AN ANALYSIS OF SPATIO-TEMPORAL TEMPERATURE VARIABILITY IN UPPER INDUS BASIN, PAKISTAN.

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ABSTRACT: This study was aimed at exploring the temperature fluctuations in the Upper Indus Basin (UIB) and to find any correlation between the temperature fluctuations with the flow of the Indus water. Correlation between summer temperature and runoff of Indus at Besham Qilla gauging station was performed in Statistical Package for the Social Sciences (SPSS), while the map of decadal difference of mean annual temperature in UIB for the period of 1980-2010 was prepared in Arc Geographic Information Systems (GIS) 9.0. The results proved a negative correlation between the two variables of summer temperature and runoff, with a Pearson Correlation value of -.004, in the middle elevation basins of ephemeral snow of UIB. The decadal temperature variance map proved that extreme northern UIB lies in region experiencing decadal variance between -0.30°C to 0.16°C. The map also indicated a 0.4°C rising trend of temperature in areas around Kakul and Astore. This rising trend could lead to increase flow and sedimentation rates of Indus. Such fluctuations in temperature trends of UIB were critical since this region served as the freshwater reserve of our country.

Key words: Decadal Temperature variance, Upper Indus Basin, Geographic Information Systems (GIS), Climate change, runoff.

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INTRODUCTION

Pakistan has an agrarian economy which depends on the flow of the mighty Indus River. Temperature, as a meteorological variable, controls the factors which have an impact on the timing and amount of runoff being generated in Upper Indus Basin. UIB contributes the maximum to the flow of Indus River, on which the agricultural and power sectors of Pakistan mostly rely (Tahir *et al.*, 2015). Glacial melt and seasonal snowmelt plays a vital role in shaping the hydrograph of the UIB (Savoskul and Smakhtin, 2013). In a study Archer (2003) highlights the significance of summer mean temperature in the sub-catchments of UIB, by mentioning that in the high altitude regions of UIB, the summer mean temperature is highly correlated with summer runoff.

In this region, most of the runoff and resultant sediments are derived from the melting of ice and snow. The magnitude and timing of flow and the amount of sediments that Indus carries, are vulnerable to the changes in temperature of UIB (Archer and Fowler, 2004). Although the annual temperature of this region is rising, however the summer temperature (July-Sep), which is critical for glacial melt, has continued to decline in various valley stations of Karakoram, during 1961-2000 (Fowler and Archer, 2006). Mean air temperature decides the amount of precipitation and evapotranspiration which in turn controls the runoff that contributes to the main rivers of the UIB (Savoskul and Smakhtin, 2013).

Climate change as a phenomenon affects temperature which has an impact on the melting of ice and snow, rainfall, amount of runoff generated, and patterns and timing of sediment fluxes in the UIB. The mean and minimum summer temperatures show a decline during 1961-2000, while winter mean and maximum temperatures presented a considerable increase (Fowler and Archer, 2005). A general temperature trend has been reported to increase by the end of 21st century (Akhter *et al.*, 2008).

Increase in temperature in UIB results in increased evaporation which leads to limiting of the snow cover and thus reduced runoff. An increase in Diurnal Temperature Range (DTR), in all the seasons in UIB, has been recorded which leads to great variability of climate in UIB (Fowler and Archer, 2006).

Skardu experienced a rise in mean annual temperature of 1.4° C through the last century. Critical is the fact that the winter temperature rose more than the summer temperature, i.e. up to 0.51˚C in winter maxima per decade since 1961(Jilani *et al.*, 2007). Such shifts in temperature can lead to a 400m upward shift of the frost line. Such shift trend in temperature has an impact on the amount of inflow of the major rivers and the sediments that will be eventually reaching the Tarbela reservoir, built downstream.

MATERIALS AND METHODS

The study area chosen for this research was part of Upper Indus basin lying within Pakistan. The time period was from 1980-2010. The main aim of this study was to explore the temperature trend fluctuations in the UIB and to find any correlation between the temperature fluctuations with the flow of the Indus. These objectives were achieved with the help of finding Correlation between summer temperature and runoff of Indus at Besham Qilla gauging station and preparing map of decadal difference of mean annual temperature in UIB for the period under study. The meteorological stations from where the data was acquired from Pakistan Meteorological Department (PMD) for this study were Astore, Chilas, Bunji, Skardu, Gilgit and Kakul. Limitation of this study was that instead of runoff data for UIB, discharge data of Indus being gauged at Besham Qilla was used. For temperature data, the six meteorological stations data, available for this research, was used generally on the entire UIB region, within Pakistan.

Decadal mean annual Temperature difference: The map of decadal difference of mean annual temperature in UIB was made using the following steps. The decadal mean values of temperature in UIB were calculated for 1980-2010, in excel. Then the values were fed in the attributed table of Arc GIS in which the location of six meteorological stations was shown with the help of point shapefile. The mean temperature values of each decade were entered against each station. Later three different surfaces of mean annual rain for UIB and KPK were developed using Inverse Distance Weighted (IDW) interpolation technique and lastly raster calculator was used to calculate a single interpolated surface that presented the three decadal mean temperature differences for UIB and KPK, with the help of the following equation:

$$DTD = (D2 - D1) - (D3)$$

Where,
DTD = Decadal Temperature difference
D1= Decade 1
D2= Decade 2
D3= Decade 3

RESULTS AND DISCUSSIONS

Correlation was performed using 16 years data set, i.e. from 1993-2010, between summer temperature and runoff in snow fed catchment of UIB in middle elevation basins. The Pearson Correlation value is -.004, i.e. a negative correlation between summer temperature and runoff in snow fed catchment of UIB in middle elevation basins. Since significance was .988, and $p > \alpha$, therefore the null hypothesis was accepted, according to which there was negative correlation between summer temperature and runoff in middle elevation basins of UIB, i.e. as the temperature increased the runoff decreased (figure-1).

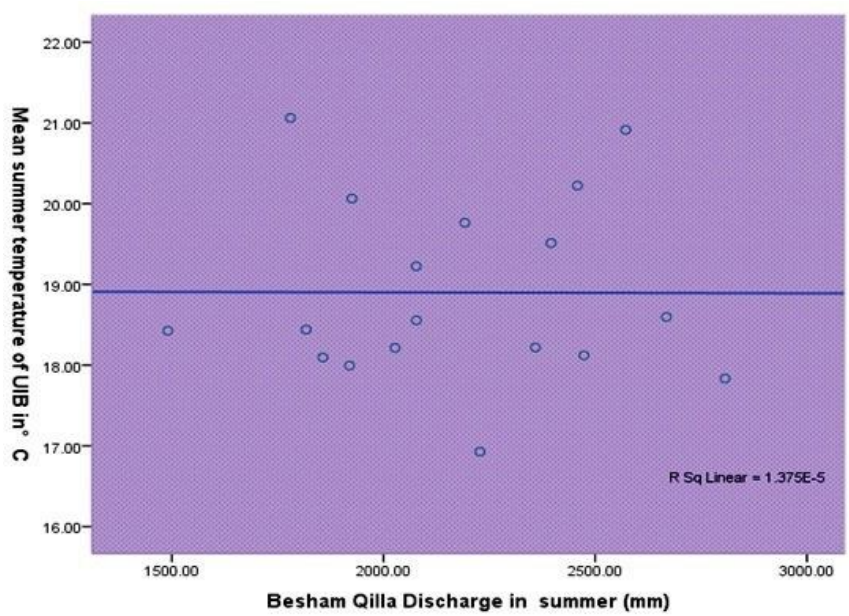

Figure-1. Correlation between Summer Temperature and Runoff in Snow fed catchment of UIB in middle elevation basin.

Decadal Difference of Mean Annual Temperature: The decadal difference of temperature in northern areas of Pakistan and KPK for the time period of 1980-2010, is shown through figure-2. The final resultant map presented the fact that major mean temperature difference over the three decades, i.e. from 1980-2010, was experienced by Bunji, (figure-2) i.e. a difference from -1.4 to -0.30 °C, almost 0.11°C difference. This was a huge difference for a station located at the south of major glaciers of Pakistan.

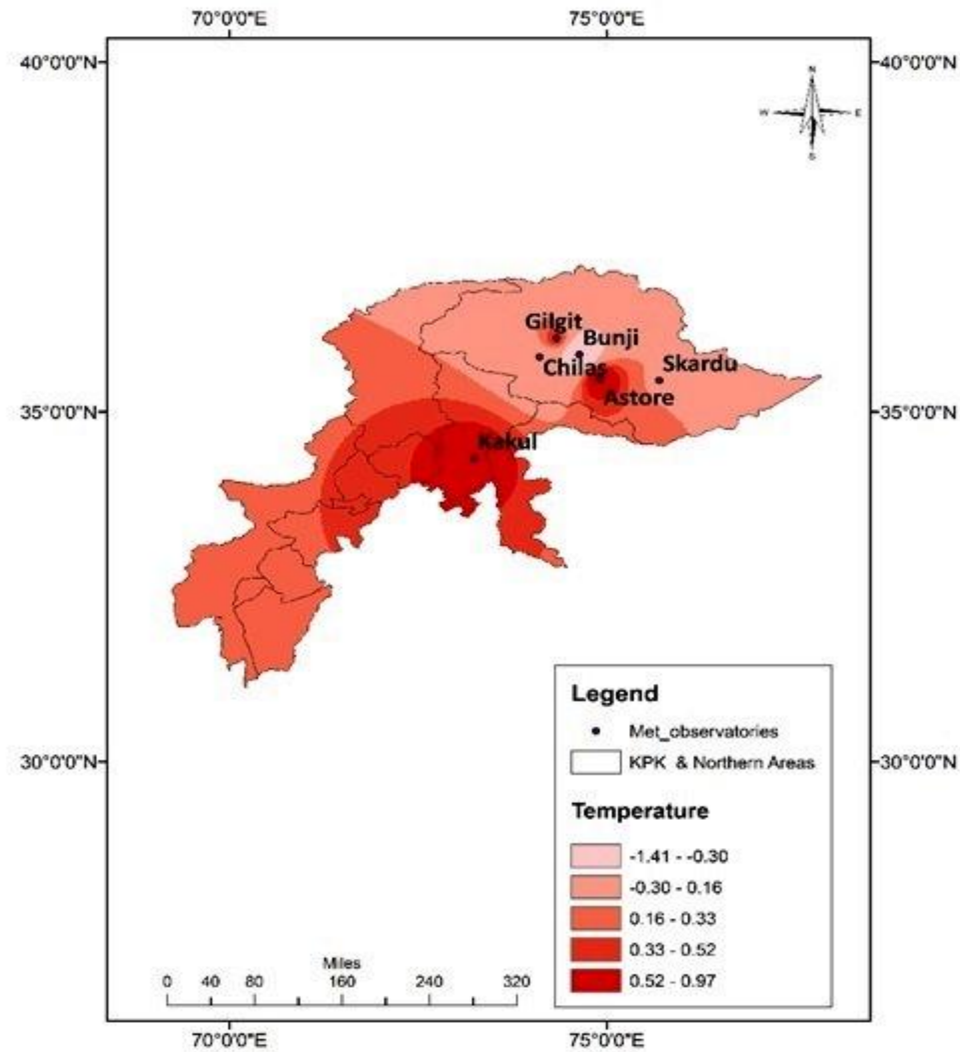

Figure-2. KPK and Northern Areas of Pakistan, Temperature Decadal Difference, 1980-2010

The map further presented the temperature rising trend ranging from 0.52-0.97°C in areas around Kakul and Astore. This 0.4° rising trend over the three decades meant more warming in these stations which would definitely prove greater snow melt, that would lead to increase in inflow and hence rise in sedimentation.

Comparison of Mean Temperature Decade wise in °C, 1980-2010: The decadal average temperature maps of KPK and Northern areas of Pakistan are presented through figure-3. During 1992-2000, the micro region experiencing 7-13°C of temperature was covering more area than its counterpart in 2001-2010. In decade two, i.e. 1990-2000, eastern most area of UIB surrounding Astore and Skardu, fell in the zone experiencing 11-13°C, while in 2001-2010, this area shrank and the zone of temperature 13-16°C expanded and surrounded this zone of 11-13°C, indicating more warming. In decade 1, the eastern section of the temperature zone experiencing 11-13°C was also surrounded by 13-16°C zone. Thus we can sum up by saying that the climate in north eastern UIB was warmer in 1980-1990, and then slightly became milder in 1991-2000 and again warmer in 2001-2010.

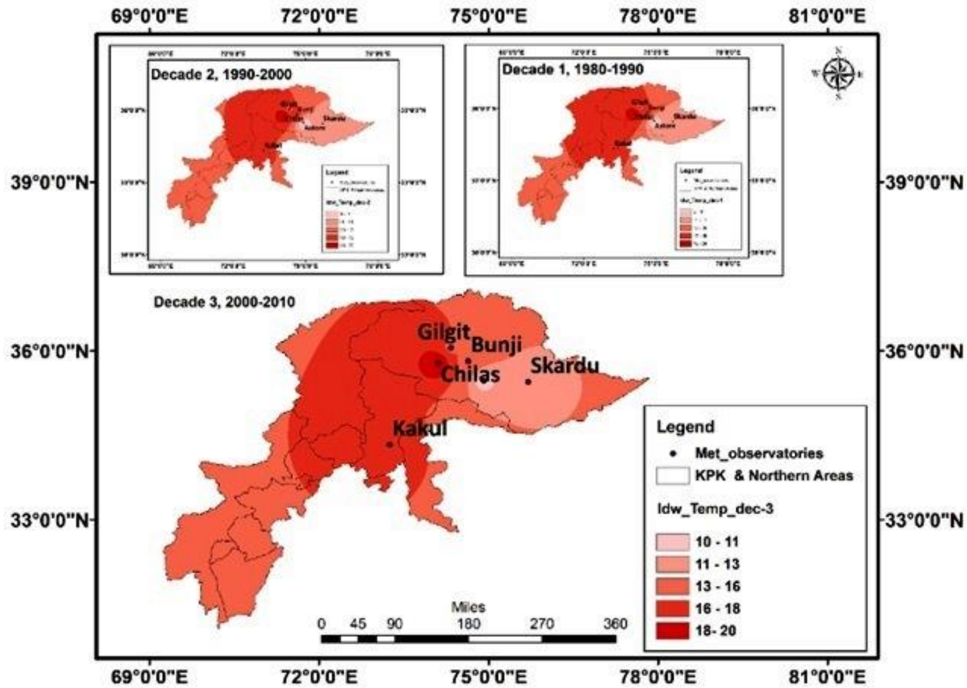

Figure-3. KPK and Northern Areas of Pakistan, Temperature Decade wise Mean Temperature in °C, 1980-2010.

The result of the Pearson correlation was -.004, which proved the null hypothesis i.e. negative correlation was proved between summer temperature and runoff in middle elevation basins of UIB, i.e. as the temperature increased the runoff decreased (figure-1).This hypothesis could be supported by the finding of Singh and Bengtsson (2005), who reported an increase in evaporation loss due to increase in mean temperature of snow fed catchment. This in turn resulted in reducing runoff as the snow cover volume also decreased. The results of the present study are also in line with the findings of (Archer, 2003) who reported a negative correlation between temperature and runoff in the middle-altitude catchments.

The results of this study can also be supported by the findings of (Khattak *et al.*, 2011), who indicated an increasing trend in the winter maximum temperature of this region and with the finding of (Yadav et. al, 2004) who indicated a steady increase in the maximum temperature trend throughout the last century. The Inter government Panel on Climate Change also reported on the same warming trend of this region in their report (IPCC 2007a). Such warming might prove to be critical for this region where huge population is dependent on irrigation based agriculture (Immerzeel *et. al*., 2010).

Conclusion and Recommendation: The results of Pearson correlation proved a negative correlation between summer temperature and runoff in the middle elevation basins of UIB. The temperature decadal difference map (figure-2) concluded a temperature variance of -1.41°C to -0.30°C, experienced by areas around Bujni, for the period 1980-2010. A 0.4°C rising trend of temperature in areas around Kakul and Astore was witnessed, which would lead to increase in inflow and sedimentation. Extreme northern UIB lied in region experiencing decadal variance between -0.30°C to 0.16°C. Therefore, it can be suggested that smaller dams must be built in this region which might prove helpful to prevent flood and reduce the bulk of sediments transfer to the major reservoir, Tarbela, built downstream. Further research must be carried out on the relationship between the rise in winter mean temperature and the runoff produced in higher elevation regions of UIB.

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