An Analytical Study of Variations in the Monsoon Patterns over Pakistan

Imran, A.[1, 2], Q. Zaman[2], G. Rasul[2], A. Mahmood[2]

Abstract

In the recent era, the climate change has not only triggered the extreme weather events but also brought uncertainties in the behavior of certain weather phenomenon. These variations in the weather patterns are very significant in their consequences. So to enhance the understanding of these uncertainties, the study of these variations is of utmost importance. This study is carried out to investigate the variations in the precipitation patterns over the major monsoon belt of Pakistan during the summer monsoon period. Frequency of extreme precipitation events, onset, withdrawal, duration of monsoon season, total amount of rainfall during the season and total number of rainy days, all these parameters are the key factors not only in understanding the uncertainties caused by the climate change but also from the socio-economic point of view. Daily rainfall observed data is used to compute the above mentioned parameters of the monsoon system. Islamabad has a high frequency of extreme events with rainfall 50 mm, 100 mm or more per day, as compared to the other stations of the same monsoon belt. Southeastern part of the country experiences a trend towards increasing frequency of such extreme events during the last decade. In the northeast, Lahore is the only station where the duration of the monsoon season is increasing significantly. Southeastern monsoon belt has a suppressing trend in terms of the duration of the summer monsoon. Generally the northeastern stations show a direct relationship between the variation of the total amount of rainfall and number of rainy days. Stations located in the southeastern monsoon belt of the country exhibits a trend towards the occurrence of extreme precipitation events as the number of rainy days are not increasing accordingly with the amount of rainfall.

Key Words: Summer monsoon, Onset, withdrawal, duration, rainy days

Introduction

Southwest monsoon is the main rain producing system for South Asia and a major contributor to the total rainfall of the region. It is an important meteorological phenomenon of much economic value. Onset date of monsoon rainfall is very important for agricultural point of view as an abnormal onset can adversely affect the crop growth and yield. Withdrawal determines the stock to meet the water requirements of transition period before the start of winter rains. The summer Monsoon in subcontinent is defined by the reversal of winds up to 180° but a remarkable increase in the rainfall amount is an essential feature of the onset of the monsoon (Wang and Ding, 2008). Human life and economy in Pakistan considerably depends upon the monsoon activities. To address the water resource challenges, the need is to develop a basis of scientific understanding of different contrast of the climatology of heavy rainfall events over Pakistan (Ahmad et al., 2010).The summer monsoon enters Pakistan in two different ways; first the south westerly winds from Bay of Bengal strikes the Himalayas, deflected and travelling along the foothill of Himalayas and enters Pakistan. The stations receiving first monsoon rainfall from these currents are Sialkot, Jhelum, Islamabad and Lahore; make the northeastern belt of summer monsoon. Second is the southwest winds from Arabian Sea enters south Pakistan. Badin and Chhor are the first stations to get rainfall from these currents and can be considered as the southeastern belt of the Pakistan's summer monsoon.

Criteria described by WMO, for the onset of monsoon known as Pentad criteria is defined as "the five day mean rainfall averaged over calendar day intervals of five days is called pentad rainfall"(Compendium of Meteorology, WMO (1979). Ananthakrishnan and Sonam (1988) took the date of the onset over Kerala, India as the first day of the transition from light to heavy rainfall category with the condition that the average daily rainfall during the first five days after the transition should not be less than 10 mm. Wang et

[1] aimranshah.pmd@gmail.com
[2] Pakistan Meteorological Department, Pitras Bukahari Road, Sector H-8/2, Islamabad, Pakistan.

al., (2008) set an objective definition of monsoon onset over kerala on the basis of the arrival of sustained 850hpa zonal winds. They took the average of these winds over the southern part of Arabian Sea lies from 5° N to 15° N latitude and 40° E to 80° E longitude. There results were in excellent agreement with the onset dates defined by the Indian Meteorological Department. As kerala lies on the southern tip of India so onset over kerala is actually considered as the onset over India. According to Rao (1976), Indian Meteorological department forecasters (IMD) consider the onset of monsoon on the following basis. First, the rainfall must be widespread over kerala and nearby areas. Second, the rainfall spell should be prolonged for many days. Third, low tropospheric westerlies at and around kerala must be strong. Fourth condition is that the humidity must be much high up to 500hpa or beyond.

According to Taniguchi and Koike (2006), the increase in the strength of low level wind over the low-latitude region of India serve as an indicator of the onset of southwest monsoon. Fasullo et al., (2002) using vertically integrated moisture transport tried to set a hydrological definition for Indian summer monsoon onset and withdrawal. Although there is no widely accepted criteria of monsoon onset but the surface observation of monsoon is concerned with the rapid and sustained increase in precipitation. Certainly the effect of monsoon is more important than mere its phenomenon and its effectiveness is always considered in terms of rainfall received. Vincent et al., (2009) set a criteria for the onset of summer monsoon over India. They consider the onset date as the first wet day of the five consecutive wet days from first April not followed by 10 dry days in the next 30 days after the onset. The condition for the day to be taken as first wet day is that it has a minimum of 1 mm of rain. The condition of not followed by 10 dry days is applied to avoid the false onset related to pre monsoon rainfall. The criteria of not followed by 10 dry days with rain not less than 5 mm is not suitable for Pakistan where rainfall is quite sparse.

The onset, progress and offset are the most significant aspects of summer monsoon. Duration of monsoon season and total amount of monsoon rainfall during the season depends upon these factors. (Raju, 2005). Subbaramagya et al., (1981) stated that for India the duration of monsoon season is from June to September. Shamshad (1988) also consider the same period as the duration of monsoon over Pakistan. The monsoonal winds arrive over Srilanka and central Burma from the start of May and reach over Northern India by the end of June. The withdrawal process commences from mid of September (WMO, 1979). According to this statement the duration of rainy season over the Northern limits of southwest monsoon is about two and a half month. Rasul et al. (2010) stated that as Pakistan is located at the western edge of southwest monsoon so duration of monsoon for Pakistan is less as compared to the other regions of the same monsoon regime. The effective duration of monsoon for Pakistan is about one and a half month.

Two remarkable features of the summer monsoon are its regular occurrence every year from June to September and the irregular variations in the amount of seasonal mean rainfall it brings from one year to another. Even within a season, there is a considerable variation, both in space and time in the rainfall. The interseasonal and interannual variability of the summer monsoon has a tremendous socio-economic impact in the field of agriculture (Krishnamurthy et al., 2002). The frequency, intensity, life cycle and propagation characteristics of the monsoon disturbances determine the regional distribution of rainfall (Shukla, 1987). South Asia has diversity in orography. Monsoon current tracks and hence the rainfall is very much affected by the presence of Great Himalayas. In constract to the onset of monsoon, the withdrawal in September is very much less affected by the orography (Chakraborty et al., 2006).During the withdrawal phase of monsoon, the reduction in moisture convergence over Pakistan is an indication of the decay of the system (Fasullo et al., 2001). Rasul et al. (2004) stated that the withdrawal over Pakistan begins in the first week of September.

Goswami et al., (2006) investigated the trend in extreme precipitation events over central India in the summer monsoon season. They concluded that the number of extreme events with rainfall $\geq$ 100 mm per day during 1981-2000 was larger than that of during 1951-1970. The frequency of heavy rainfall events ($\geq$ 100 mm) and very heavy events ($\geq$ 150 mm) per day showed significant increasing trend while

frequency of light to moderate events (5 ≤ rainfall <100 mm/day) showed decreasing trend. They stated that the increasing trend in the heavy rainfall events is offset by the decreasing trend in the light to moderate rainfall events. This results in no significant trend in the seasonal mean rainfall.

Data and Methodology

The data used for research purpose is that of daily rainfall over the selected stations for the years 1961-2010.The data was obtained from Climate Data Processing Centre (CDPC) Met Complex Karachi. The data was minutely examined for the month of June, July, August and September to find out the onset and withdrawal dates. The extreme rainfall events with 50 mm, 100 mm and 150 mm were also analyzed. Duration of monsoon season, total amount of rainfall during the season and total number of rainy days were also calculated in order to find a relation between the frequency of extreme events and other parameters of the monsoon system.

The criteria used in this research to compute the date for the onset of Monsoon over Pakistan is described as: For northeastern region of Pakistan onset of monsoon is considered as the first day of the three consecutive wet days when at least one day received 10 mm or more rainfall during the month of June or July. For two consecutive wet days one day among them must receive 20 mm or more rainfall. The first day of these consecutive wet days is declared as the onset of summer monsoon. First day must receive more than trace amount as onset of monsoon must have some significant increase in the amount of rainfall. Southeastern part of Pakistan receives much less amount of precipitation as compared to the northeastern parts of the country. Due to this variability, an exactly same criterion is not applicable for this region. For this reason, the rainfall amount of 5 mm is considered instead of 10 mm and 10 mm is taken instead of 20 mm. All other criteria are same. For withdrawal of monsoon, the day of the last monsoon rainfall followed by 10 dry days in August or September is taken as the withdrawal date. Standard deviation in the onset and withdrawal dates of each station was also calculated. Gaps in the data show the missing data sets.

All the stations selected for study have their own importance because of their geographical location. These stations are considered as the gateway of monsoon over Pakistan. The selected stations are listed in the table 1.

Table 1: List of selected stations

Station	Latitude(° N)	Longitude(° E)	Height above mean sea level MSL(m)
Sialkot	32.31	74.32	255
Jhelum	32.93	73.73	287
Islamabad	33.71	73.06	622
Lahore	31.54	74.22	214
Badin	24.38	68.54	09
Chhor	29.53	69.43	05
Karachi	24.54	66.56	22

Results and Discussions

The result and discussions of the various features of the monsoon over Pakistan is based on the statistical analysis of the daily rainfall data for the selected stations. As monsoon currents encounter Pakistan in two different ways, the two branches of summer monsoon system caused the rainfall in two regions of Pakistan separately. In this regard it is more purposeful and convenient to study the behavior of these two branches separately.

Northeastern Monsoon Region of Pakistan

Northeastern monsoon belt of Pakistan receives rainfall mainly from the deflected monsoon currents travelling from the Bay of Bengal along the foothills of Himalayas and enter the northeastern part of the country as southwest monsoon currents.

Frequency of Extreme Rainfall Events

Frequency of the extreme rainfall precipitation events with rainfall equal to or more than 50,100 and 150 mm during a single day is calculated. The frequency of these events is calculated on decadal basis in order to make the changes more visible. In the graphs, frequency plotted along Y-axis shows the number of events during a decade. Among the station selected from the monsoon belt of northeast (NE) Pakistan, Islamabad has the highest frequency of the occurrence of extreme events of precipitation with 50 mm or more rainfall in a single day during the monsoon season. The decade 1981-1990 was the one with highest frequency of such extreme events over the whole monsoon belt except Sialkot, which experienced highest frequency in the next decade 1991-2000. Lahore showed relatively weak tendency towards the occurrence of such extreme events. During the last decade all stations of the Northeast monsoon belt experienced a significant number of 50 mm or more rainfall extreme events.

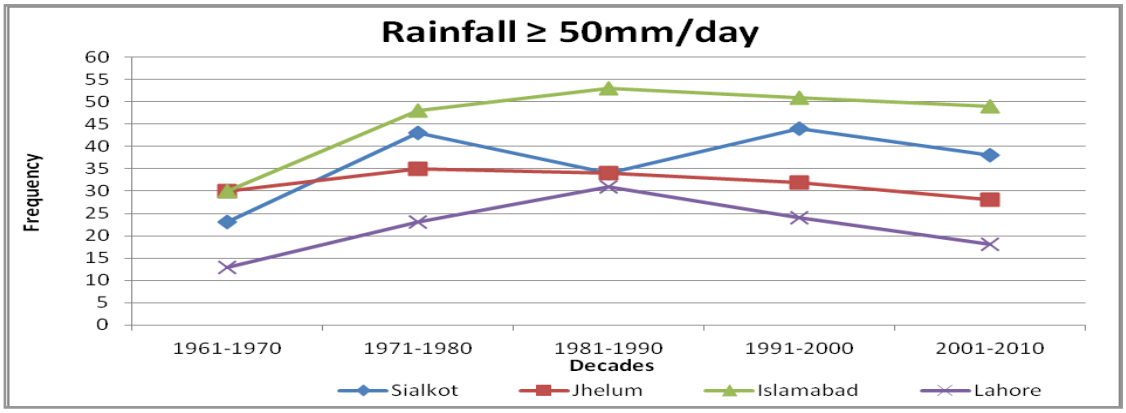

Figure 1: Frequency of rainfall ≥ 50 mm/day extreme events over the elected stations of northeastern monsoon belt of Pakistan.

In case of heavy event with rainfall ≥100 mm /day over the northeast monsoon belt of Pakistan, the variations are somewhat more complex. Islamabad has a very sharp increase in the occurrence of such events from the decade 1961-1970 to1981-1990. Decade 1991-2000 exhibits a high frequency of the occurrence of such extreme events at all the stations. Again Lahore has the lowest frequency among the stations selected. Last decade did not experience the highest occurrence of 100 mm or more rainfall events but the occurrence is quite notable expect at Jhelum.

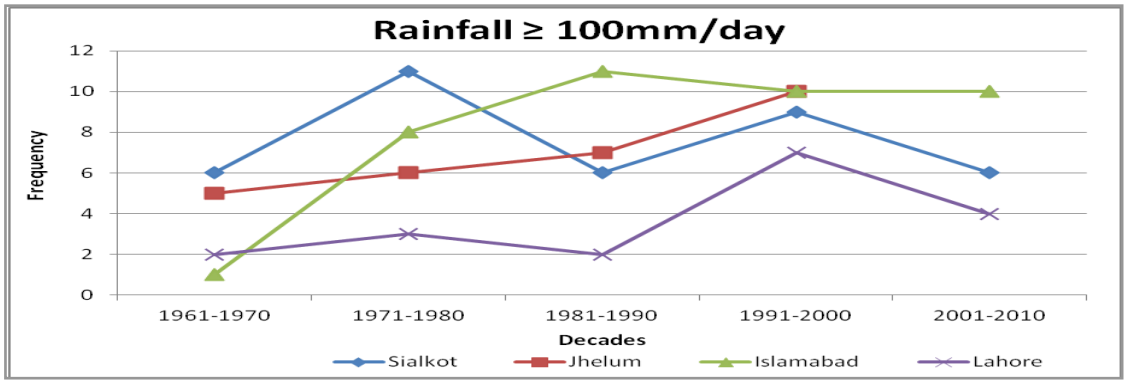

Figure 2: Frequency of rainfall ≥ 100 mm/day extreme events over the selected stations of northeastern monsoon belt of Pakistan.

The situation is even more complicated in case of very heavy rainfall events with rainfall ≥150 mm/day. Since the occurrence of such events is quite unique so each station has its own time scale for the occurrence of highest frequency. Due to very rare occurrence of such events, there is no apparent trend in the occurrence of such very heavy events.

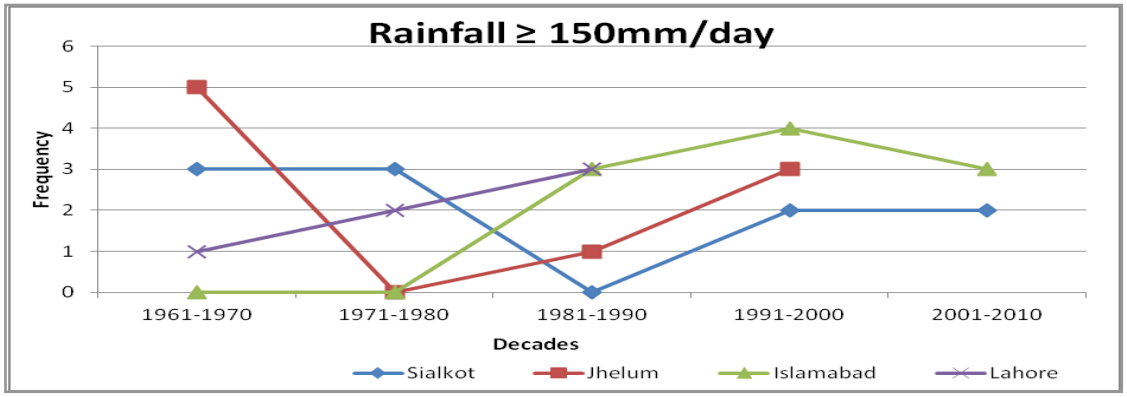

Figure 3: Frequency of rainfall ≥ 150 mm/day extreme events over the selected stations of northeastern monsoon belt of Pakistan.

Duration of Monsoon Season

In case of Sialkot onset has a very steady trend while withdrawal shows a trend towards somewhat late dates so duration of monsoon over Sialkot seems to be increasing. Standard Deviation in onset is 9 while in case of withdrawal it is 8 days.

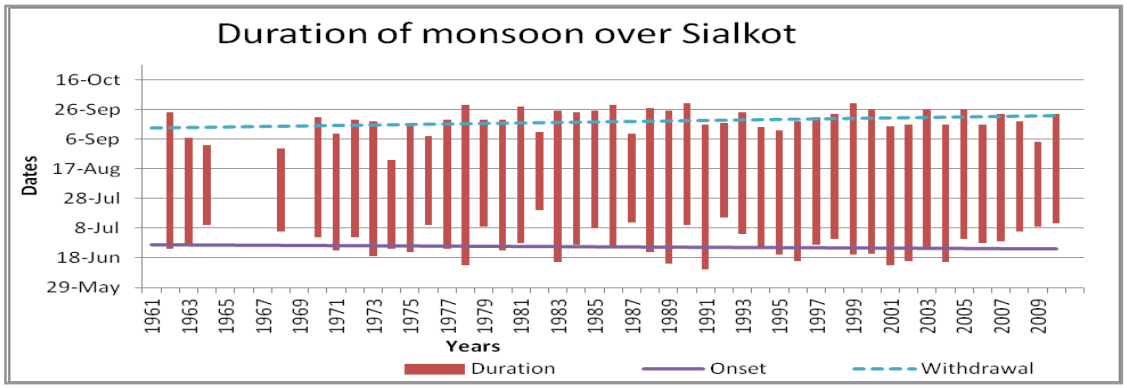

Figure 4: Duration of summer monsoon season over Sialkot. Onset and withdrawal trends determine the duration of the season.

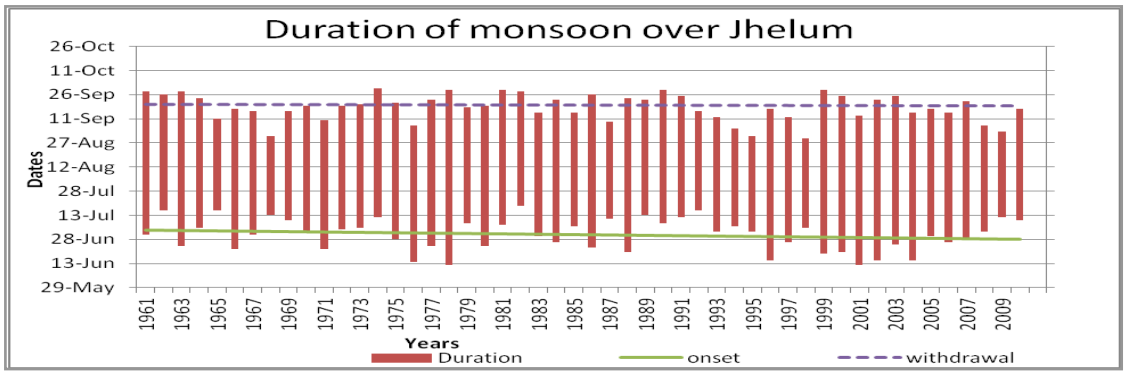

Figure 5: Duration of summer monsoon season over Jhelum. Onset and withdrawal trends determine the duration of the season.

For Jhelum the onset trend is toward somewhat earlier dates and same is the case for the withdrawal trend, so duration pattern seems to remain steady. Standard deviation in onset is 9 while in withdrawal date is 8 days.

Islamabad showed a trend towards earlier onset and earlier withdrawal as in case of Jhelum, so there is no significant variation in terms of length of the monsoon season. Standard deviation in onset is 10 while in withdrawal date it is 7 days.

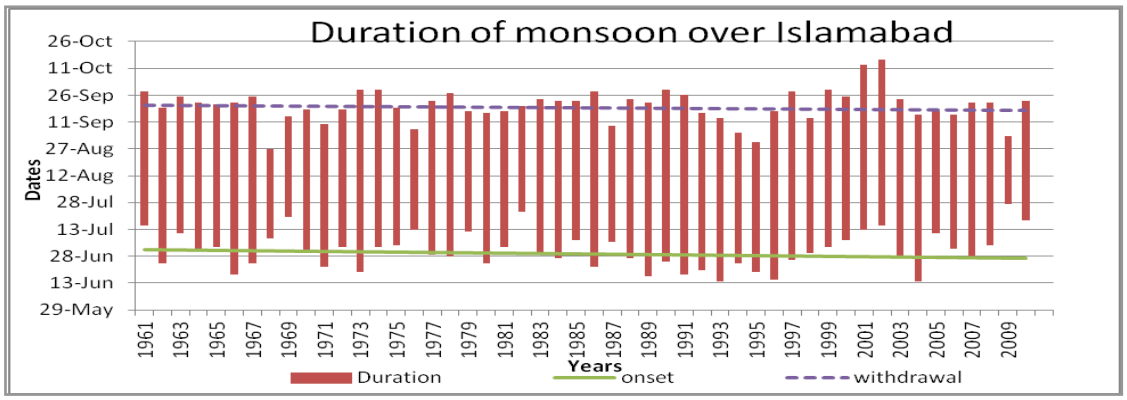

Figure 6: Duration of summer monsoon season over Islamabad. Onset and withdrawal trends determine the duration of the season.

In case of Lahore onset has a sharp earlier trend while withdrawal has a sharp trend towards late withdrawal. Duration of the monsoon season for Lahore seemed to be increasing significantly. Standard deviation in onset is 12 while in withdrawal date is 10 days.

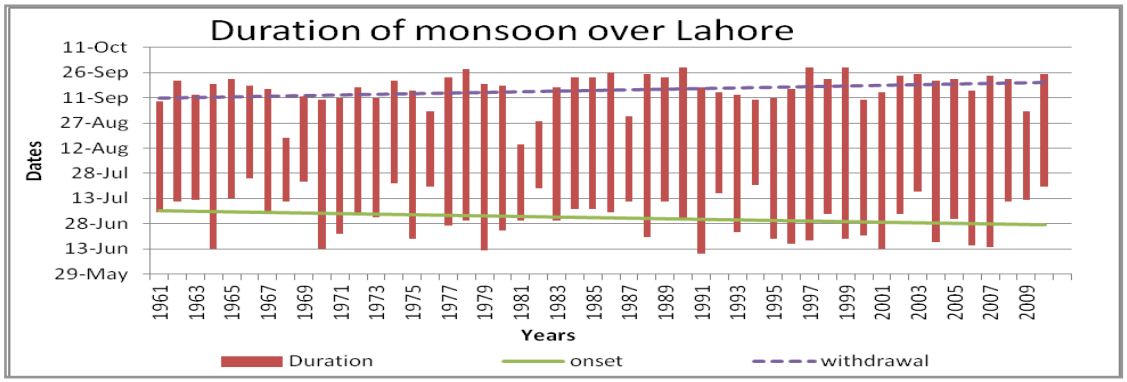

Figure 7: Duration of summer monsoon season over Lahore. Onset and Withdrawal trend determine the duration of the season.

Amount of Rainfall and Number of Rainy days

For Sialkot, the trend for the total rainfall amount during the season and total number of rainy days during a particular season both are increasing. It is evident from the graphical display that when the cumulative value of rainfall for a particular year increases, the total number of rainy days also increases. The direct relation ship between the amount of rainfall and number of rainy days is very well justified. The average number of rainy days per year is 34.

In case of Jhelum there is no significant change for both amount of rainfall and number of rainy days, although the trend is towards slight increase in number of rainy days. Again the variations in rainfall amount and rainy days are in unison with each other. The average number of rainy days is 30.

Islamabad showed a behavior different from the other stations. Rainfall amount has a sharp increasing trend while rainy days have a very steady tend. There is an increase in number of rainy days with

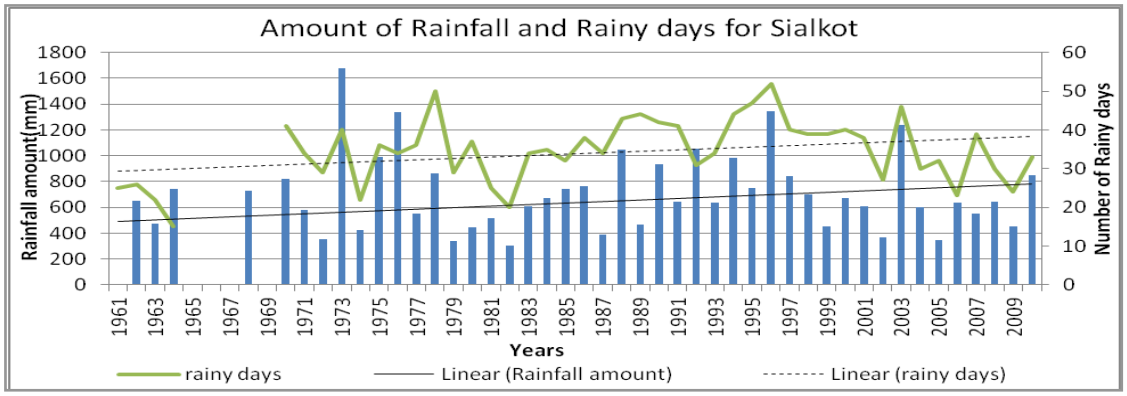

Figure 8: Cumulative rainfall for the monsoon season and number of rainy days for Sialkot, along with the trend line for the two parameters.

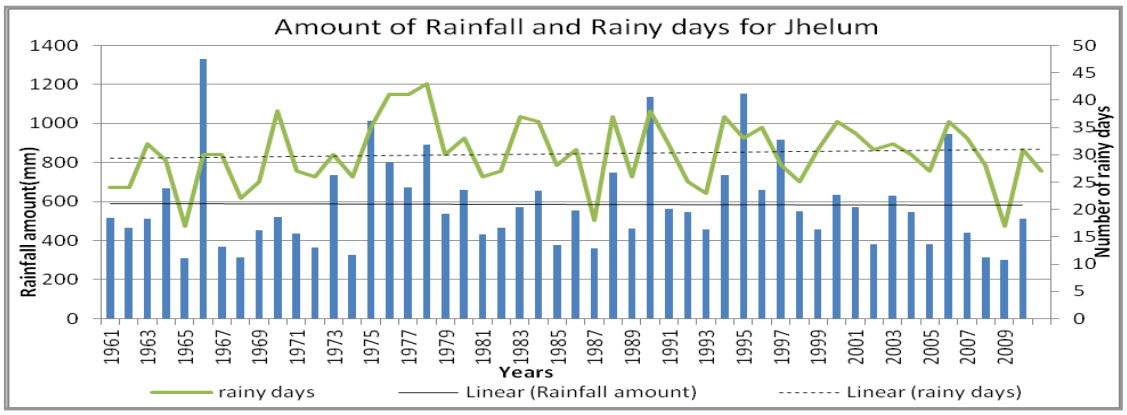

Figure 9: Cumulative rainfall for the monsoon season and number of rainy days for Jhelum, along with the trend line for the two parameters.

increase in rainfall amount during a particular season but increase is not as sharp as that of rainfallamount. The trend for the length of monsoon season is also steady. This might be due to the occurrence of heavy spells of rains which cause the rainfall amount to increase significantly. The average number of rainy days is 32.

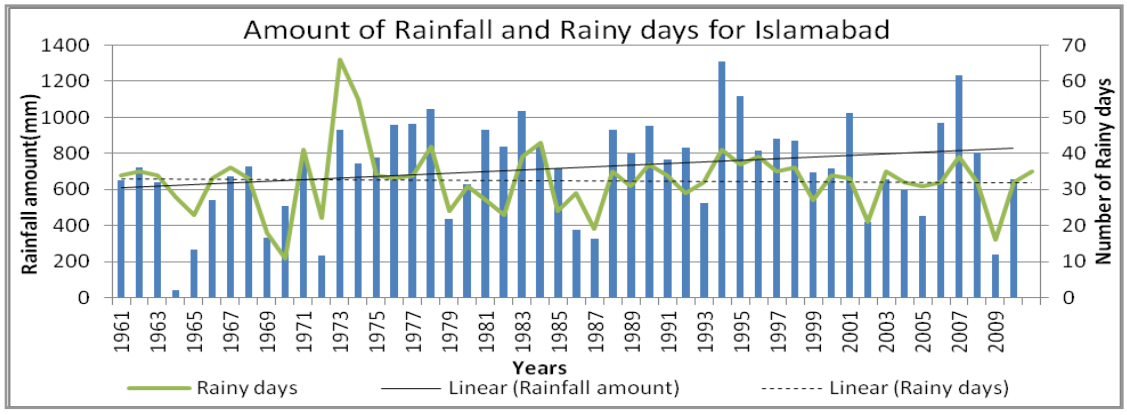

Figure 10: Cumulative rainfall for the monsoon season and number of rainy days for Islamabad, along with the trend line for the two parameters.

Lahore has a trend towards increase both in case of rainfall amount and number of rainy days. The variations in number of rainy days and total rainfall amount during a particular season are in very good agreement with each other. The duration of monsoon season is also increasing (Figure 7), so Lahore seems to be enjoying a good monsoon in future. The average number of rainy days is 24.

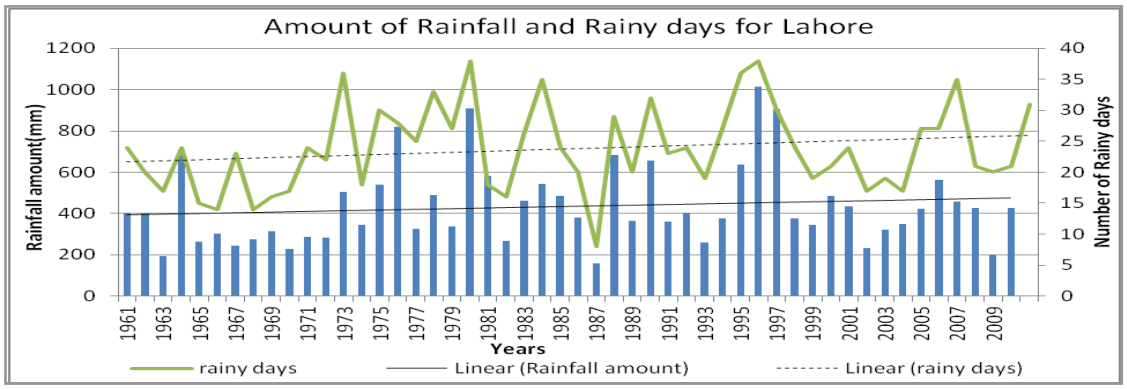

Figure 11: Cumulative rainfall for the monsoon season and number of rainy days for Lahore, along with the trend line for the two parameters.

Southeastern Monsoon Region of Pakistan

Southeastern monsoon belt of the country gets its share of summer rainfall from the Arabian Sea branch of monsoon. This part of the country receives considerably less amount of rainfall as compared to the northeastern monsoonal belt.

Frequency of Extreme Rainfall Events

For the southeast Pakistan, all the stations experienced the highest frequency of the occurrence of extreme rainfall events of 50 mm or more rainfall recorded in a single day during the monsoon season in the last decade. Karachi has the highest frequency among the selected stations. This part of the country seems to experience the triggered weather phenomenon more than the others.

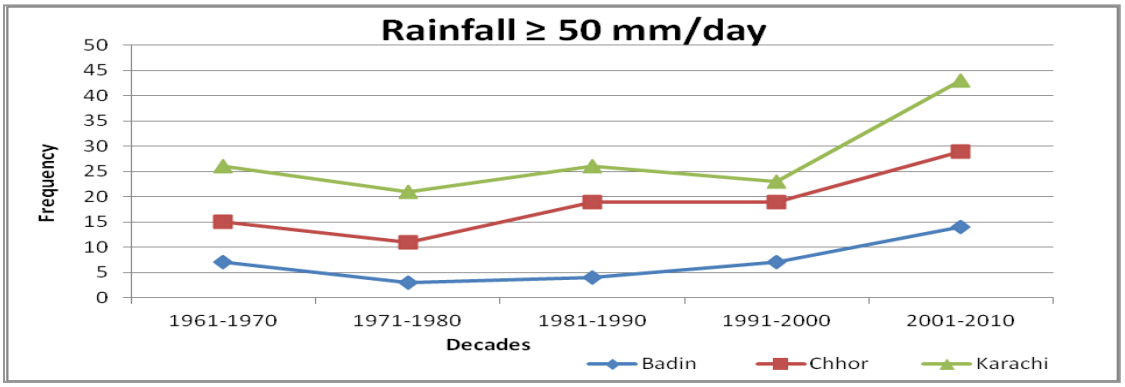

Figure 12: Frequency of rainfall ≥ 50 mm/day extreme events over the selected stations of southeastern monsoon belt of Pakistan.

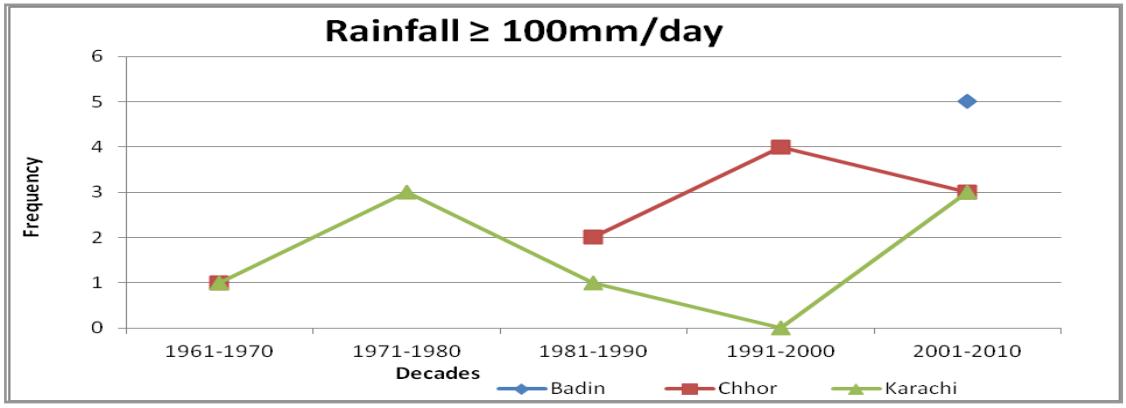

Figure 13: Frequency of rainfall ≥ 100 mm/day extreme events over the selected stations of southeastern monsoon belt of Pakistan.

The frequency of the occurrence of heavy precipitation events with 100 mm/day or more rainfall is quite low for the southeastern monsoon region of the country. There is no apparent trend in the occurrence of such events. Karachi is the only station which has some consistency in terms of occurrence of such events.

The occurrence of very heavy event with 150 mm/day or more precipitation is quite unique in the southeastern monsoon region of Pakistan. Chhor is the only station which experienced such events in the past.

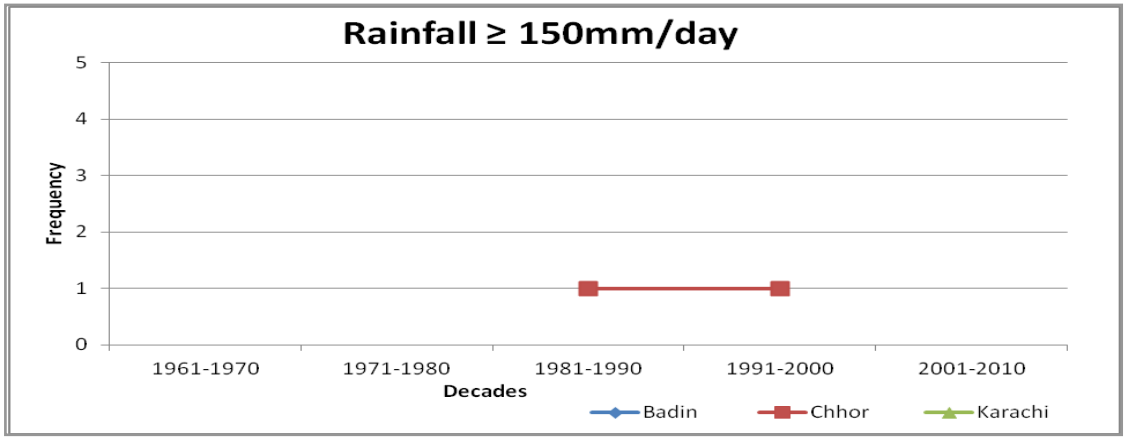

Figure 14: Frequency of rainfall ≥ 150 mm/day extreme events over the selected stations of southeastern monsoon belt of Pakistan.

Duration of Monsoon Season

In case of Badin, onset and withdrawal both have earlier trends but trend is sharper in case of withdrawal. Due to this reason the monsoon season is seems to be suppressing. Standard deviation in onset is 13 while in withdrawal date is 14 days.

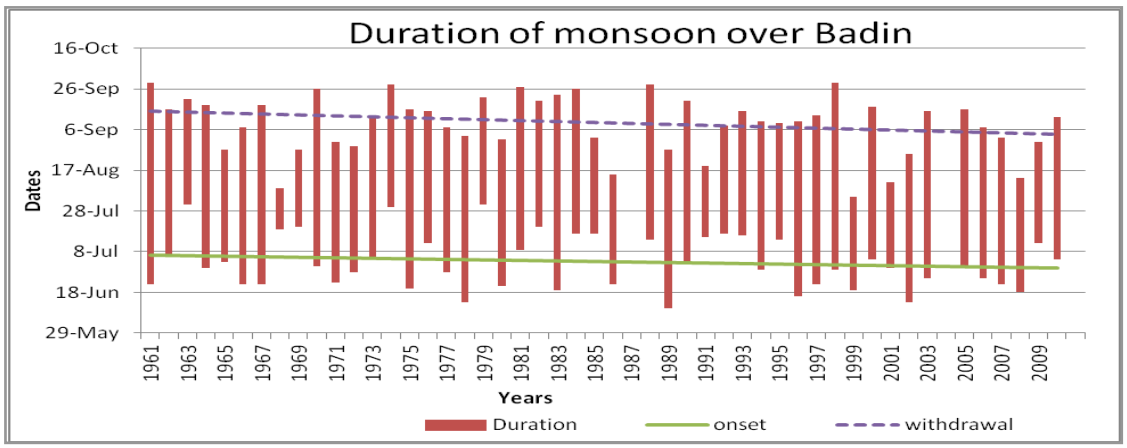

Figure 15: Duration of summer monsoon season over Badin. Onset and Withdrawal trend determine the duration of the season.

Chhor shows a late trend in case of both onset and withdrawal of summer monsoon. There seemed to be no significant variation in the duration of monsoon season. Standard deviation in onset is 16 while for withdrawal it is 15 days.

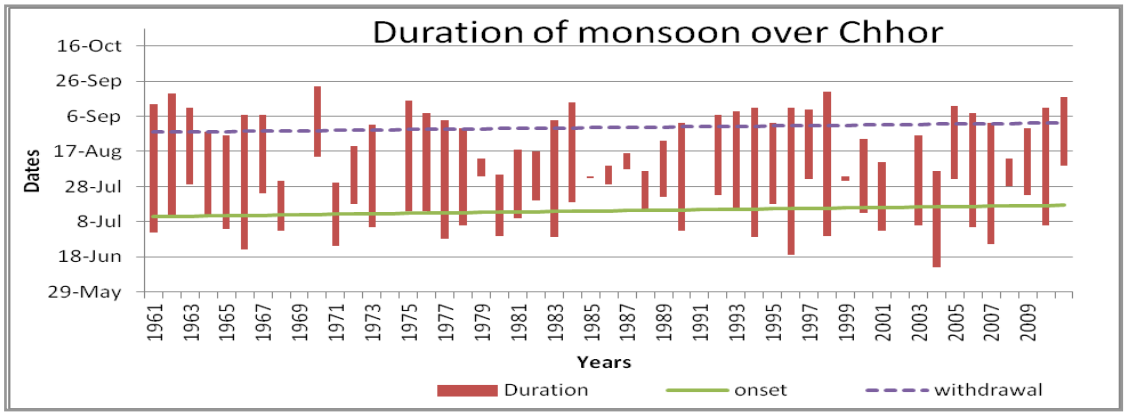

Figure 16: Duration of summer monsoon season over Chhor. Onset and Withdrawal trend determine the duration of the season.

Karachi has a trend towards late onset and same is the case for withdrawal. The onset trend is more sharp so duration of monsoon period seems to be decreasing. Standard deviation in onset is 18 while in withdrawal date is 17 days.

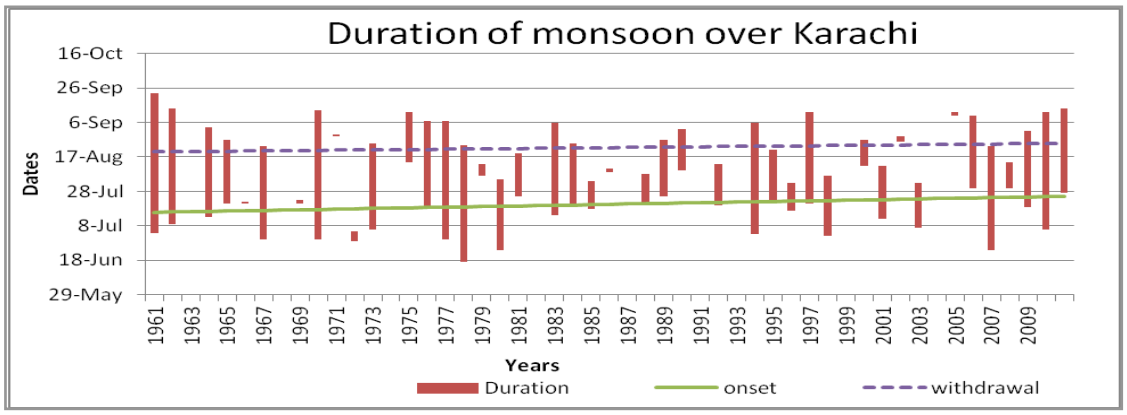

Figure 17: Duration of summer monsoon season over Karachi. Onset and Withdrawal trend determine the duration of the season.

Amount of Rainfall and Number of Rainy Days

For Badin there is an opposite trend in case of total amount of rainfall and number of rainy days. Total amount of rainfall has increasing trend while number of rainy days has a sharp decreasing trend.

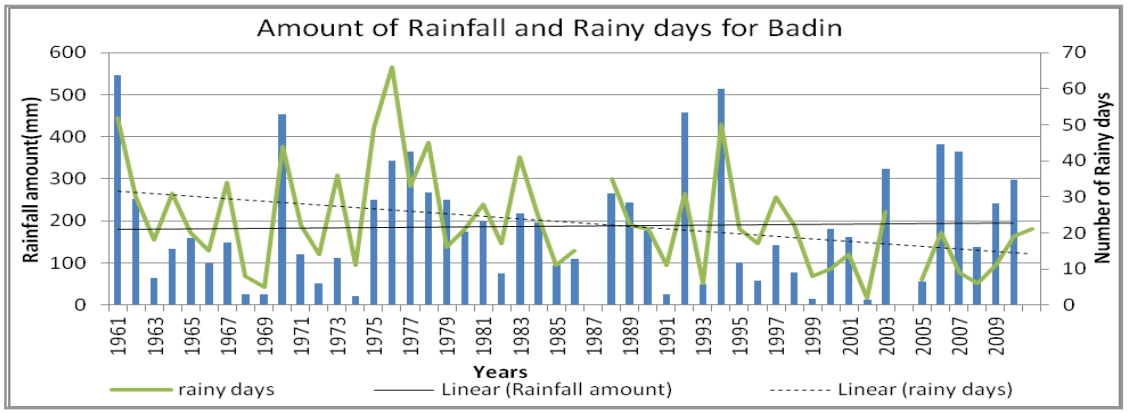

Figure 18: Cumulative rainfall for the season and number of rainy days for Badin, along with the trend line for the two parameters.

This indicates the increase in the frequency of extreme rainfall events. Instead of having more rainy days, heavy events contribute more to the total amount of rainfall. The decrease in length of the monsoon season (Figure 15) but increase in the total amount of rainfall also supports the increasing frequency of heavy events. The average number of rainy days is 22.

In case of Chhor the trend for both, the amount of rainfall and number of rainy days is increasing but trend is sharper for amount of rainfall. Variations in rainy days curves and rainfall amount bar graph justify each other with same trend of increase and decrease most of the times, deviations from the pattern again indicates the occurrence of heavy events. The average number of rainy days is 11.

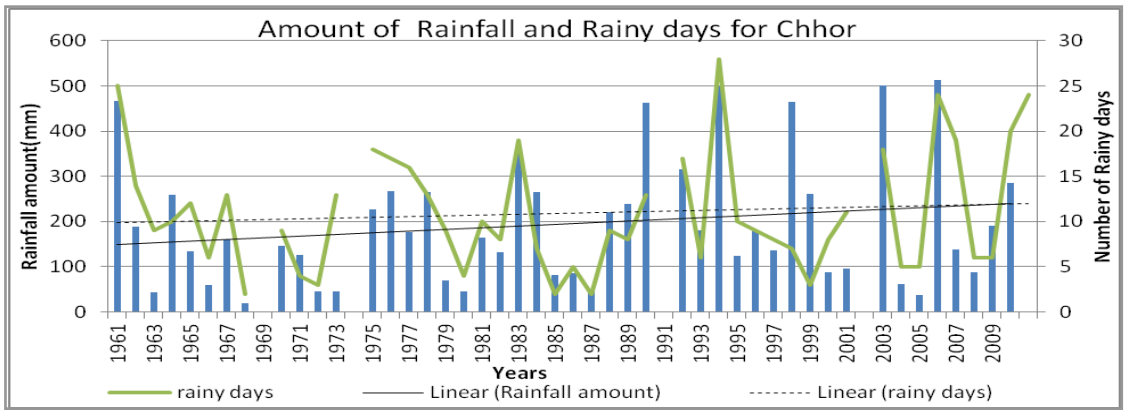

Figure 19: Cumulative rainfall for the season and number of rainy days for Chhor along with the trend line for the two parameters

Karachi exhibits a trend towards decrease in case of both amount of rainfall and number of rainy days. There were years with no rainfall indicating that the monsoon currents could not reach Karachi during a particular year. The increase or decrease in the number of rainy days is according to the variations in the amount of rainfall. The duration of monsoon season also seems to be decreasing (Figure 17). These all trends cumulate to predict a poor monsoon season for Karachi in future. The average number of rainy days is 10.

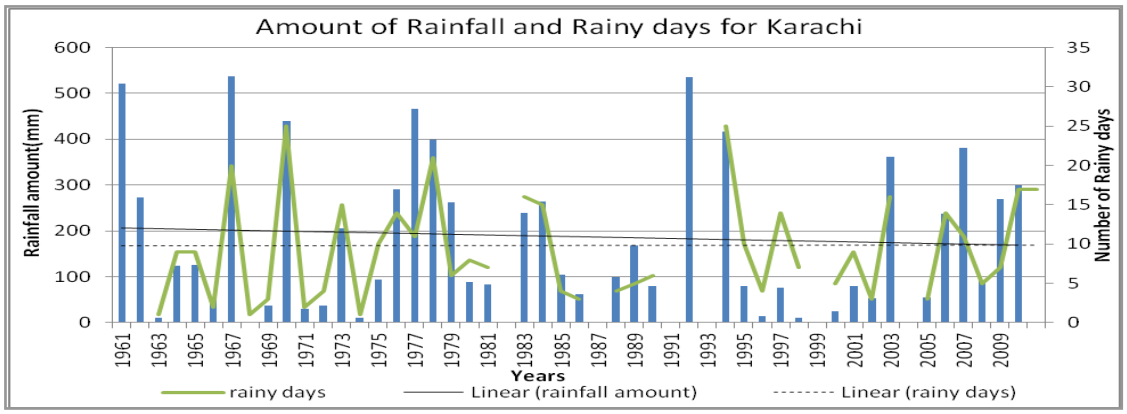

Figure 20: Cumulative rainfall for the season and number of rainy days for Karachi, along with the trend line for the two parameters.

Conclusion and Recommendations

The following results can be drawn from the above discussion.

- Islamabad has the highest frequency of the occurrence of rainfall ≥50 mm/day events while Lahore has the least frequency. Jhelum has a smooth trend and did not experience much variation in the existence of such events.

- In case of heavy events with rainfall≥100 mm/day, the decade 1991-2000 exhibited a higher frequency of such events, so was the case with rainfall ≥ 50 mm/day.
- The duration of monsoon season seems to be increasing for the stations Sialkot and more sharply in case of Lahore while Jhelum and Islamabad has a steady trend.
- At all the selected stations of the northeast Pakistan, the total amount of rainfall and the number of rainy days were in good agreement with each other except for Islamabad where the amount of rainfall was increasing much more rapidly than rainy days, indicating the occurrence of heavy events.
- Among the stations selected from the northeastern monsoon belt of Pakistan, Jhelum has a very steady trend for the monsoon season in terms of all the parameters under study. Analysis for Sialkot and Islamabad predicts increase both in rainfall amount and number of rainy days in future; although duration of the summer rainy season is not going to be alter much. Lahore seems to enjoy good monsoon in future with enhanced amount of rainfall, more rainy days and elongated duration.
- During the last decade all the selected stations of the southeastern Pakistan experienced highest frequency of extreme events with rainfall ≥ 50 mm/day during the last half century period. This indicates an active shift in the behavior of this branch of monsoon.
- For southeastern monsoon belt of the country, duration of monsoon season was seemed to be decreasing although Chhor has a steady trend.
- The trend for the total amount of rainfall and number of rainy days over the southeastern Pakistan supports the occurrence of heavy rainfall events. The average number of rainy days for the southeast Pakistan was much less as compared to the main monsoonal belt i.e. northeastern part. Having small duration of rainy season with comparatively little amount of rainfall, the probability of extreme precipitation events in future is not that much low.
- This paper is merely based on the quantitative analysis of the precipitation. Because despite of all the underlying weather phenomenon which derive the weather system, the outcome i.e precipitation is still the major influencing parameter. The objective of this paper is fulfilled by the analysis of the amount of rainfall as criteria adopted are also based upon the quantitative measurement of precipitation. To address the factors influencing these changes a separate study is needed. In that study the factors such as position and intensity of seasonal heat low and Tibetan high, formation and position of monsoon trough, position of Somali Jet etc could be analyzed. Effect of ENSO and IOD on the monsoon precipitation over Pakistan should also be investigated. In the recent era of climate variability each parameter need a separate detailed study.

References

Ahmad, S., T. Kioke and K. Nshii, 2011: Characteristics features of the Dry and Wet Summer Monsoon in Pakistan by Focusing on the Anomalous States of the Upper Troposphere.

Ananthkrishnan, R. and M. K. Sonam, 1998: The Onset of Southwest Monsoon over Kerala.1901-1980. J. Climatol, 8, 283-296.

Chakraborty, A., R. S. Nanjundian and J. Srinivasan, 2006: Theoretical aspects of the onset of Indian summer monsoon from perturbed orography simulations in a GCM. Ann. Geophys, 24, 2075-2089.

Compendium of Meteorology, 1979: World Meteorological Organization, WMO (364), 238.

Fasullo, J. and P. J. Webster, 2001: A Hydrological Definition of Indian Summer Monsoon Onset and Withdrawal. Journal of Climate, American Meteorological Society, 16, 3200-3211.

Goswami, B. N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan and P. K. Xavier, 2006: Increasing trend of extreme rain events over India in a warming environment. Science, (314), 1442-1445.

Krishnamurthy, V. and J. L. Kinter III, 2002: The Indian Monsoon and its Relation to Global Climate Variability. Global Climate. Springe-Verlage. 1-85.

Raju, P. V. S., U. C. Mohanty and R. Bhatla, 2005: Onset Charteristics of the Southwest monsoon over India. Int. J. Climate, 25,167-182.

Rao, Y. P., 1976: South West Monsoon. Indian Meteorological Department, 376

Rasul, G. and Q. Z. Chaudhry, 2004: A diagnostic study of Record heavy Rain in twin cities Islamabad-Rawalpindi, Advances in Atm. Science, 21(6), 970-988.

Rasul, G. and Q.Z.Chaudhry, 2010: Review of Advance in Research on Asian Summer Monsoon. Pakistan Journal of Meteorology, 6(12), 1-10.

Shamshad, K. M, 1988: Meteorology of Pakistan. Royal Book Company, 66.

Shukla. J., 1987: Interannual Variability of Monsoons.Monsoons, J.S. Fein and P.L Stephens, Eds., Wiley and Sons, 399-463.

Subbaramagya, I. and R. Ramanadhan, 1981: On the Onset of Indian Southwest monsoon and monsoon Genaral Circulation. Cambridge University press, 211-220.

Tanigucchi, K. and T. Kokie, 2006: Compositions of definitions of Indian summer monsoon onset: Better representation of rapid transitions of atmospheric conditions. Geophys. Res. Letter. 33

Wang, B. and Q. Ding, 2008: Objective Definition of the Indian Summer Monsoon Onset. American Meteorological Society, 3303-3316.

Wang, B. and Q. Ding, 2008: Objective Definition of the Indian Summer Monsoon Onset. American Meteorological Society, 3303-3316.