FREQUENCY OF EXTREME TEMPERATURE & PRECIPITATION EVENTS IN PAKISTAN 1965-2009

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ABSTRACT: The frequency of extreme temperature (maximum and minimum) and precipitation events have been analyzed from 1965-2009 for Pakistan located with in South Asia. The real time long-term data spread over 45 years for temperature (maximum& minimum) and precipitation has been used to calculate the frequency of extreme temperature and precipitation events in Pakistan. The thresholds for all the regions have been defined on the basis of percentile to investigate maximum, minimum temperature and precipitation extremes. The statistical significance of temperature extreme events has been evaluated through F-Test and for precipitation extreme events K-S Test has been applied at 95% confidence interval. The extreme temperature (maximum & minimum) events analysis showed that the frequency of extreme maximum temperature events is increasing throughout the country. However a well marked increase has been seen in Northern Areas, Southern Punjab, Sindh and Balochistan making these regions vulnerable to future extremes. The frequency of extreme minimum temperature events are significantly decreasing in Northern Areas, Southern Punjab, Sindh and Balochistan while rest of the country showed insignificant increase in extreme minimum temperature events. The frequency of extreme precipitation events investigation has shown evident increase in all the regions of Pakistan. The significant increase in extreme precipitation episodes has been observed in Azad Jammu & Kashmir, Sindh , Northern Areas and Balochistan at all thresholds except that the events at 98th percentile has not been found in Northern Areas and Balochistan. It has been noticed that the southern half of the country is now experiencing more wet spells in the recent years under the influence of changing climate and global warming.

Key words: Extreme events, temperature, precipitation, diurnal temperature range and frequency.

INTRODUCTION

Global warming is the serious threat for the human civilization in the recent era. The abrupt changes are occurring in the world's climate at an unprecedented rate principally as a consequence of anthropogenic activities. Now there is a global consensus among the scientists around the world that climate is changing and warming is due. The increase in intensity and frequency of extreme events in different parts of the world is more pronounced in the last two decades of the 20th century. These extreme events have gained lots of attention in recent times due to massive economic losses. However, there is a doubt about there occurrences as few regions have become extremely vulnerable to these events while others are non vulnerable [1]. The temperature extremes at both ends either hot or cold and intensive precipitation frequency have increased not only in Alps but also in low lying region during the 20th century [2 &3]. The European states have also reported increase in their average winter heavy precipitation events and temperature extremes in 21st century [4]. The trend analysis of heavy precipitation is also showing marked increase in Italy according to [5]. The warming of climate system is unequivocal as indicted by increases in average global temperature, snow melting, rise in sea levels and frequent occurrence of extreme events according to Fourth Assessment Report (AR4) of Intergovernmental Panel on Climate Change (IPCC). They will lead to climate related disasters like hurricanes, droughts, floods, heat waves, cold spells, landslides and cyclones etc. There is an evidence of prominent increases in the intensity /frequency of extreme events in the Asian region. In particular, climate models indicate temperature increases in the Asian region on the order of 0.5-2°C by 2030 and 1-7°C by 2070. Temperatures are expected to rise more rapidly in the arid regions of northern Pakistan, India and western China [6].

The trends of temperature extremes from 1961-2000 depicts that the warming has occurred at the cold and the warm tails in Central & South Asia. [7]. The significant increase in annual number of warm nights and hot days while significant decrease in cool nights and cool days has been analyzed across the Southeast Asia and South Pacific [8]. The high frequencies of extreme high temperature (EHT) days are found in North Western China and south eastern regions along Yangtze River [9]. [10] stated the increased frequency of heavy precipitation events contributed 95% of the total increase of precipitation (2%) from 1960-2000 in China. The positive trends of maximum and minimum temperature extremes have also been observed all over the Iran. The warm nights and warm days show statistically significant increase in Iran. The positive trend of extreme precipitation have been studied in the northern half and central region of Iran [11]. In India the frequency of extreme weather events in recent decades particularly from 1991-2000 have showed increase in persistency, severity and spatial coverage of severe heat wave conditions as compared to the earlier decades from 1971-1980 & 1981-1990. The 2/3rd of all the time series 1910-2000) reveal increasing trends in the indices of precipitation extremes in India [12].

Pakistan is also facing the threat in response to global warming. The total change in temperature per decade has been found to be 0.06°C [13]. Increased frequency of heat waves from 1985-2005 and the rapid melting of glaciers in Northern Areas of Pakistan is the patent proof of enhancing warming trends in Pakistan [14]. They are responsible for changes in evaporation and precipitation patterns, and enhanced severe water losses causing water scarcity. The mean annual temperatures of Pakistan has increased by

0.47°C from 1960-2007. The highest increase occurred in the last decade. Heat waves are held accountable for casualties related to weather in Pakistan. Heat waves frequency has risen in almost all parts of the country [15]. It is a general perception that many regions of Asia are the highly susceptible regions of the world due to increase in frequency of extreme events (IPCC, 2007). Pakistan is located in Asian region therefore considered equally vulnerable to climate and weather extremes. The aim of this study is to calculate the frequency of extreme temperature (maximum & minimum) and precipitation events in Pakistan using long-term data from 1965-2009 in order to reveal the fact that how much frequent extreme events are in Pakistan with changes in its climate during the course of the study period. Furthermore the vulnerable regions of Pakistan will be clearly highlighted through this investigation within the Asian region.

DATA & METHODOLOGY

The available daily temperature (maximum & minimum) and precipitation data of forty one synoptic stations of Pakistan Meteorological Department (PMD) have been used to calculate the frequency of extreme temperature and precipitation events in this study. The spatial distribution of stations has been shown in Figure 1. The criteria/thresholds have been defined on the basis of 90^{th}, 95^{th} and 98^{th} percentile to calculate the frequency of maximum temperature extremes and to calculate frequency of minimum temperature extremes 10^{th}, 5^{th}, 2^{nd} percentile value. Percentiles having the property of being station specific represent the frequency of extreme temperature events with respect to local climate [15]. This is the reason that use of percentile is very important for analyzing the extremes. Five criteria's for frequency of maximum temperature events, Six criteria's for frequency of minimum temperature events and three criteria's for the frequency of extreme precipitation events in different regions of Pakistan were developed as shown in Table 1. These threshold values vary from area to area depending upon the climatic conditions of that region.

Statistical test is a method which tells us that whether information obtained from the data sets are significant or insignificant. F-Test is a parametric statistical test generally applied on the time samples and parameters like temperature in which data is continuous. KS-Test (Kolmogorov-Smirnov test) is a non parametric statistical test, applied on precipitation events which are not continuous. Therefore both the statistical tests are valid for this study to investigate the 'Level of Significance' of the results for a particular region. The level of significance is a maximum probability of significance or insignificance of the results. The most commonly used values for level of significance is 5% (0.05). The 5% means that there are 5 chances in 100 of incorrectly rejecting a true hypothesis but 95% confident in making correct decision. The result of analysis is said to be statistically significant if probability value is < 0.05 and statistically insignificant if it is > 0.05.

Table 1 Thresholds used to analyze extreme precipitation and temperature Events

Parameter	Thresholds/Criteria					
	i	ii	iii	iv	v	vi
Maximum Temperature	≥ 30°C	≥ 35C	≥ 40°C	≥ 45°C	≥ 50°C	--
Minimum Temperature	≤ -10°C	≤ -5°C	≤ -2°C	≤ 0°C	≤ 2°C	≤ 5°C
Precipitation	≥ 50 mm	≥ 100 mm	≥ 150 mm	--	--	--

Figure 1 Map showing spatial distribution of meteorological stations of Pakistan

RESULTS & DISCUSSION

A. Frequency of Extreme High Temperatures

The maximum temperature events are increasing throughout the country at all the defined thresholds for the study of maximum temperature events from 1965-2009. However the statistically significant increase in frequency of extreme maximum temperature events has been observed in the Northern areas, Southern Punjab, Sindh and Balochistan at 95% confidence level as shown in Figure 2 & 3. Northern areas are the home of Himalaya Karakorum Hindukush (HKH) which is the biggest repository of snow and glaciated ice outside the polar region. The HKH frozen water resources are regulated by temperature. The more warming in this region will lead to conversion of large amount of solid mass into liquid. The frequent increase in extreme temperatures will ultimately results in accelerated depletion of ice from the glaciers and posing serious threat in the form of water scarcity to future generations. Like Siachin glacier which has reduced by 2.9 km in longitudinal extent from1989 to 2006 reported by [14].Glaciers are the source of water in Pakistan besides Monsoon system. If the snow and ice extent will shrink much faster then downstream channels will receive more water and due to insufficient storage capacity for this increased flow it will either results into flooding or this water will be wasted directly into the Arabian Sea. The increase in maximum temperature events

will also cause increase in frequency and intensity of extreme precipitation events which will further accelerate melting of ice producing lakes larger not only in number but in size as well. Glacial Lake Outburst Floods (GLOFs) will also increase causing risk for human settlement and infrastructure down slope.

The Punjab province has been divided into two halves i.e. Northern Punjab and Southern Punjab on the basis of their cropping pattern. Like in Northern Punjab we have rice and wheat as a major crop while in Southern Punjab we have mostly cotton crop. Both the crops require different climatic conditions for their growth. Therefore increase or decrease in frequency of extreme temperature events will have different impacts on these crops depending on the climate of that region. The Southern Punjab, Sindh and Balochistan are the hub of agriculture activities in Pakistan. Agriculture productivity can be affected by two ways; firstly due to changes in seasonal temperature, precipitation and level of carbon dioxide (CO_2). It is a common understanding that if weather conditions are favorable then there will be optimum crop production and incase of unfavorable conditions crop production will drop drastically. But weather and climate of any area are open parameters so they can not be controlled. Secondly due to changes in soil distribution and frequency of infestation by pests, insects, disease or weeds.

Crops are totally dependent on weather conditions and being open to vagaries of nature agriculture sector is highly vulnerable. Rise in temperature and fall in temperature both make changes in weather pattern. The crop growth cycle mainly rely on temperature. The increase in frequency of extreme temperature events will affect the growth in such a way that rise in temperature will speed up crop maturity and significant pre and post harvest losses. Fall in minimum temperature will affect the crop in a way that the temperature required by crops for shooting will not be available and thus resulting in crop failure. The early harvesting of wheat crop and decrease in wheat crop yield has been observed in the last decade in Sindh. The duration between sowing and harvesting has shortened in case of annual crops due to extreme temperature events. The frequency and intensity of heat wave conditions have also increased in Sindh and Southern Punjab as the record heat wave gripped Pakistan during June, 2007 where 48°C temperature was recorded on 9th June at Lahore, a record repeated after 78 years. Earlier it was recorded on 8th June 1929. Previous extreme heat wave conditions were observed in 1998 & 2002 in the country. The rise in heat waves results in higher heat related (Sun Stroke, Heat stroke, heat exhaustion, diarrhea) mortality rate during summer.

The areas of southern Punjab already facing problem of water logging and salinity according to Pakistan Agriculture Research Council, which may become worse with increasing extreme temperature events. Rise in temperature will evaporate the water from the soil making it more saline and this increase in salinity will adversely affect the crop production and crop yield of this region. This part is facing increase in water requirement of crops and plants resulting in water stresses on crops and plants. Cotton is considered as the cash crop of Pakistan and it is cultivated in Southern Punjab and some parts of Sindh. It requires high temperature during its growing season and cooler conditions at the time of harvesting. The unpredictable extreme weather events can badly affect its yield and eventually ends up in the form of economy crisis. Balochistan experienced severe drought from 1998 to 2002. This drought has not only affected the agriculture systems but as well as lower down the level of water table and almost totally drying up the Karez. The agriculture sector is facing problem of water shortages in this area and when the region did not receive snowfall in Northern parts of Balochistan and had below normal rains during period of droughts the crop yield decreases drastically. The production of wheat, barely and pulses entirely depend on precipitation availability during October to January.

The wide fluctuation in rainfall distribution has become very erratic and irregular along with periods of frequent extreme droughts. Due to this uncertain weather conditions the productivity of grains in this region is a quite risky exercise. Balochistan is also famous for quality deciduous fruit like apple, grapes, almond apricot, cherry, pomegranate, peaches and plum. Their production highly depends on ground water resources. But high temperatures extremes are setting these underground water resources under extreme pressure of extinction.

B. Frequency of Extreme Low Temperatures

The analysis of frequency extreme minimum temperature events have demonstrated marked variation at all defined criteria's among different regions of Pakistan. The areas of Khyber Pakhtoonkhwah, Azad Jammu & Kashmir and Northern Punjab have shown non significant increasing trend of extreme minimum temperature events at all thresholds during the study period (1965-2009).While the Northern areas, southern Punjab, Sindh and Balochistan are the areas which have shown significant decreasing trend in frequency of extreme minimum temperature events as shown in Figure 4 & 5. This decreasing trend of minimum temperature events in these regions have been found statistically significant at 95% confidence level. The decreasing trend of minimum temperature events indicates the increase in minimum temperature in Northern areas. The change in diurnal temperature range (DTR) may be attributed to increase in cloud cover.

The dry mountains retain heat during day and at night they emit. This heat does not escape back in to the space due to cloud cover which traps these heat waves in the atmosphere increasing the minimum temperature. Azad Jammu & Kashmir, Khyber Pakhtoonkhwah and northern Punjab are the rain fed areas of the country with lots of vegetation. Both these characteristics of the area contribute in enhancing the rate of evapotranspiration in this region and producing more humid environment. The dense vegetation of these areas maintains the balance of both temperature (maximum & minimum) extremes. This might be the reason of insignificant increase minimum temperature events in this area. The increase in minimum temperature examined in Sindh, Balochistan and Southern Punjab most probably due to humidity in plain areas.

The amount of vapors present in the atmosphere in form of humidity absorbs heat and retains this heat in the atmosphere keeping it warm at night. Cloud cover is considered

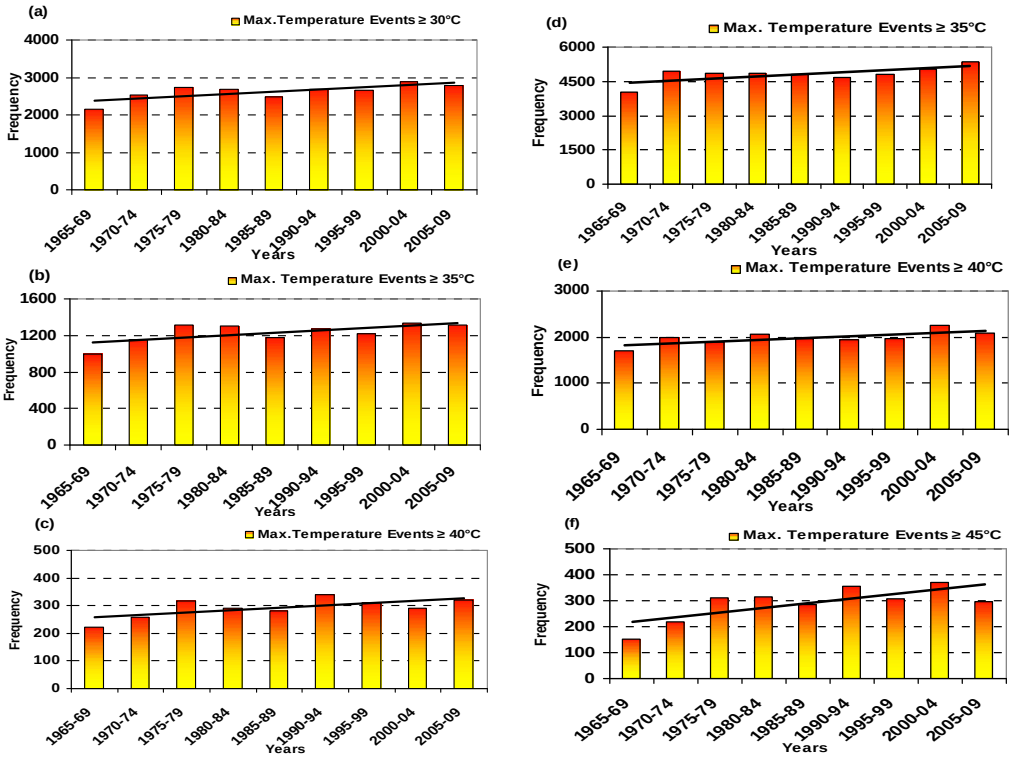

Figure 2 The frequency of extreme maximum temperature events in Northern areas **(a)** at threshold ≥30°C **(b)** at threshold ≥ 35°C **(c)** at threshold ≥ 40°C. The frequency of extreme maximum temperature events in Southern Punjab **(d)** at threshold ≥35°C **(e)** at threshold ≥ 40°C **(f)** at threshold ≥ 45°C.

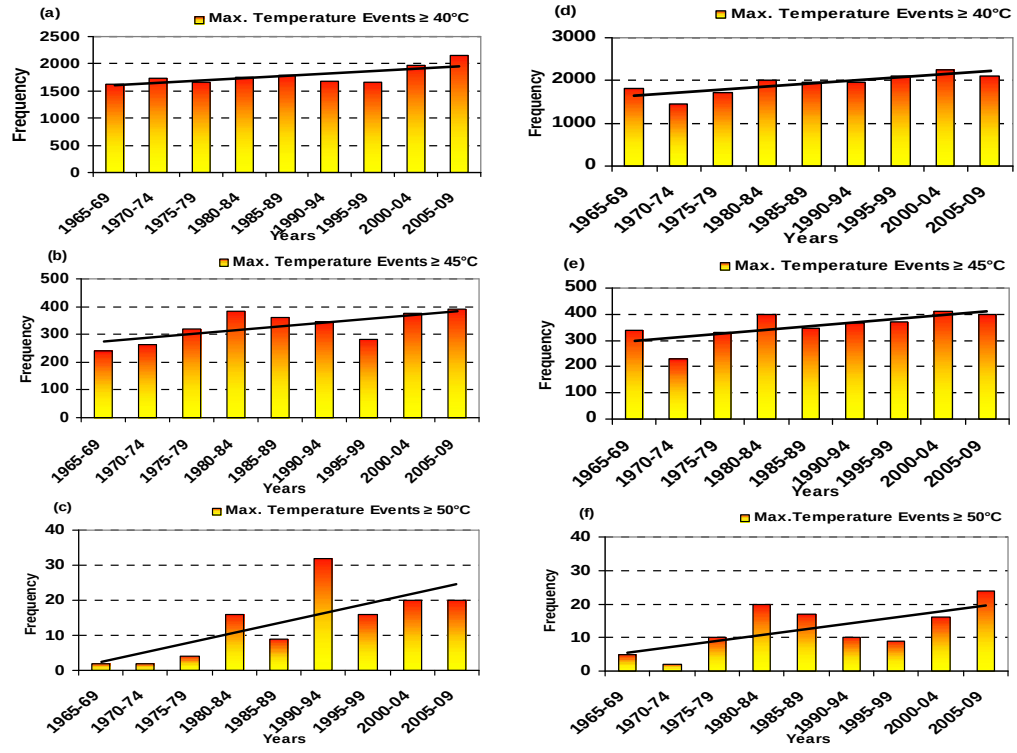

Figure 3 The frequency of extreme maximum temperature events in Sindh **(a)** at threshold ≥ 40°C **(b)** at threshold ≥ 45°C **(c)** at threshold ≥ 50°C. The frequency of extreme maximum temperature events in Balochistan **(d)** at threshold ≥40°C **(e)** at threshold ≥ 45°C **(f)** at threshold ≥ 50°C.

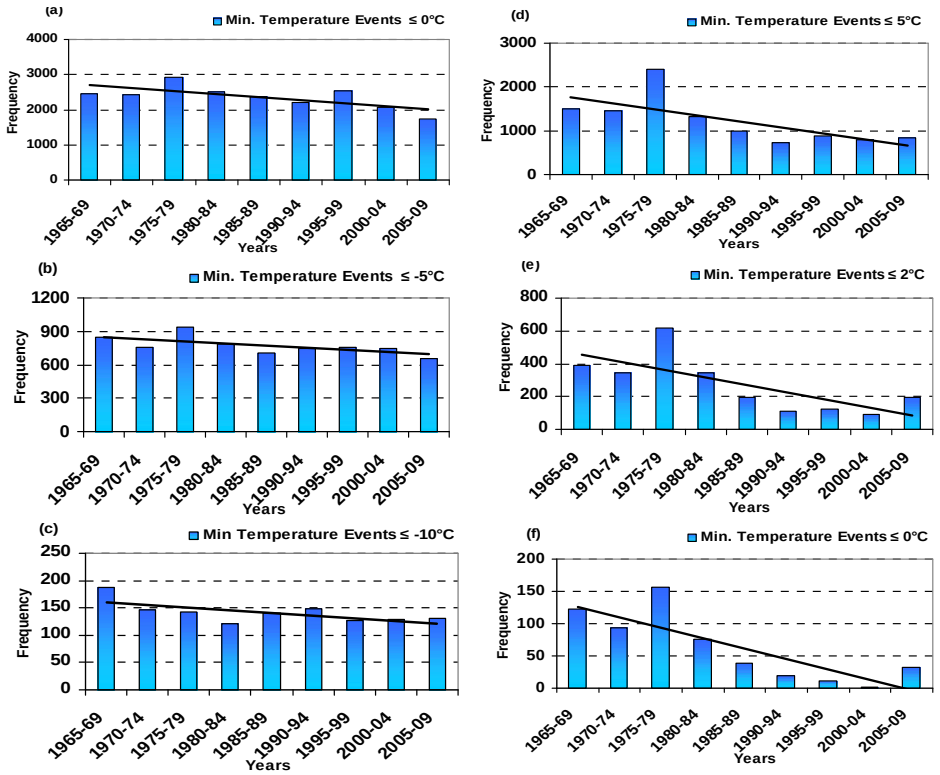

Figure 4 The frequency of extreme minimum temperature events in Northern areas **(a)** at threshold ≤ 0°C **(b)** at threshold ≤ -5°C **(c)** at threshold ≤-10°C. The frequency of extreme minimum temperature events in Southern Punjab **(d)** at threshold ≤ 5°C **(e)** at threshold ≤ 2°C **(f)** at threshold ≤ 0°C.

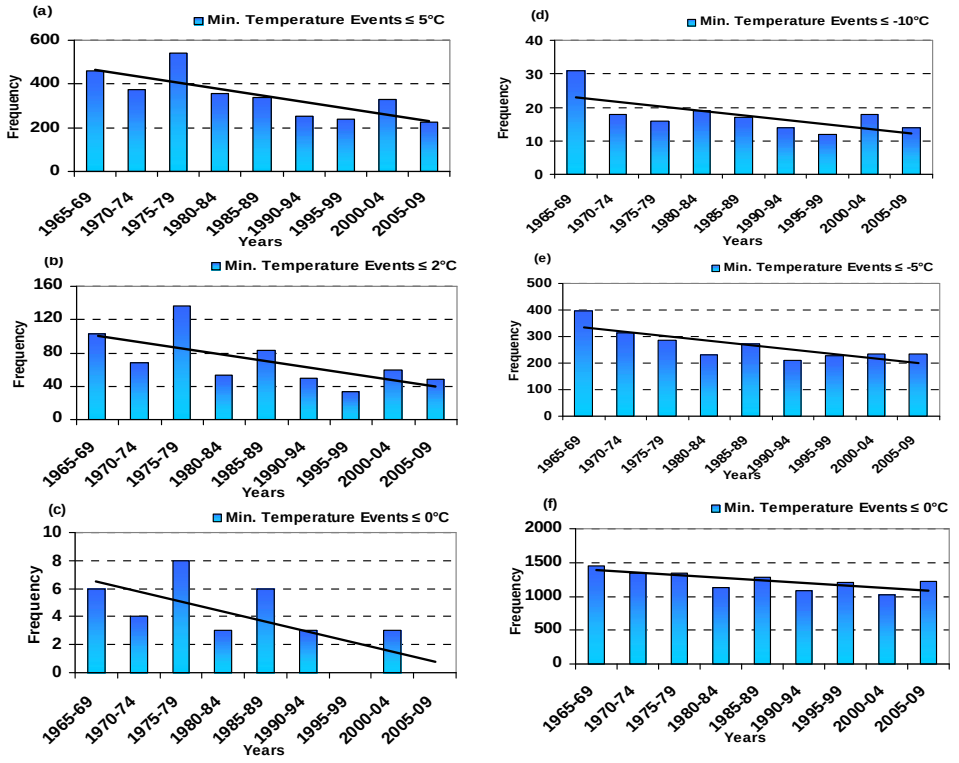

Figure 5 The frequency of extreme minimum temperature events in Sindh **(a)** at threshold ≤ 5°C **(b)** at threshold ≤ 2°C **(c)** at threshold ≤ 0°C. The frequency of extreme minimum temperature events in Balochistan **(d)** at threshold ≤ -10°C **(e)** at threshold ≤ -5°C **(f)** at threshold ≤ 0°C.

responsible for the increase in minimum temperature events as well. The presence of clouds does not let the heat radiations to escape into the space and causes rise in minimum temperature. Elevated levels of pollution are the biggest contributor in enhancing Green House Effect and eventually temperatures. There is strong evidence that anthropogenic warming is affecting trends in warm nights globally.

C. Frequency of Extreme Precipitation Events

The analysis of extreme precipitation events has shown increasing trend throughout the country at all thresholds set for the calculation of extreme precipitation events from 1965-2009. The results reveals a statistically significant and sharp increasing trend of extreme precipitation events frequency in Sindh and Azad Jammu & Kashmir regions at all criteria's (≥ 50mm, ≥100mm, and ≥150mm) at 95% confidence level. The trend of events that have occurred in Northern Areas and Balochistan at ≥ 50mm and ≥100mm have also shown significant rise during the investigation period. The southern Punjab areas has also exhibited the significant increase in frequency of extreme precipitation events but only at ≥100mm. Northern Areas, Southern Punjab and Balochistan regions have not shown any events at threshold ≥150mm. The non significant increase has been observed in Khyber Pakhtoonkhwah and Northern Punjab regions at ≥ 50mm and ≥100mm (90^{th} & 95^{th} percentile) statistically. However these regions experience significant increase at ≥150mm (98^{th} percentile) events have been detected as shown in Figure 6. The northern half of Pakistan is wetter as compared to southern half but due to climate change scenario the change in precipitation pattern has been observed in the recent era. The rise in extreme precipitation events frequency has also been observed in southern parts of the country since last few years. This part of the country did not receive much rainfall in the past. Urban flooding due to occurrence of extreme rainfall events have become more frequent causing heavy damage to infrastructure and loss of lives in major cities and impeding the civic activity. This erratic heavy downpour episode can be related to increase in extreme temperature events. The increase in temperature may change the physical processes of weather making hydrological cycle more vigorous. High temperatures cause enhanced evapotranspiration and water holding capacity also increases which ultimately leads to strong convective activity and results in more intense precipitation and frequent droughts. The torrential rains not only impact the infrastructure but instead it will expedite the soil erosion process degrading the land and incase of flooding situation filling the reservoirs with sediments, reducing its storage capacity. Aquifers are the source of ground water in some areas and intense rain will not let recharge of aquifer timely causing water scarcity in those areas.

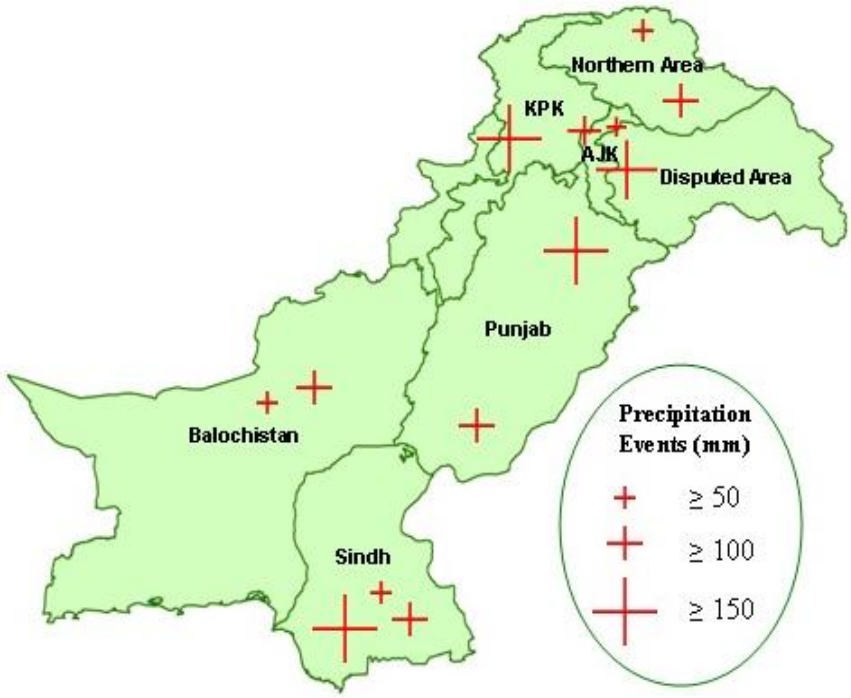

Figure 6: Frequency of significant extreme precipitation events in different regions of Pakistan 1965-2009

CONCLUSION

Major parts of the country have been experiencing a warming trend according to extreme temperature events analysis. The frequency of extreme maximum temperature events are increasing significantly in Northern Areas, Southern Punjab, Sindh and Balochistan whereas the rest of

the regions exhibited non significant increase. The frequency of extreme minimum temperature events has shown variation. The Northern areas, Southern Punjab, Sindh and Balochistan have shown significant decrease in extreme minimum temperature events. However, non significant increase in events frequency has been observed in Khyber Pakhtoonkhwa, Azad Jammu & Kashmir and Northern Punjab. Therefore the Northern areas, Southern Punjab, Sindh and Balochistan regions are the highly vulnerable zones of Pakistan. The overall trends show that summers are becoming hotter and winters are growing milder. Increase in frequency of temperatures will increase the heat waves frequency which will result in number of diseases and will adversely impact crop production. Due to increased frequency of temperatures the water requirements of crops, domestic and industrial user will increase. Surface water resources are limited and likely to decline further under global warming pressure of ground water pumping will deplete ground water reservoir. Increasing frequency of extreme maximum temperature is likely to create alarming conditions in glaciated Northern regions of Pakistan under the influence of increased and consistent heat, the glaciers will melt at a much faster rate giving rise to formation of the glaciated lakes which will outburst causing damage to human settlements and infrastructure down slopes. The trend of extreme precipitation events has shown increase throughout the country but the significant and sharp increase at all thresholds has been observed in Azad Jammu & Kashmir and Sindh. The Northern areas and Balochistan regions have also shown significant increase at thresholds 90^{th} & 95^{th} percentile only. The Northern Punjab and Khyber Pakhtoonkhwah has also shown significant increase merely at 98^{th} percentile. Thus it is concluded that frequency of precipitation extremes are approaching the country and southern half of Pakistan are becoming wetter as compared to earlier era.

REFERENCES

[1] Easterling, D. R., J. L. Evans, P. Ya. Groisman, T. R. Karl, K. E. Kunkel and P. Ambenje, Observed Variability and Trends in Extreme Climate Events: A Brief Review. *Bulletin of the American Meteorological Society*, **81**, 417-425 (2000).

[2] Jungo, P., 20th Century Minimum and Maximum Temperature Variations Analyzed on a Regional Scale in Switzerland – Statistical analyses on observational data, *Ph.D. Thesis No.1365, University of Fribourg, Switzerland*, 221 (2001).

[3] Frei, C and C. Schar, Detection probability of trends in rare events: Theory and application to heavy precipitation in the Alpine region, *Journal of Climate*,**14**, 1568–1584 (2001).

[4] Klein, T.A.M.G., and G. P. Konnen, Trends in indices of daily temperature and precipitation extremes in Europe, 1946–99. *Journal of Climate*, **16**, 3665–3680 (2003).

[5] Brunetti, M., M. Maugeri and T. Nanni, Variations of temperature and precipitation in Italy from 1866 to 1995. *Theoretical and Applied Climatology*, **65**, 165–174, (2000).

[6] IPCC, Asia in Climate Change, Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: *Cambridge University Press*, 469–506 (2007).

[7] Tank, A.M.G. K., T.C. Peterson, D.A. Quadir , S. Dorji, X. Zou ,H. Tang, K. Santhosh, U.R. Joshi , A.K. Jaswal, R.K. Kolli, A. Sikder , N.R. Deshpande , J.V. Revadekar, K. Yeleuova , S. Vandasheva , M. Faleyeva , P. Gomboluudev, K.P. Budhathoki , A. Hussain , M. Afzaal , L. Chandrapala , H. Anvar, D. Amanmurad , V.S. Asanova , P.D. Jones , M.G. New and T. Spektorman, Changes in Daily Temperature and Precipitation Extreme in Central & South Asia, *Journal of Geophysical Research*, 1-18 (2005).

[8] Gwangyong, C., D. Collins, G. Ren, B. Trewin, M. Baldi, S. Fukuda, M.Afzaal, T. Pianmana, P. Gomboluudev, P. T. T. Huong, N. Lias, W. Kwon, K.Boo, Y. Cha and Y. Zhouc, Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955–2007, *International Journal of Climatology*, (2009).

[9] Zhang, F., H. Gao and X. Cui, Frequency of Extreme High Temperature Days in China, 1961-2003, *Weather*, **63(2)**, pp 46-49(2008).

[10] Liu, B., M. Xu, M. Henderson and Y. Qi , Observed trends of precipitation amount, frequency, and intensity in China, 1960–2000", *Journal of Geophysical Research*., 110, (2005).

[11] Rahimzadeh, F., A. Asgari and E. Fattahi, Variability of extreme temperature and precipitation in Iran during recent decades, *International Journal of Climatology*, **29**, 329–343 (2009).

[12] De, U. S., R. K. Dube and G. S. P. Rao, Extreme Weather Events over India over last 100 years, *J. Ind. Geophys. Union*, **9(3)**, 173-187 (2005).

[13] Afzaal, M., M. A. Haroon and Q. U. Zaman, Interdecadal oscillations and the warming trend in the Area Weighted Annual Mean Temperature of Pakistan, *Pakistan Journal of Meteorology*, **6(11)**, 13-19 (2009).

[14] Rasul, G., Q. Dahe and Q. Z. Chaudhry, Global Warming and Melting Glaciers along Southern Slopes of HKH Ranges". *Pakistan Journal of Meteorology*, **5(9)**, 63-76 (2008).

[15] Chaudhary, Q. Z., A. Mahmood, G. Rasul, and M. Afzaal, "Climate Change Indicators of Pakistan", *Technical Report* No. D-22/2009,1-43 (2009).