CLIMATE CHANGE AND VARIABILITY IN MOUNTAIN REGIONS OF PAKISTAN IMPLICATIONS FOR WATER AND AGRICULTURE

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Abstract:

This *paper analyzes climate variability in the mountain areas of Pakistan covering winter dominated high mountain region and monsoon dominated sub-mountain region and on the bases of these analyses, discusses implications for water and agriculture for the country. Trend analyses of the historical data for the period 1971-2000 show that winter season temperatures have increased in both sub-mountain and high mountain region during the past 30 years. Relatively higher increase in maximum winter temperatures was observed, whereas minimum temperatures during winter showed a slight decline. These results suggest that days have become warmer whereas nights have become cooler during the winter season in the high mountain areas. Monsoon temperatures (particularly maximum temperatures) have also increased in both the regions. More interestingly, maximum temperatures in the transitional periods "October-November" and "April-May" particularly in the high-mountain areas are at a rising trend. All these changes and seasonal variations have important implications for water resources and agriculture in the mountain areas in particular and for Pakistan in general.*

The results indicate that the maximum temperatures have increased all around the year particularly in the high mountain region during the last 30 years. Winter temperatures have increased in both sub-mountain and high-mountain regions during this period. Rainfall has also increased in both regions. The paper concludes that the increasing trends in temperature in the high mountain areas may have some positive impact on crop area and yields. However, these rising temperature trends may increase the melting of glaciers and snow, reduce snow accumulation during winter and enhance the overall de-glaciations process and therefore could well endanger the country's sustained sources of fresh water from glaciers and snow melting. Detailed analysis is however recommended to assess the impact of climatic variability and change on water and agriculture in the mountain areas.

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Introduction:

Global climate change means change in the climate of the Earth as a whole, whereas climate change is a shift in the "average weather" that a given region experiences over a long period of time (30 years or so). Climate variability here refers to variations in the mean state. These are measured by changes in all the features we associate with weather, such as temperature, wind patterns, precipitation, and storms.

Particularly, the temperature on earth is regulated by a system known as the "greenhouse effect", a phenomena through which the green house gases primarily carbon dioxide, methane, and nitrous oxide together with water vapor trap radiation from the sun preventing it from dissipating back into space. While the green house gases naturally occur in space, as without these the average temperature on the earth would be -18°C instead of the current average of 15°C and life on earth would be impossible, the concentration of these green house gases since the Industrial Revolution has significantly increased e.g., carbon dioxide has increased by 30 percent, methane by 145 percent, and nitrous oxide by 15 percent.

By increasing the amount of these heat-trapping gases, the natural greenhouse effect has enhanced to the point that it has the potential to warm the planet at a rate that has never been experienced in human history. Already, the IPCC work over the last ten years suggest that the average global temperature has increased by 0.6 °C since industrial revolution, and that future change in global average temperature is expected in the order of 1.4 °C – 5.8 °C over the 21'st century (IPCC 2001). These increases in temperature will have considerable impact (both positive and negative) on various socio-economic sectors e.g., water, agriculture, health, forestry, biodiversity etc.

Understanding of climate change impacts on mountains is vital as mountains cover 20% of the Earth's surface, are home to 10% of the world's human population, and provide 50% of the freshwater consumed by humans for irrigation of crop lands, industrial use and home consumption. They are storehouses of genetic diversity that help feed the world. Furthermore, mountain areas provide essential resources such as timber, minerals, and recreational escapes. World's 845 million chronically undernourished people live in mountain areas. Mountain environments are, however, under severe threat as climate change and various other factors (e.g., deforestation, overexploitation of natural resources and unsustainable agricultural practices) are leading to irreversible natural resources degradation in the form of erosion of top soil, loss of vegetative cover and loss of overall biodiversity. When mountain forests are cut unsustainably or too much land is cleared for farming, ranching or mining, the water that normally flows into mountain watersheds washes over barren slopes. The resulting erosion leads to land degradation and increases the threat of deadly avalanches, landslides and flooding. As fertile soil and forests are lost, water runoff increases, rivers and water reservoirs begin to silt up, resulting in to reduction in overall water availability, degradation of overall ecosystems and loss of overall biodiversity (including extinction of species of plants and animals, genetic biodiversity and habitats).

Life for most mountain people will get even harder with the advent of climate change and variability as it is expected to further disrupt mountain environments. The sensitivity of mountain ecosystems to climate change is particularly high because of their fragile nature, topography, steep gradients, and diversity of ecosystems. For example mountains will become more dangerous as rising temperatures enhance melted permafrost and glacial run-off that in turn would accelerate soil erosion as well as the likelihood of falling rocks, landslides, floods and avalanches. Extreme events and catastrophes are predicted to become more and more common. Warming trends would also force many species to migrate uphill in search of habitat and mountain people too will have to adapt to changes – or leave their homes as traditional sources of food and fuel grow scarce.

Many mountain peoples depend upon agriculture for their livelihoods, but climate change could have an adverse impact on farming. Irrigation will be affected, first by floods and then by drought, making survival harder for subsistence farmers as well as those who grow cash crops both in these mountain areas as well as in the lower catchments.

Mountain areas due to their fragile nature are prone to small changes in climate, i.e., temperature and precipitation. The purpose of this paper is to analyze climate change and variability in the mountain areas of Pakistan with a focus on changes in temperature and rainfall in these areas. On the basis of these analyses, implications for water and agriculture for the mountain area and lower catchments will be assessed.

Climate Change Impacts in World's Mountains – A review

The greatest and most unpredictable risks in the mountain areas are expected to come from more frequent extreme events, such as forest fires, floods, avalanches, and landslides. These extremes are already becoming more and more common in the mountain areas and have threatened the world forests. These extremes have also enhanced severe water losses due to changes in evaporation and precipitation patterns, and caused water needs to outstrip supply (IPCC 2001).

There is now substantial evidence that glaciers in most of the World Mountains are melting due to increases in temperatures in the mountain areas, and if current trends continue, many of the world mountain glaciers will have vanished entirely by the end of this century. The famous snow-capped peak of Mount Kilimanjaro (Tanzania) has already lost some 82% of its permafrost since 1912 - and a third of this in the past two decades (Global Mountain Summit, 2002). In Montana, Glacier National Park's largest remaining glaciers are now only a third as large as they were in 1850, and one study estimates that all glaciers in the park may disappear completely in the next 30 years (US Environmental Agency, 2000). Glaciers in the European Alps and the Caucasus Mountains have shrunk to half of their size, while in Africa only 8 percent of Mount Kenya's largest glacier remains. Researchers have documented rapid mountain glacier retreat in Greenland, Ecuador, Peru, Venezuela, New Guinea, and East Africa, among other places (Mountain Partnership, 2004).

Study by Rees and Collins (2004) indicates that glaciers in the Himalayas are receding faster than in any part of the world and the likelihood of their disappearing by the year 2035 is very high at its current rate. This impact will be observed more in the western Himalayas as the contribution of snow to the runoff of major rivers on the western side is about 60 - 70% compared to only 10 % on the eastern side (IPCC 2001).

The increased rate of glacial melting in Himalayas has caused vast lakes to develop, and if these lacks outburst, these can inundate towns and villages below. UNEP scientists, working with experts from the International Centre for Integrated Mountain Development (ICIMOD) based in Kathmandu, have used satellites and on-the-ground studies to pinpoint 44 glacial lakes in Nepal and Bhutan that are now so swollen, that they could burst their banks in as little as five years (UN 2004). Similar lakes are also being studied by National Agricultural Research Centre (NARC) and ICIMOD in the Himalayas region of Pakistan. Changes in the depth of mountain glaciers and in their seasonal melting patterns will have an enormous impact on water resources particularly in Pakistan as the country's 70% of fresh water resources are met from these glaciers and snow melting in the high mountain areas of Himalaya and Hindu Kush.

Rising temperatures may also cause snow to melt earlier and faster in the spring, shifting the timing and distribution of runoff. These changes could affect the availability of freshwater for natural systems and human uses, such as agriculture. With temperatures warming considerably in winter, precipitation will fall more as rain than as snow. Less water, then, is stored and available during water-deficient times later in the year. Most of this rainfall will run off immediately. Increased run-off during the winter and spring months can increase the risk of landslides and flooding (both in the mountains and downstream). Furthermore, if freshwater runoff is reduced in the summer months because of earlier snow melting, soils and vegetation may become drier, increasing the risk and intensity of wildfires. It will also affect vegetation cover, disrupt agriculture and threaten overall biodiversity. Mountainous areas may experience more intense bursts of heavy rains in the summer; any resulting run-off would carry more sedimentation and soil nutrients than snow melt. It is also likely that the variability of precipitation of the Asian summer monsoon will increase.

Increasing temperatures may have a positive impact on agriculture in the mountain areas, for instance through shortening of growing period for the winter season crops. Winter crops (e.g. wheat) in the high mountain areas, do not even reach to maturity in most cases and as such the crop is harvested premature and used as fodder. The shortening of the growing season length due to rising temperature could be beneficial in the mountain areas as it would help the winter crops in timely maturity and as such would allow the crop to mature in the optimal period of time, with beneficial effects on crop area and yields (Hussain & Mudasser, 2004). Past temperature trends in the high mountain areas (e.g., Chitral district) have already led to the shortening of the growing season length which certainly has helped in increasing wheat yield as well as crop area in these high mountain areas (Hussain and Mudasser, 2004). Moreover, future increases in temperature would probably make it possible to grow two or more crops per year due to the shortening of the growing season length for winter crops at higher elevations in the mountain areas (Rosenzweig and Hillel, 1995 and Hussain and Mudasser, 2004). In the high mountain areas (e.g., Chitral district) the practice of only one crop per year is prevalent on almost half of the arable land due to low temperatures (IUCN, 2004).

Mountains of Pakistan:

Geographical Location

Pakistan is located within the latitudinal and longitudinal extensions of 24 to 37°N and 61 to 76°E respectively. The country has Arabian Sea to the south and high mountains in the north. Northern mountains comprise parts of the western Himalayan and Karakoram ranges with a small part of the Hindukush range. Pakistan is the only place where these three great mountain ranges meet. Besides the northern mountains, there are western highlands separated by Kabul river from the mountainous north and consist of series of dry and lower hills. The eastern half of the country is mostly dominated by the flood plains of the river Indus and its tributaries viz. Jhelum, Chenab, Ravi and Sutlej rivers. Parts of Balochistan and Sindh provinces constitute deserts (Sheikh and Manzoor, 2004).

Study Area

This paper covers the northern mountainous and sub-mountainous regions of Pakistan which covers parts of Himalayas, Karakurum and Hind Kush ranges. For the purpose of our study, we have classified these mountains in two regions as follows:

High mountain region - between 35 to 37°N: Comprises the high mountains of Himalayas, Karakurum and Hind Kush.

Sub-mountain region - between 31.5 to 35°N: Comprises sub-mountainous ranges located along the southern slopes of western Himalayan and Hindu Kush mountains.

The high mountain region is mostly winter rain dominated, whereas the sub-mountain region is summer rain dominated (Sheikh and Manzoor, 2004). These two regions are the main source for water in the country. The winter rains are brought during December to March due to the western disturbances passing along the path between 30 - 60°N, whereas monsoon rains are caused by lows and depressions developing in the Arabian Sea and Bay of Bengal during July to September (Sheikh and Manzoor, 2004).

Data Sources and Methodology:

Monthly data on temperature and rainfall covering the period from 1971-2000 was used. The data was obtained from Pakistan Meteorological Department. The study areas covered 9 meteorological stations in high mountain region and 6 stations in sub-mountain region as shown in Table 1.

Table 1: Meteorological Stations Covered in the Study Area

High mountain region (between 35 0N to 37°N)	Average Altitude above Sea Level (meters)	Sub-mountain region (between 31 0N to 35°N)	Average Altitude above Sea Level (meters)
Skardu	2210	Balakot	981
Astor	2168	Garhi Dupatta	813
Gupis	2165	Muzaffarabad	702
Chitral	1500	Kotli	615
Drosh	1465	Islamabad	508
Gilgit	1460	Sialkot	253
Bunji	1372		
Dir	1370		
Chilas	1251		

Trend analyses were conducted separately for temperature and precipitation using the following relationship.

Y = b0 + b1t + b2D + b3SD + e

Where

Y	=	Temperature (0°C) or Precipitation (mm)
t	=	Time as trend variable
D	=	Dummy variable (Above 35°N = 1, otherwise = 0)
SD	=	Slope Dummy variable for trend variable Above 35°N
(SD = t * D)		
b0…b3	=	Coefficients to be estimated
e	=	Error term

Results and Discussions:

Climate Variability in the Mountain Areas

Thirty year average monthly temperatures covering the period 1971 – 2000 reveal that sub-mountain regions obviously were hotter than the high mountain region through out the year, except during the monsoon period (July – September) where both the regions experienced almost the same mean monthly temperatures (Figure 1). Sub-mountain region also received higher

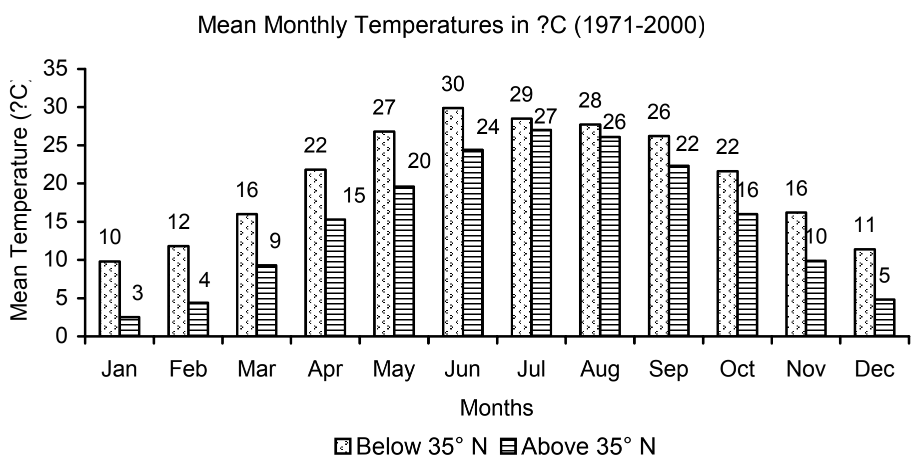

Figure 1: Mean Monthly Temperatures in the Sub Mountain and High Mountain

rainfall in all the months and much higher in the monsoon period compared to

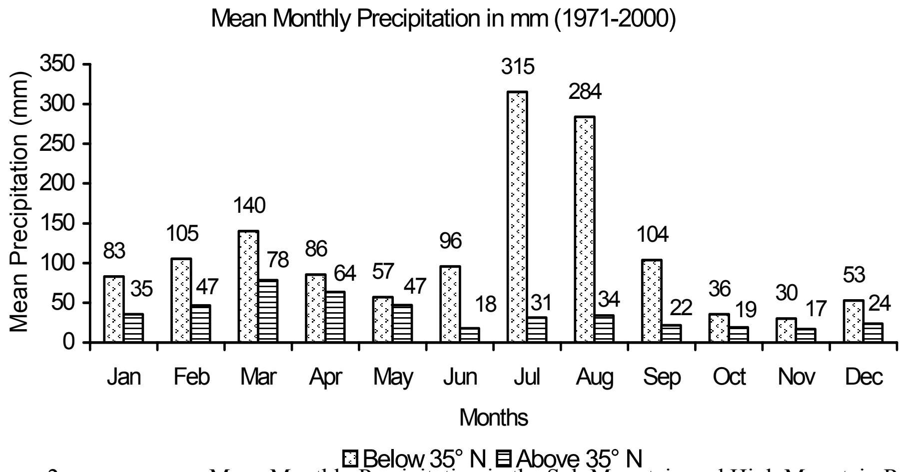

Figure 2: Mean Monthly Precipitation in the Sub Mountain and High Mountain Regi

the high mountain region (Figure 2).

Regression Results

Separate regressions were fitted for average, maximum and minimum temperatures as well as annual average rainfall using data for the period 1971 – 2000. Similar regressions for temperature and rainfall were also fitted for the average temperatures and rainfall, each for the four different seasons of the year viz. monsoon (July – September), winter (October – March), transitional period-1 (April-May) and transitional period-2 (Oct-Nov)]. The results are presented in Table 2. The slope co-efficient in the all the regressions was found statistically highly significant. Slope dummy separating the high mountain region and sub-mountain region trends was not statistically significant in almost all the regressions, suggesting that trends in the two regions in the study period were statistically not different from each other.

Temperature trends:

Average annual temperature was observed to be about 5 °C higher in the sub-mountain region compared to high-mountain region. The regression results suggest that annual average temperatures have declined over the last 30 years both in the sub-mountain and high-mountain regions. But the magnitude of these declines is very small: -0.02 °C and -0.25 °C in the sub-mountain and high-mountain regions respectively (Table 3). Average annual maximum temperatures have also declined in the sub-mountain region (-0.08 °C) but show an increasing trend (0.33 °C) in the high-mountain region. On the other hand average annual minimum temperatures have increased in the sub-mountain region but show an opposite trend in the high-mountain region. These results suggest that on average, mountain regions have got cooler during the last 30 years.

However, trend analysis for various seasons provides a different picture. The monsoon and winter seasons temperatures have increased in the sub-mountain region by 0.11 °C and 0.21 °C respectively. Winter temperatures have also increased in the high mountain region by 0.46 °C but a slightly declining trend could be observed in the monsoon period in this region. These results suggest that on average the winters have become hotter in both the region. On the hand, summers have become relatively hotter in the sub-mountain region but slightly cooled down in the high mountain region.

Another interesting trend was observed for the transitional period temperatures. Temperatures in both the transitional periods (October-November) and (April-May) show declining trends (-0.26 °C and -0.42 °C respectively) in the sub-mountain region. On the other hand, temperatures in April-May period (that proceed the winter seasons) as well as maximum temperatures during October-November (that generally reflect noon temperatures) show an increasing trend in the high mountain areas. These results point towards an onset of early summers in high-mountain region.

Precipitation trends

Regression trends for precipitation (Table 2) suggest that in the sub-mountain region, precipitation has generally declined in all the seasons except during winter season where an increasing trend was observed. On the other hand, precipitation has increased throughout the year in the high-mountain region.

Summary of Regression Results

In summary, the trend analyses suggest that winter temperatures both in sub-mountain and high-mountain regions have increased during the period 1971 – 2000 (Chart-1). Monsoon temperatures (particularly maximum temperatures) have also increased in both the regions. More interestingly, maximum temperatures in the transitional periods “October-November” and “April-May” particularly in the high-mountain areas are also rising. All these changes and seasonal variations have important implications for water resources and agriculture in the mountain areas in particular and for Pakistan in general.

Chart 1: Summary of temperature trends in the sub-mountain and high-mountain regions

Regions	Temp	Oct-Nov	Winter	April-May	Mon-soon	Annual
High Mountain Region	Average	- - - -	++++	- - - -	- - - -	- - - -
Sub Mountain Region		- - - -	++++	- - - -	++++	- - - -
High Mountain Region	Maximum	++++	++++	++++	++++	++++
Sub Mountain Region		- - - -	++++	- - - -	++++	- - - -
High Mountain Region	Minimum	- - - -	++++	- - - -	- - - - -	- - - -
Sub Mountain Region		++++	++++	- - - -	++++	++++

- - - - Indicates a decline in temperature; ++++ indicates an increase in temperature

Table 2: Regression Results Regarding Temperature and Precipitation in High Mountain and Sub Mountain Regions

Dependent Variable	Intercept	Time (Trend)	Intercept Dummy for Above 35° N Region	Slope Dummy for Above 35° N Region	R^2
Average annual Temperature	20.649	-0.001*	-5.368	-0.008	0.4994
Average annual maximum Temperature	27.397	-0.003*	-5.749	0.014	0.4743
Average annual minimum Temperature	13.900	0.002*	-5.001	-0.030	0.4945
Average monsoon Temperature	27.992	0.004*	-2.679	-0.027	0.2193
Average maximum monsoon Temperature	34.042	0.002*	-1.770	0.000	0.0800
Average minimum monsoon Temperature	21.932	0.008*	-3.547	-0.058***	0.3327
Average winter Temperature	12.109	0.007*	-7.108	0.008	0.6222
Average maximum winter Temperature	18.561	0.008*	-8.244	0.020	0.6235
Average minimum winter Temperature	5.654	0.007*	-5.927	-0.005	0.5713

Average April-May Temperature	24.519	-0.015*	-6.879	0.004	0.5354
Average maximum April-May Temperature	31.727	-0.008*	-7.531	0.012	0.5058
Average minimum April-May Temperature	17.312	-0.020*	-6.150	-0.011	0.5320
Average Oct-Nov Temperature	19.051	-0.009*	-5.918	-0.002	0.5416
Average maximum Oct-Nov Temperature	27.327	-0.027*	-6.791	0.031	0.5186
Average minimum Oct-Nov Temperature	10.781	0.008*	-5.035	-0.036	0.4835
Annual Precipitation	116.524	-0.021*	-84.759	0.309	0.5794
Monsoon Precipitation	822.287	-1.534*	-731.699	2.427	0.7639
Winter Precipitation	376.384	0.412*	-210.031	0.862	0.1832
April-May Precipitation	145.136	-0.185*	-45.974	0.894	0.0273
Oct-Nov Precipitation	58.616	0.373*	-36.058	0.483	0.0765

Table 3: Percent Change in Temperature and Precipitation in High Mountain and Sub Mountain Regions during 1971

	Change in Temperature in °C 1971-2000	
Seasons	Sub-mountain Region	High-mountain Region
Temperature		
Average annual	-0.02	-0.25
Maximum annual	-0.08	0.33
Minimum annual	0.05	-0.8
Average Oct-November	-0.26	-0.31
Maximum October - November	-0.78	0.13
Minimum October - November	0.24	-0.79
Average winter	0.21	0.46
Maximum winter	0.23	0.82
Minimum winter	0.21	0.07
Average April-May	-0.42	-0.32
Maximum April-May	-0.24	0.11
Minimum April-May	-0.58	-0.9
Average monsoon	0.11	-0.68
Maximum monsoon	0.07	0.07
Minimum monsoon	0.24	-1.45
Precipitation	mm	mm
Annual	-0.61	8.34

Oct-Nov	10.82	24.82
Winter	11.94	36.93
April-May	-5.37	20.55
Monsoon	-44.48	25.89

Implications for Water Resources:

Glaciers and snow in the high mountain regions of Himalayas and Hindu Kush feed the Pakistan's Western and Eastern rivers, and which largely forms the country's 70% of the fresh water resources. The glaciers of our region are however under severe threat due to rising temperatures associated with climate change. Study by Rees and Collins (2004) suggests that glaciers in Himalayas are receding faster than any part in the world and if the present rate continues, the likelihood of their disappearing by the year 2035 could be very high.

Our analysis in this paper points towards rising temperature trends in the high mountain areas which could have serious implications for our fresh water resources. Particularly, the increasing trends in maximum temperature during all the periods of the year in the high-mountain areas of Pakistan must have increased the melting of snow and glacier in these areas. More importantly, increases in temperatures in the winter season might have negatively affected snow accumulation in these high mountain areas, and increasing maximum temperatures during April-May and in the subsequent periods might have accelerated the depletion of snow and glaciers in these areas. This phenomenon of the melting of snow and glaciers needs a thorough investigation and is beyond the scope of this study. But a point that is made here is that temperatures in the high-mountain areas are rising which could well enhance the de-glaciation processes in these areas and could endanger the country's sustained sources of fresh water resources.

A rising trend in rainfall both in the high and sub-mountain areas might bring some beneficial effects in the mountain area. However, being highly fragile and numerous anthropogenic factors are already causing land degradation in the mountain areas, increased rainfall could enhance the land degradation process in these areas through surface run off, soil erosion, and land slides. This could also add to the increased sedimentation loads downstream, reducing the storage capacity of our limited reservoirs and eventually could decrease water for irrigation systems in the country.

Implications for Agriculture:

Unlike water, positive benefits are expected due to increases in temperature in the high-mountain areas. Recent research conducted by Hussain and Mudasser (2004) has already shown that rising temperatures during the winter season has caused shortening of the Growing Season Length (GSL) for wheat crop in Swat and Chitral districts. This shortening of the GSL has a positive impact on wheat yield in Chitral valley located in the high-mountain areas, but has a negative impact on wheat yield in Swat valley located in the sub-mountain region.

Lack of time-series data on yields precludes us to do similar analysis for the whole of mountain region. Nonetheless, the rising trends in temperature particularly in the winter season and in the subsequent transitional period of April-May as observed in our analysis for the high-mountain region provides sufficient evidence that wheat yields and other similar winter crop yields (e.g. barley) could well be benefiting from rising trend in temperatures. Future increases in temperature would increase the possibility of growing probably two or more crops per year in the mountain areas. Wheat crop area might also expand in these high mountain areas above 1,500 meters altitude because the corresponding shortening of the GSL would make it possible for wheat crop to reach to its maturity. [Until recently, wheat crop above 1,500 meters in most years does not reach to timely maturity as such was prematurely harvested for fodder production].

Conclusions and Recommendations:

Temperatures have increased in the high-mountain region of Pakistan during the last 30 years. These increases in temperature may have some positive implications for agriculture in the high-mountain areas. However, these temperature increases could well affect the country's sustained fresh water resources in the long run through accelerated melting of glaciers and snow in the high mountain areas. Detailed analyses would however be required to assess the impacts of these climatic changes in the mountain region.

An integrated adaptation strategy needs to be developed to cope with negative impacts and to reap the positive impacts of climate change. Among others, early warning and relief systems need to be developed (to closely monitor and do some remedial measures) for mitigating the negative impacts e.g., glacier outfalls, land slides etc. Efficient water management technologies need to be introduced and agricultural research need to evolve crop varieties that are suitable for the mountain areas under the changing climatic variations.

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