistan). Also, an increasing trend has been observed in the annual precipitation for the Yarlung Zangbo basin for annual, winter and spring precipitation whereas, spatially inconsistent trend for Nepal and Bhutan was reported.

Glacier Retreat and Shrinkage

Study of glaciers involves field observations, satellite imagery and photography. The Himalayan glaciers overall have reported considerable retreat over the past century except for the Karakoram region (Hewitt, 2005), the exception being because of the differing conditions in the region from the rest of the Himalayas such as orographic conditions, an all-year accumulation regime, concentration and role of avalanche, and ablation buffering due to thick debris cover.

The Western Himalayas reported retreat of glaciers through 1975-2007 (Pandey *et al.*, 2011), the study observed satellite data and imagery of 26 glaciers in the region and observed maximum retreat rate for 1989/1992-2001 period. The Nepal region also reported glacier retreat for most of the glaciers in the Dudh Koshi basin for 1976-2007 (Bajracharya and Mool, 2010). The famous Gangotri glacier in the Western Himalayas showed very high retreat rates through 1935-2005 but for the past two decades it showed relative stability (Kargel *et al.*, 2011). In 2011, a study of about 286 glaciers across the Hindu Kush, Karakoram, western Indian Himalaya, Tibetan Plateau, West Kunlun Shan, and southern central Himalaya was conducted through satellites for 2000-2008 (Scherler *et al.*, 2011), 58% of which showed stability or slow advancing and lied in the Karakoram range while as 65% of glaciers showed retreat most of which were in the monsoon-influenced regions. Most of the glaciers in the western Indian Himalayas and the northern central Himalayas and west Kunlun Shah showed retreat at high rates and it was observed that these areas had high concentration of debris-free glaciers. While as regions having higher concentration of debris cover showed relatively slower retreat rates such as in Nepal, Bhutan and the Hindu Kush. Western China showed higher retreat of glaciers especially the Tibetan Plateau where there is a large concentration of glaciers (Ding *et al.*, 2006), for the analyzed glaciers it was found that about 4.5% of their combined areal coverage was lost over the past half century. In the Tibetan plateau, central and northwest regions showed relative stability whereas the surrounding mountain glaciers showed extensive areal loss. Yao *et al.* (2007) analyzed over 600 glaciers in the Tibetan Plateau and found retreat rates increasing from 90% for 1980-1990 to 95% for 1990-2005. Mt. Qomolangma National Nature Preserve was studied for 1976-2006 and the retreat rates between -9.10±5.87 and -14.64±5.87 ma^{-1} with most retreat occurring at elevations of 4700-6400 m was observed (Nie *et al.*, 2010; Yong *et al.*, 2010). The retreating rate of glaciers was associated with the increasing temperature and decreasing precipitation in the region. Some of the glacier retreat data for the Himalayan region is given in Table 1.

Glacier area in the Nepal has shrinked considerably by 21% for 2001-2010 (Bajracharya *et al.*, 2011), shrinking and fragmentation of glaciers was more in the central Nepal and at elevations less than 3500 masl, the glaciers completely disappeared. Bolch *et al*. (2008) reported loss of ice cover throughout 1962-2005 at an average rate of 0.12% per year with a higher rate of 0.24% per year for clean ice areas. 21% of glacier area of 466 glaciers in Nepal was lost for 1962-2007 (Kulkarni *et al.*, 2007). Average glacier area loss of 16% of the 1868 glaciers studied in the Indian Himalayas was reported by Kulkarni *et al*. (2011).

Streamflow

The simulation studies conducted for this region project increased stream flows in Nepal (Fukushima *et al.*, 1991; Braun *et al.*, 1993; Shilpakar *et al.*, 2009) which increase the chances of glacier lake outburst floods (GLOF) for a 3^oC temperature rise. For a 2^oC rise in temperature, Satluj basin showed a projected increase of 18% by snowmelt and 38% from snowmelt (Singh and Kumar, 1997). Three-year simulation for Satluj river was done for temperature rise

Table 1. Glacier Retreat of some major glaciers (Gautam *et al.*, 2013)

Glacier	Region	Period	Average Rate (m/yr)	Researcher
Gangotri	Western Indian Himalayas	1935-1971 1971-2004 2004-2005 2006-2010	-26.50 -17.50 -12.10 Stable	(Bali *et al.*, 2011) (Bali *et al.*, 2011) (Kumar *et al.*, 2008) (Kargel *et al.*, 2011)
Kangriz	North West Indian Himalayas	1910-2007	Stable	(Raina, 2009)
Siachin	North West Indian Himalayas	1862-1909 1909-1929 1929-1958 1958-1985 1985-2004 2004-2005	15.42 -02.50 -14.00 Stable -03.00 Stable	(Ganjoo, 2010)
Imja Glacier	Eastern Himalayas	1976-2000 2000-2007	-34.00 -74.00	(Bajracharya and Mool, 2010)
Langdak	Western Himalayas	1976-2000 2000-2007	-09.00 -44.00	(Bajracharya and Mool, 2010)
Rongbuk	Mt. Qomolangma Nature Reserve	1960-2000	-07.50	(Yao *et al.*, 2007)
Middle Rongbuk	Mt. Qomolangma Nature Reserve	1976-2006 1966-1997 1997-2001	-14.64 -08.70 -09.10	(Nie *et al.*, 2007) (Ren *et al.*, 2004)
East Rongbuk	Mt. Qomolangma Nature Reserve	1976-2006 1966-1997 1997-2001	-09.10 -05.50 -05.56	(Nie *et al.*, 2010) (Ren *et al.*, 2004)
Reqiang	Mt. Qomolangma Nature Reserve	1976-2006	-65.95	(Nie *et al.*, 2010)
Naimonanyi Glacier	Western Nepal Himalayas	1976-2006	-04.80	(Yao *et al.*, 2007)

of 1-3^{o}C (Singh and Bengston, 2004), the basin showed reduction in melt in snow-fed basin but increase in glacier-fed basin. For 2004-2040, Rathore *et al*. (2009) reported 40% reduction in glacier extent, 5-19% reduction in snow extent, and 8-28% reduction in seasonal streamflow for 1°C temperature rise. The changing climate will result in short term increase in flows in most of the Chinese rivers attributed to accelerated glacier melting (Yao *et al*., 2007). Stream flow has indicated high sensitivity to temperature rise in the glacier-dominated regions (Zhang *et al*., 2011).

Rees and Collins (2006) predicted that the heavily glaciated catchment s showed increased stream flows of 150% and 170% of initial flow in 2050 and 2070 before complete disappearance of glaciers in 2086 and 2109 respectively in the west (Batura) and east (Langtang) glaciers. Immerzeel *et al*. (2009) projected decrease in flows by 8.4% in Indus, 17.6% in Ganges, and 19.6% in Brahmaputra basins in 2046-2065 compared to 2001-2007 highlighting the importance of glacier melt contributions. Immerzeel *et al*. (2011) projected glacier shrinks and retreat (32% by 2035 and 75% by 2088) in the central and eastern Himalayas resulting in reduced glacier melt contribution to streamflow; however, the loss in glacier melt contribution is compensated by increased baseflow and runoff leading to an increase in total runoff of 4 mm/year.

Most of the studies on the Himalayan glaciers give account of lumped meltwater (snow and glacier melt combined) contribution to streamflow (Kumar *et al*., 2007; Singh *et al*., 2008; Immerzeel *et al*., 2010; Kaser *et al*., 2010) which leads to several contradictory conclusions by the researchers. For a better understanding of the impact of climate change on glaciers, glacier melt, and total melt water should be distinguished clearly; also, considerations need to be given to the variations in different seasons.

The changing climate poses the risk of flooding especially in the Brahmaputra River Basin and Koshi Basin. The increased events of flooding increase the sediment load of rivers which adversely affects the water quality, human health, agriculture, and hydraulic structures. Increased temperatures indicate an increase in evapotranspiration which will ultimately lead to drier catchments. Higher rates of glacier melting along with reduced snowfall will reflect upon decreased glacier mass. These impacts on the glaciers will reflect in a longer time frame and cause damages that are irreversible in nature.

Glacier Dynamics

Researchers have observed that the glacier mass is more sensitive to the climate change than the areal extent of the glaciers. The glacier mass responds to the temperature fluctuations more quickly than other parameters such as flow rate and length which have longer response times (Kargel *et al*., 2011). It has been observed that the response time of Himalayan glaciers vary from 10-200 years (Kargel *et al*., 2011; Thompson *et al*., 2011). The data of the glaciers from the field directly has many limitations and hence is not sufficient to infer the decadal changes and projections.

Glacier retreat depends on precipitation, albedo, temperature, debris cover, slope, aspect, elevation etc. (Koul and Ganjoo, 2010; Venkatesh *et al*., 2011; Scherler *et al*., 2011). Debris plays an important part in the retreating rates, it slows down the retreat and such glaciers are relatively stable (Bolch *et al*., 2011; Scherler *et al*., 2011). Due to the dependence on these different parameters and the complexity, the response of glacier retreat is not quick and cannot be counted as a direct response of the changing climate, whereas the glacier mass (volume) directly responds to the climatic variations and can act as an ideal indicator (Haeberli and Hoelzle, 1995; Kargel *et al*., 2011). Number of researchers have reported decreasing mass of the glaciers throughout the Himalayas.

Mount Everest has been losing glacier mass since 1970 (Bolch *et al*., 2011). The accumulation of mass in most of the Himalayan glaciers in Nepal and China have stopped since 1950 (Kehrwald *et al*., 2008). Thinning of glaciers is distinct in the lower elevations (Bertheir *et al*., 2007).

Most of the glaciers depicted retreat with many of them losing on their mass and net accumulation. Hindu Kush glaciers are relatively stable or have low rates of retreat; Northwestern Himalayas, Karakoram and Pamir have shown mixed observations with retreat generally observed in Pamir; Western India, China and Nepal show varying rates of glacier retreat; eastern Nepal, Bhutan, Sikkim and southeast part of Xizang province of China are associated with large glacial lake formations since 1960 (Watanabe *et al*., 2009) due to the disintegration of many glaciers. Abdullah *et al*. (2020) concluded that the glaciers in the upper Indus basin have thinned at the rate of − 0.35 ± 0.33 m/a which amount to the glacier stored water loss of 70.32 ± 66.69 Gt during 2000-2012. Romshoo *et al*. (2020b) also observed substantive recession of glaciers in the upper Indus basin for 1980-2018.

GLOF

Glaciers are often associated with glacier lakes. Due to the melting and glacier retreat, for the past century, there has been enormous increase in the formation of moraine-dammed glacial lakes (Evans and Clague, 1994; Bajracharya and Mool, 2010).

In comparison with the western Himalayas, the eastern Himalayas has huge number of glacier lakes. It has been a common observation of the researchers that from 1960-2001 the number of glacier lakes has increased tremendously, and the existing lakes have grown in their size (Bajracharya and Mool, 2010). Kulkarni *et al*. (2011) reported five-fold increase in Lonak Lake for 1976-2007; in Mt. Qomolangma Nature Preserve in China, Yong *et al*. (2010) reported 64.7% increase in glacial lakes for 1976-2006. Global warming creates a favorable environment for expansion of existing glacier lakes and formation of new lakes. These moraine dam lakes pose a great risk to human life and property depending upon the local topography, geological, and glaciological processes (Watanabe *et al*., 2009; Reynolds and Taylor, 2004). They release massive amount of water in a destructive way without giving any buffer time.

CHALLENGES

The present paper focuses on the important research pertaining to the Himalayan glaciers in the light of climate change. An exhaustive survey of the literature highlights some important points which will help in drafting sustainable management practices of the water resources in the region. It is clearly deduced from the survey that the whole Himalayan region exhibits warming trends at varying rates depending on the topography and other climatic conditions and decreasing precipitation along with increased frequency of extreme climate events. Since, this region is highly glaciated, it has been suggested by most of the researchers that these glaciers can be an indicator of the global warming. Glaciers are highly sensitive to the temperature variation especially the glacier mass. It has been observed that throughout the Himalayas except for Karakoram, the glaciers report considerable loss in their areal extent as well as their mass/volume. This change is reflected in the short-term increased stream flows. But the projections indicate drier basins in the longer run which will affect the humans adversely. One more phenomenon associated with these glaciers is the expansion of glacier lakes which pose greater threat to the habitations in the mountain regions. The number of glacier lakes has showed drastic increase especially in the eastern Himalayas, these are mostly moraine-dammed lakes which are susceptible to outbursts and are a threat to human life and property.

It can clearly be inferred by the previous studies that the region which at present is rich in all types of natural resources especially the water reserves has started to show signs of water stress. It has been deduced that the zone may soon fall under the category of water scare zones. The increased population, ever increasing urbanization leads to the increase in energy and water demands which will substantially stress the natural reserves in the region.

This stress will be clearly visible in the financial status of the region, energy sector and the overall development patterns. It will have a degrading impact on the water productivity of the zone and the ecological aspects.

The studies reveal that although the studies on the glaciers in the Himalayas have been taken up, but an updated inventory and the subsequent inferences need to be validated properly in order to contain the drastic impacts that the climate change can reflect upon by way of change in the glacier extent and dynamics.

SUGGESTIONS

The extensive study of the results obtained till date can be rightly used to suggest some major points for the study area.

The increasing water demands in the area requires the energy sector to judiciously utilize the resources adopting a comprehensive approach. Water conservation and a sustainable management is a must to deal with the water stress imposed in this region due to various factors. The region needs to focus on the development of water harvesting techniques as an important technique to address climate change scenario. Integrated watershed development approach is the need of the hour.

An elaborate and updated inventory of the glaciers and their present status is a must to elaborate on the impacts of warming on their glacier dynamics and the effect it imposes on the water productivity of the region. Environmental Impact Assessment of all of the water projects in the region will help in retarding the adverse impacts on the climate and help in tackling the issue of water in this critical region.

In addition to the water stress, the increasing temperatures lead to rapid melting of glaciers and an increase in the stream flows, this temporary increased trend is a major cause of the increase in the intensity and frequency of floods which pose a greater threat to the environment and humans. It is necessary to adopt integrated and sustainable management programs in the region. In view of the importance of glaciers in the region’s economy and growth, it is the need of the hour to incorporate glacier modules in the soil assessment techniques in the region to integrate the glacier response in the studies of the region.

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