MONITORING DECADAL PRECIPITATION VARIABILITY IN UPPERINDUS BASIN, PAKISTAN

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ABSTRACT: Upper Indus Basin (UIB) is critical for Pakistan's economy as it is glacial in composition and snow melt that provides 80% of the fresh water to Indus River. Decadal fluctuations in the precipitation in UIB during 1980-2010, using interpolation technique in Arc Map were explored in present study. The results provided a positive correlation between the winter precipitation and summer runoff in middle elevation basins of UIB. The map of decadal difference of mean annual rainfall (1980-2010), prepared in Arc Geographic Information System 9.0, revealed that around Gilgit, Skardu, Astore, Chilas and Bunji, was found the least difference in mean annual rainfall, *i.e.* of -1.68 to-2.14mm, whereas area around Kakul experienced maximum rainfall decadal difference ranged from -13.63 to -17.45mm. The study suggested that south of lesser Himalayan areas experienced maximum rainfall variability during the period 1980-2010, whereas, lesser variability in north of Himalayan areas inferred safer addition in fresh water in Indus from its glacial reserve.

Key words: Climate change, rainfall variability, sediments and snow cover.

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INTRODUCTION

The flow of the rivers in Pakistan especially at Indus depends on glacial melt and seasonal snowmelt in the UIB.Therefore changes in precipitation have a strong impact on the flow magnitude and timing of this major river of Pakistan (Fowler and Archer, 2006; Archer and Fowler, 2004).The melt water from glaciers and seasonal snow provides the freshwater, essential for Pakistan's irrigation and power production (Hasson *et al.,* 2013). The magnitude and timing of stream flow is affected by initial snowpack and varying temperature trends (Sharif *et.al;* 2013). Variations of climate in the Himalayan arc affect the mass balance of glaciers and placement of snow and ice, which in turn has an impact on the river regimes and sediment generation. Most of the precipitation in the Himalayan region occurs in the winter and arises from the westerly disturbances. The mean monthly temperatures from Oct to March are below freezing, thus no direct runoff from rain occurs during these months (Tate and Farquharson, 2000).Melting of ice and snow provides most of the runoff and resultant sediments to this river (Archer and Fowler, 2004). West Himalayan ranges act as a barrier to the monsoons, however, the western disturbances bring a lot of snow that gets entrapped in the nesting grounds of glaciers in UIB (Savoskul and Smakhtin, 2013). However, not all the rain that falls in summer can be associated solely to the monsoons (Wake, 1989).

The small area that lies exactly towards the north of Tarbela, is subject to south west monsoons. The slower responding snowmelt runoff, superimposes this runoff, caused by monsoons. Snowmelt provides runoff from April-October, while monsoons usually provide runoff during July and August. The peak flow at Tarbela due to snowmelt can be as high as 11300 m^3 s^{-1}, however a rainfall contribution can cause a maximum flow of 5660 m^3 s^{-1}(Tate and Farquharson, 2000).An increase in winter, summer and mean precipitation from 1961-1999 for several stations in UIB was reported by (Fowler and Archer, 2006).

Middle elevation basins in UIB are highly significant as this is from where according to Sharif *et.al;*(2013) the melt of seasonal snow comes from, which inturn contributes significantly to the runoff of the Indus. Significant basins in middle elevation include Astore, parts of Upper Indus and Jhelum basins.

Farhan *et al.*, (2014) significantly mentioned that at lower elevated basins in UIB the runoff created by snow-melt and spring peak flows were going through major change. This is where even the winter temperatures were found to be closer to melting point. The authors also mentioned that more of precipitation was falling as rain rather than snow in UIB, in recent years.

The main area left undiscovered while reporting the variations in decadal precipitation variability is its mapping, which would provide an immediate visual image of these significant variations that have a strong impact on the hydrological regime of this region. This study aims to fill this gap.

MATERIALS AND METHODS

The study was planned to monitor the changes in precipitation of UIB in the past thirty years i.e. 1980-2010 and to link these shifts of precipitation variability with the flow of Indus.In order to prove strong positive correlationbetween the winter precipitation and summer runoff in middle elevation basins of UIB, multiple line graph was prepared in Microsoft Excel and Pearson Correlation was performed in Statistical Package for the Social Sciences (SPSS).

The data of mean monthly rainfall was obtained for the six meteorological stations of Astore, Chilas, Gilgit, Kakul, Skardu and Bunji, from the Pakistan Meteorological Department, Lahore.The map of decadal difference of mean annual rain in UIB was prepared based on the methodology adopted by Mazhar*et.al;*(2015). The decadal mean values of rain in UIB for 1980-2010 were calculated in excel, then fed in the attribute table of Arc Geographic Information System (GIS). The mean values of decadal rainfall for each decade were entered against each of the six stations. Three different surfaces of mean annual rain for UIB and Khyber PakhtoonKhwa (KP) were developed using Inverse Distance Weighted (IDW) interpolation technique. Raster calculator in Arc GIS was used to calculate a single interpolated surface that presented the three decadal mean rainfall difference for UIB and KP (Mazhar*et.al;* 2015).There is a certain limitation of this study that instead of runoff data for UIB, discharge data of Indus being gauged at BeshamQilla was used. For precipitation data, the six meteorological stations data, was applied generally on the entire UIB region, within Pakistan.

RESULTS AND DISCUSSION

A positive correlation between winter precipitation and summer discharge in higher elevation basins of UIB was observed(Figure-1).

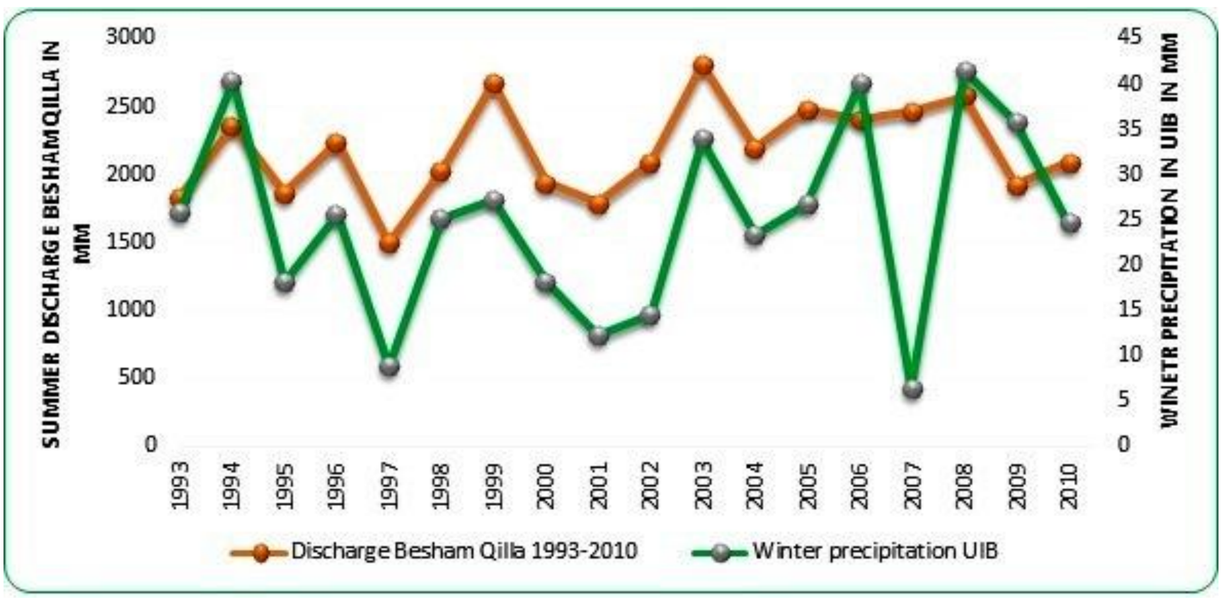

Figure 1:Comparison between Winter Precipitation and Summer Discharge

Almost in all the years the crests and troughs of winter precipitation and discharge of Indus, gauged at BeshamQilla, coincided, which proved that a greater accumulation of winter precipitation led to greater summer melting and thus greater summer discharge.

Pearson correlation in SPSS was applied to the same data set of winter precipitation and summer discharge, to affirm the finding (Figure-2). The Pearson Correlation value for this test was .518, so there was a positive correlation between the winter precipitation and summer runoff in middle elevation basins of UIB. Correlation was significant at 0.05 level. The test was performed using 17 years data set, from 1993-2010.

Comparative line graphs (Figure 3 and 4) proved that almost during all the years the rise in snow covered area and rise in mean annual rainfall in UIB coincided with the rise of inflow, coming into Tarbela reservoir built downstream. In 1984, 1992, 1999, 2006 and 2010 (Figure 3) higher precipitation in UIB coincided with greater bulk of freshwater that came into the Tarbela reservoir. Similarly in 2003, 2005 and 2006 (Figure 4), the higher snowfall in UIB coincided with the higher inflow in Tarbela reservoir.

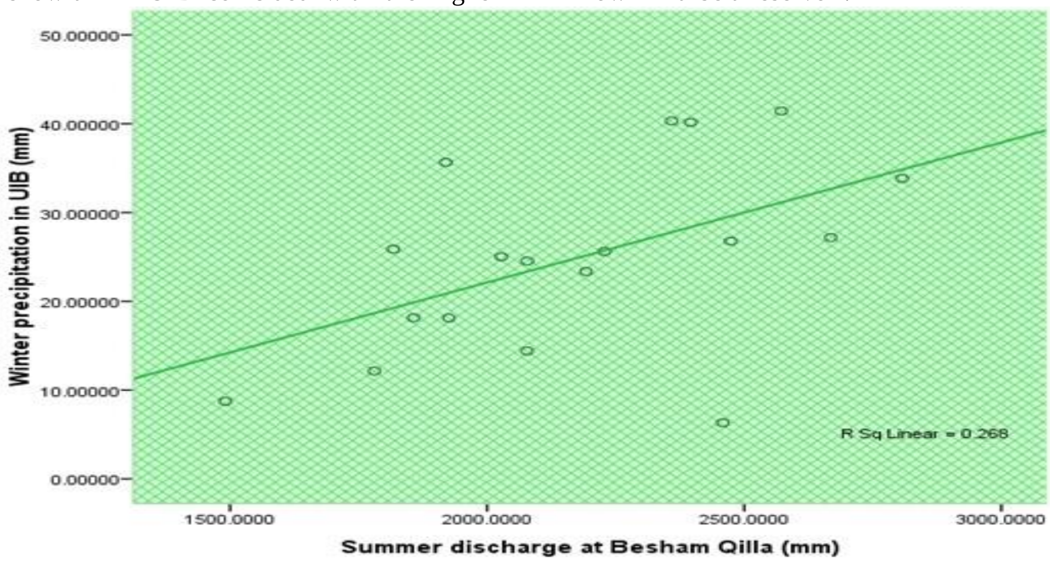

Figure2:Correlation between Winter Precipitation and Summer Runoff

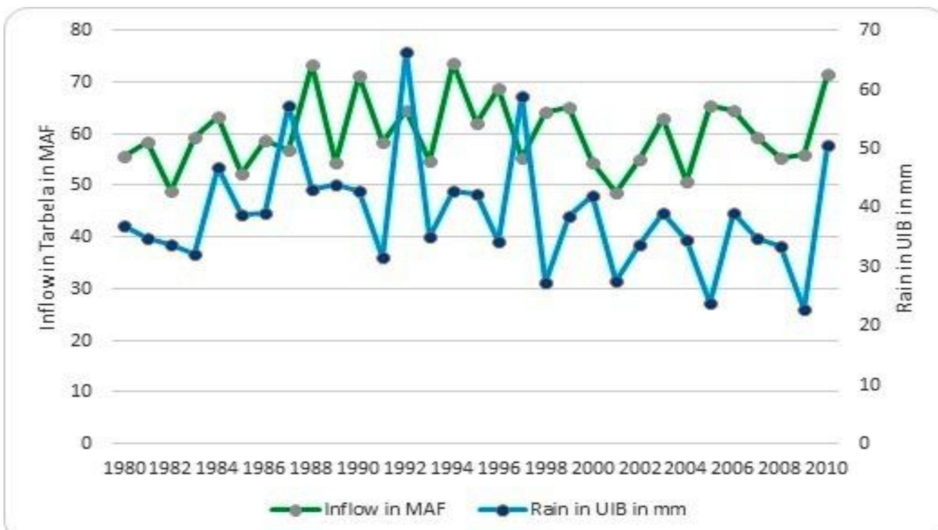

Figure 3: Comparison of Mean annual Rainfall in UIB and Inflow in Tarbela

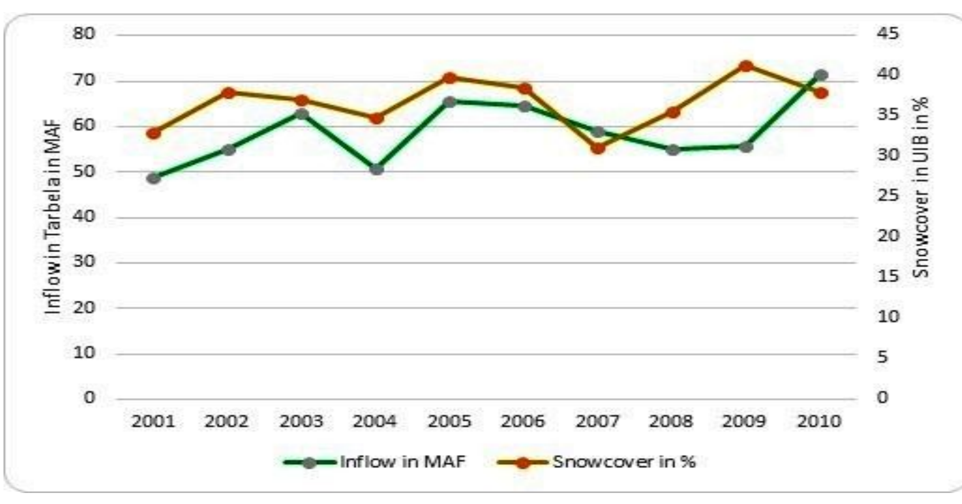

Figure 4: Comparison of Snow cover in UIB and Inflow in Tarbela

The decadal difference of rainfall in northern areas of Pakistan and KP for the time period of 1980-2010, is presented (Figure 5). Minimum difference in mean annual rainfall *i.e.* of -1.68- -2.14mm was experienced in broader area around.

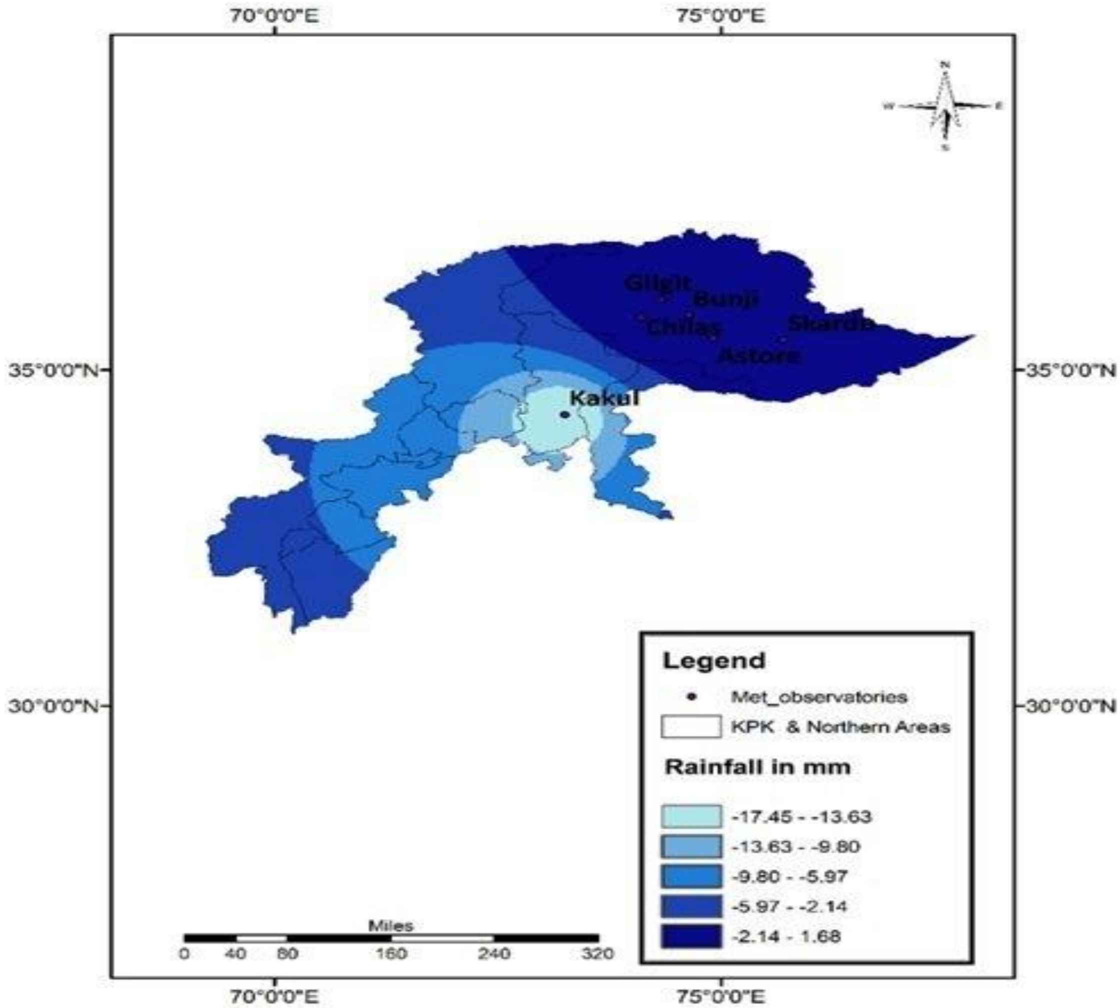

Figure 5: KP and Northern Areas of Pakistan, Rainfall Decadal Difference

meteorological stations of Gilgit, Skardu, Astore, Chilas and Bunji, which covered the entire north eastern portion of Pakistan. Contrarily, Kakul experienced maximum rainfall decadal difference ranging from -13.63 to -17.45 mm. It was concluded that over the decades maximum rainfall variability was experienced in the areas south of Lesser Himalayas, and the rainfall variability over the decades decreased from south to north.

The results of present study were in line with the finding of Fowler and Archer, (2005) who stated that winter precipitation in UIB and the summer runoff in the basins that had a middle elevation,were positively correlated.

The results were also in accordance with the findings of the study of Tahir *et.al;* (2015) according to which the discharge of UIB was more dependent on snow and glacial melt of northern region, than on rainfall generated runoff of southern region.

Correlation between winter precipitation and summer runoff in middle elevation basins of UIB was presented in (figure 2). Middle elevation basins in UIB were chosen for this comparison as this was from where according to Sharif *et al.,* (2013) the melt of seasonal snow came from, which in turn contributed significantly to the runoff of the Indus. Dimri and Chevuturi, (2014)mentioned in their study that UIB received the bulk of its precipitation in spring and winter, which came from the western disturbances.The findings of (Akhtar *et al.* 2008) were also in accordance with the findings of the present study where the authors reported a precipitation increase in UIB in their study.

An increase in winter, summer and mean precipitation from 1961-1999 for several stations in UIB was reported by (Fowler and Archer, 2006). Similar increase in snow covered area in UIB had been reported by Space and Upper Atmosphere Research Commission (SUPARCO, 2013) i.e. an increase of 191813 km^2 in snow cover of UIB, in February 2013. Archer and Fowler (2004) also reported a slightly higher trend in the precipitation of this region.Treydte*et al.,* (2006) reported that the last century was the wettest in the last millennium for UIB. Gemmer*et al.*, (2003) reported a precipitation increase for the period 1951-2002, in Xijiang and Jammu Kashmir. The above mentioned works were in line with the findings of the present study that concluded a highly significant addition of freshwater from the northern part of UIB, as compared to non-significant addition from the southern part of UIB, in the Indus. However, Bhutiyani*et al.,* (2010) reported an increasing yet insignificant trend in winter precipitation for the period 1866-2006, in North Western Himalaya (NWH). The annual precipitation in NWH presented a decreasing trend for the study period.

Conclusion and Recommendation: The decadal rain difference map showed that there was decadal decrease of about -13.63 to-17.45 mm at Kakul which lied in the south ofUIB, which caused a decrease in the flow of Indus being contributed from southern part of UIB. Areaaround Gilgit, Skardu, Astore, Chilas and Bunji were found to experience least difference in mean annual rainfall for the period 1980-2010, i.e. of -1.68 to -2.14m. It could be concluded that lesser variability of rainfall, over the decades proved a safer addition in the fresh water reserve for Indus from its northern part and hence a less variable addition in the inflow of Indus.

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