Research Paper

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Spatio-Temporal Variation of Precipitation in Kashmir Valley, Global Teleconnections

Geography

KEYWORDS : Climate variability, precipitation, regression, correlation, NAO

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ABSTRACT

The impacts of climate variability and change are global concerns. This study analyses the frequency of local and teleconnective association between precipitations over Kashmir valley and NAO using the monthly data for the period 1975–2009. Regression and correlation methods are used to analyze the spatial variation in precipitation. The overall association of the stations is analyzed by fitting a linear least square trend line to the annual deviation from the mean. All the stations except Qazigund have shown a decreasing trend. Correlation analyses have been discovered using Karl Pearson's method. A significant positive correlation is found at stations of Srinagar, Kupwara and Qazigund. The correlation of the stations during spring and summer seasons is also showing high degree of positive correlation. Most of the stations are strongly correlated with each other. Also the investigation of the association of NAO and precipitation shows a positive correlation in winter for most of the stations. However least positive correlation was found in summer.

Introduction

Global surface temperature has significantly risen during the last century and will continue to rise unless greenhouse gas emissions are drastically reduced (Houghton et al. 2001). The international panel on climate change (IPCC) predicts that the average global surface temperature will increase by between 2 and 4.5ºC and that there will be major changes in seasonal precipitation patterns by 2100 (IPCC, 2007). Global surface temperature has significantly risen during the last century and will continue to rise unless greenhouse gas emissions are drastically reduced (Houghton et al. 2001). Changes in the distribution of precipitation would also be likely to occur with serious consequences in some parts of the world (Mitchell, 1983). Ever increasing attention is devoted by climatologists to the study of precipitation trends, because, owing to possible variations or changes in the climate, the geographic distribution of rainfall frequency and intensity could be subjected to substantial modifications (IPCC, 1996). According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001), the global average surface temperature has increased by about 0.6 ± 0.2° C over the 20th century, and rainfall has decreased over much of the Northern Hemisphere sub-tropical regions by about 0.3% per decade during the 20th century. In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades. Though each and every part of the world is more or less susceptible to natural calamities, the Himalaya due to its complex geological structures, dynamic geomorphology, and seasonality in hydrometeorological conditions experience natural disasters very frequently, especially water induced hazards (Rawat et. al., 2011). Negative impacts of climate change on society and ecosystems are mostly expected to arise from extreme events, which highlight the need to identify climate extremes (Sillmann and Roeckner, 2008). Palmer and Raisanen (2002) analyzed 19 GCM simulations, and estimated that the probability of winter rainfall exceeding two standard deviations above normal will increase by factors of five and three respectively over northern and southern parts of the UK by 2100. The daily precipitation time series indicate significant positive trends for the United States (Karl and Knight, 1998). On a global scale, an increase in the rainfall should occur at middle and high latitudes, and a reduction at lower ones (Hulme *et al.*, 1998; Doherty *et al.*, 1999). Groisman *et al.* (1999) studied the relationship between the increase in total precipitation, and the frequency of heavy rain events by applying a simple statistical model based on the gamma distribution to summer data of eight countries: Canada, the United States, Mexico, the former Soviet Union, China, Australia, Poland and Norway. The results showed that the shape parameter of the precipitation distributions remained rather stable, independent of total precipitation, while the scale parameter was most variable. If these results can be generalized and used as a model for the future, as total precipitation increases, a disproportionate increase in heavy precipitation has to be expected (Groisman *et al.*, 1999).

Data and methodology

Kashmir valley is a region of northern Jammu and Kashmir with an area of 4865 km^2. Because of its geographic position and mountainous environment, its climate is characterized by cold winters and mild summers. The monthly and annual rainfall data from 1975 to June 2009 set used in this work were selected from Indian Metrological Department, Pune. Due to lack of data, only six main stations representing the valley were taken into account for the study which are given in table. The Pearson correlation was used to investigate the association between total rainfall of various stations. Also, correlation between various stations and NAO data was also established. The NAO index for the period 1975 to 2009 was downloaded from www.cru.uea.ac.uk. The cumulative departure from the mean (CDM) was also calculated to detect the trends over shorter period of time using the following formula:

$$CDM = \sum_{i=1}^{n} \frac{Xi - X'}{X'}$$

Study area

The study area is located in the northwest corner of India in the state of Jammu and Kashmir. Its geographical position is between 30°17' N and 37°5' N (latitude) and 73° 26' E and 80°30' E (longitude). Kashmir is situated within the Himalayan mountain system. The valley of Kashmir was formed by folding and faulting as the Himalayan mountain chain was thrust between the Indian sub continent and the rest of Asia. The valley runs northwest to southeast along the strike of the mountain chain and is drained by the river Jhelum which cuts through the Pir Panjal at the Baramullah gap. This structural basin is 135 kilometers in length with a maximum width of 40 kilometers and ranges in altitude from 5200 -6000 ft above the sea level. Its floor stands 1600 meters above sea level in the Jhelum flood plain. It covers an area of about 4865 km2. The valley is accessible from the Punjab plain through two famous passes; the Pir Panjal pass (3494m) and Banihal pass (2832m). The Jhelum is the main artery of the valley. The seasonal and total precipitation of Kashmir valley is given in table 1.

Table 1: Seasonal and total precipitation of Kashmir Valley

Station	Total	Jan.- March	April-June	July-September	October-December	October-March %age of total	April-September %age of total
Pahalgam	1124.7	439.2	361.8	186.6	137.1	51.24	48.76
Kokernag	1100.9	459	329.8	187.3	124.8	53.03	46.97
Kupwara	913.5	415.4	300.4	119.1	78.6	54.08	45.92
Gulmarg	933.1	350.4	355.7	137.8	89.2	47.11	52.89
Srinagar	649.7	190.7	158.5	120.9	179.6	56.99	43.01
Qazigund	990.5	427.9	279.5	196.5	86.6	51.94	48.06

Correlation of precipitation time series

Ever increasing attention is devoted by climatologists to the study of precipitation trends, because, owing to possible variations or changes in the climate, the geographic distribution of rainfall frequency and intensity could be subjected to substantial modifications (IPCC, 1996). On a global scale, an increase in the rainfall should occur at middle and high latitudes, and a reduction at lower ones (Hulme *et al*., 1998; Trenberth, 1998; Doherty *et al*., 1999).As it has been seen that the global change is a multi-faceted issue incorporating direct and indirect effects of human activity. In this regard mountain environments are specifically important particularly the steep slopes found in these regions. Therefore, some of the sharpest environmental gradients are found in the mountains on the earth surface (Singh and Roy; 2002). Global land precipitation has increased by about 2% since the beginning of the 20th century (Jones and Hulme, 1996; Hulme et al., 1998). Mekis and Hogg (1999) showed that precipitation in Canada has increased by an average of more than 10% over the 20th century. Haylock and Nicholls (2000) reveal a large decrease in total precipitation and related rain days in southwestern Australia.

Table 2: Seasonal rainfall/ precipitation correlation between stations in Kashmir Valley (Upper Triangle) October to March (Lower Triangle) April to September

Station	Pahalgam	Kokernag	Kupwara	Gulmarg	Srinagar	Qazigund
Pahalgam		-0.068	0.59	0.42	0.68	0.52
Kokernag	0.74		-0.196	-0.208	0.022	-0.057
Kupwara	0.65	0.361		0.21	0.664	0.215
Gulmarg	0.352	0.217	0.338		0.192	0.104
Srinagar	0.72	0.761	0.685	0.427		0.18
Qazigund	-0.026	0.095	0.333	0.056	-0.013	

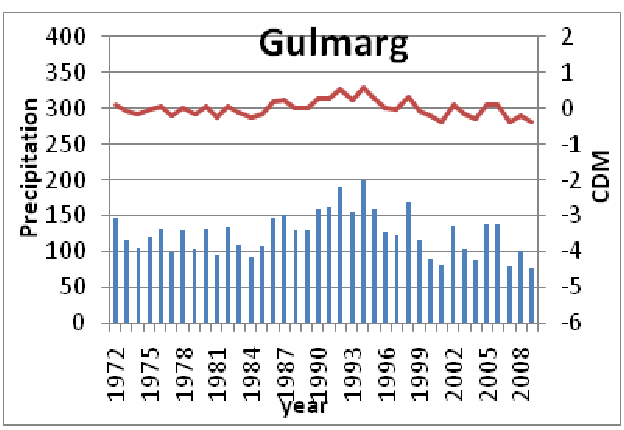
The valley receives considerable rainfall throughout the year but mostly during winter in the form of snow due to western disturbances originating from the Mediterranean Sea. Correlation matrixes between various stations of the valley are shown in table 2. The region receives most of the rainfall during winter season. The stations are mostly positively correlated across the valley. Significant correlations (>.30) are obtained by stations of Srinagar, Kupwara and Qazigund. Srinagar which receives the least annual rainfall than other stations of the valley has secured the highest correlation. Pahalgam and Kokernag, the two important stations of the valley receive highest annual rainfall, are negatively correlated. The correlation of Kupwara with Pahalgam and Srinagar is also significant. There is also occasional weak negative correlation between stations of the valley.

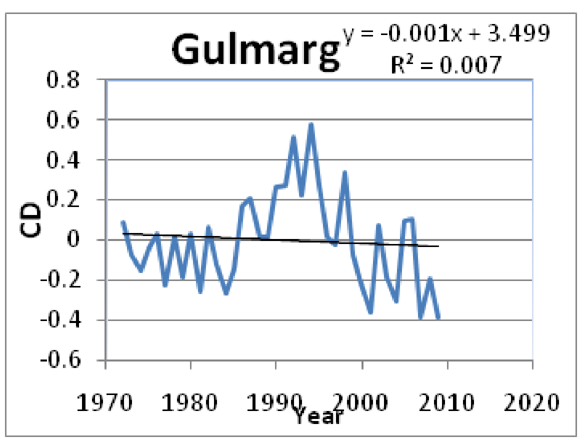
The correlation of the stations during spring and summer (April to September) is also showing high degree of positive correlation. Most of the stations are strongly correlated with each other. The highest correlation in this part of the year is again witnessed by Srinagar. Again, very weak and insignificant correlation is witnessed by few stations of the valley. Archer and Fowler in 2004 found that correlated winter precipitation over the upper Indus Basin may be a consistent regional pattern of time series change over an area which include stations north and south of Himalaya divide and incorporated stations situated on valley floor. Also, the weak spatial summer correlation suggested a consistent pattern of change only for north stations, with diverse and possibly opposing patterns elsewhere.

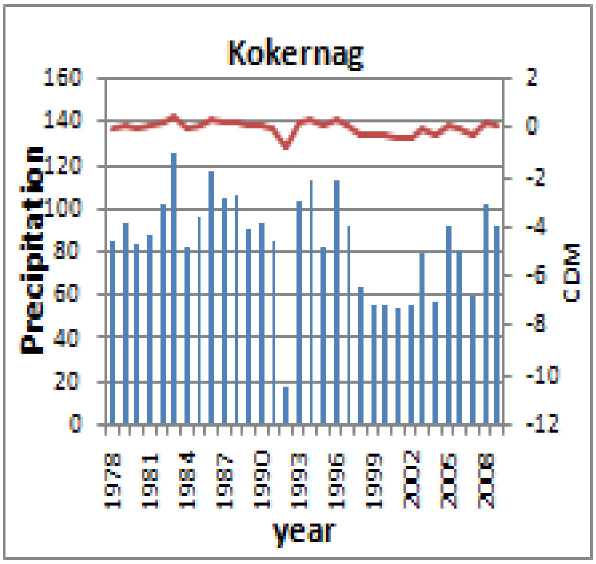
Time series analysis: regional trends

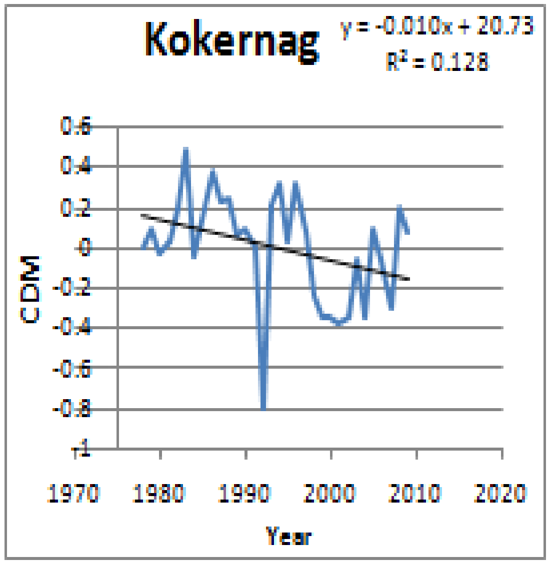
The overall association of the stations is analyzed by fitting a linear least square trend line to the annual deviation from the mean. Seasonal, summer and winter trends are shown in Fig. 2, Fig 3 and Fig 4 respectively. The stations of Srinagar, Kupwara, Kokernag and Pahalgam are witnessing a significant downward annual trend. Qazigund on the other hand is highlighting a slight upward annual trend. There is a sharp increasing trend for the stations of Kupwara and Pahalgam.

It is interesting to note that Pahalgam is the station which receives maximum precipitation in the valley is affected most. The precipitation in the winter season is received by virtue of the cyclones which develop in the Mediterranean Sea. The only first class city of the area, Srinagar is witnessing a significant downward trend. Rupa Kumar et. al. (1994) reported that warming trend over India was 0.57˚ C per 100 years. The summer precipitation of the valley shows no significant trend. There is a slight decreasing summer precipitation trend for the stations of Pahalgam, Kupwara and Kokernag. According to Rashid Ashraf Wani and Vijaya P. Khairkar (2012), the seasonal mean minimum temperature series of Srinagar indicate that the winter season and spring season show warming trend especially for winter season. Murugan et al. (2005) found rainfall has increased over all states except Punjab, Rajasthan, and Tamil Nadu, which showed slight decrease in precipitation during 1960-1990. Krishnakumar et al. (2009) revealed that there is a significant decrease in southwest monsoon rainfall while increase in post-monsoon rainfall over the state of Kerala and rainfall during winter and summer seasons show insignificant increasing trend. Climate change scenario in India revealed that the annual mean temperature has increased by 0.48˚ C in the past 100 years (Srivastava, 2007)






Kokernag
Precipitation
CDM
year


Kokernag
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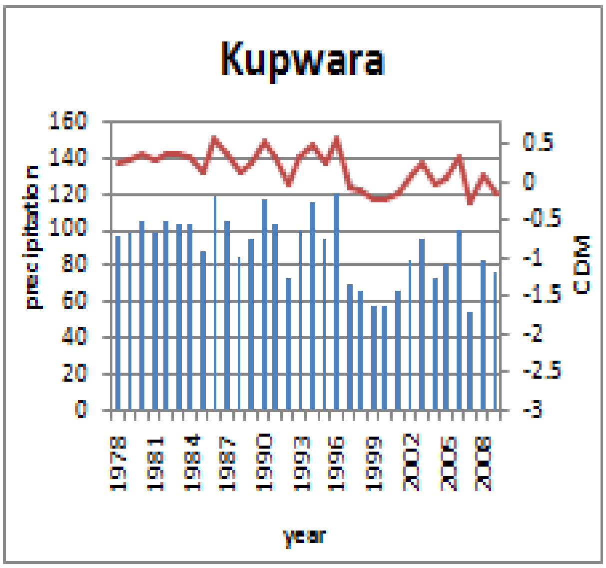
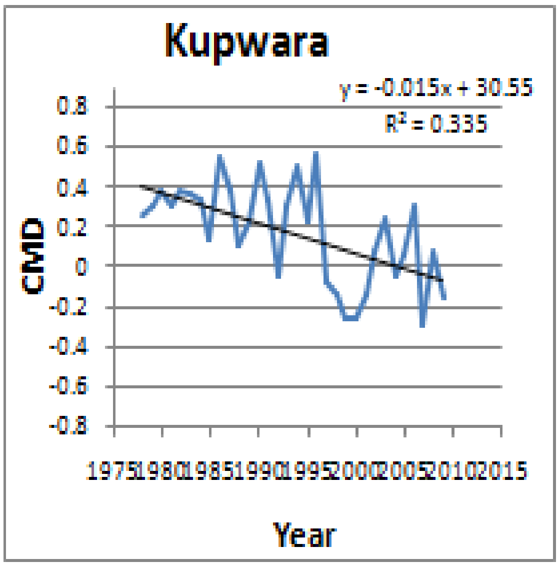
R² = 0.128
CDM
Year


Kupwara
precipitation
CDM
year


Kupwara
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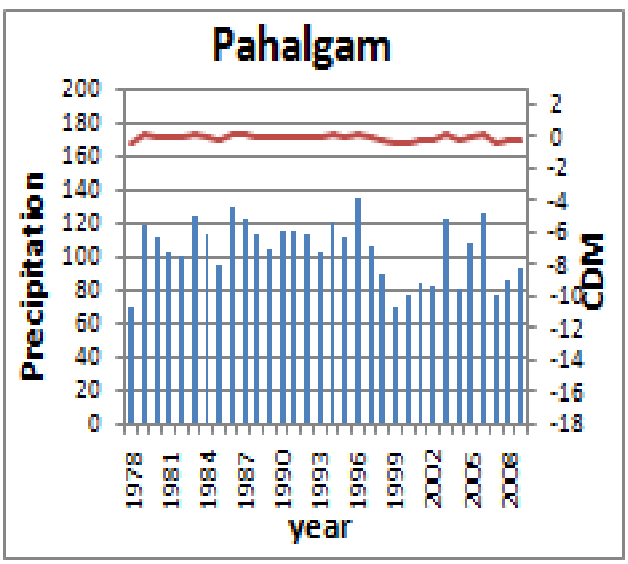
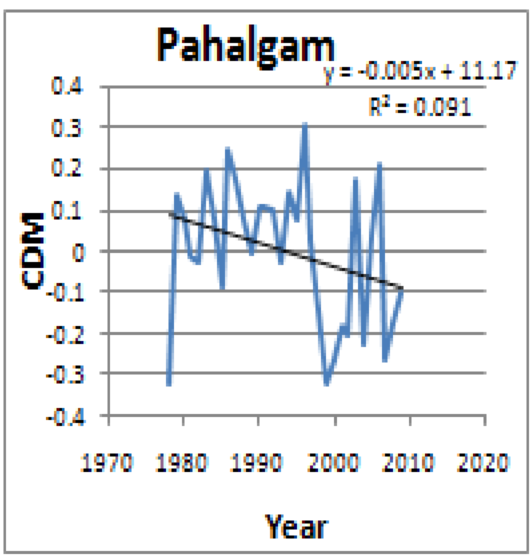
R² = 0.335
CMD
Year


Pahalgam
Precipitation
CDM
year


Pahalgam
y = -0.005x + 11.17
R² = 0.091
CDM
Year

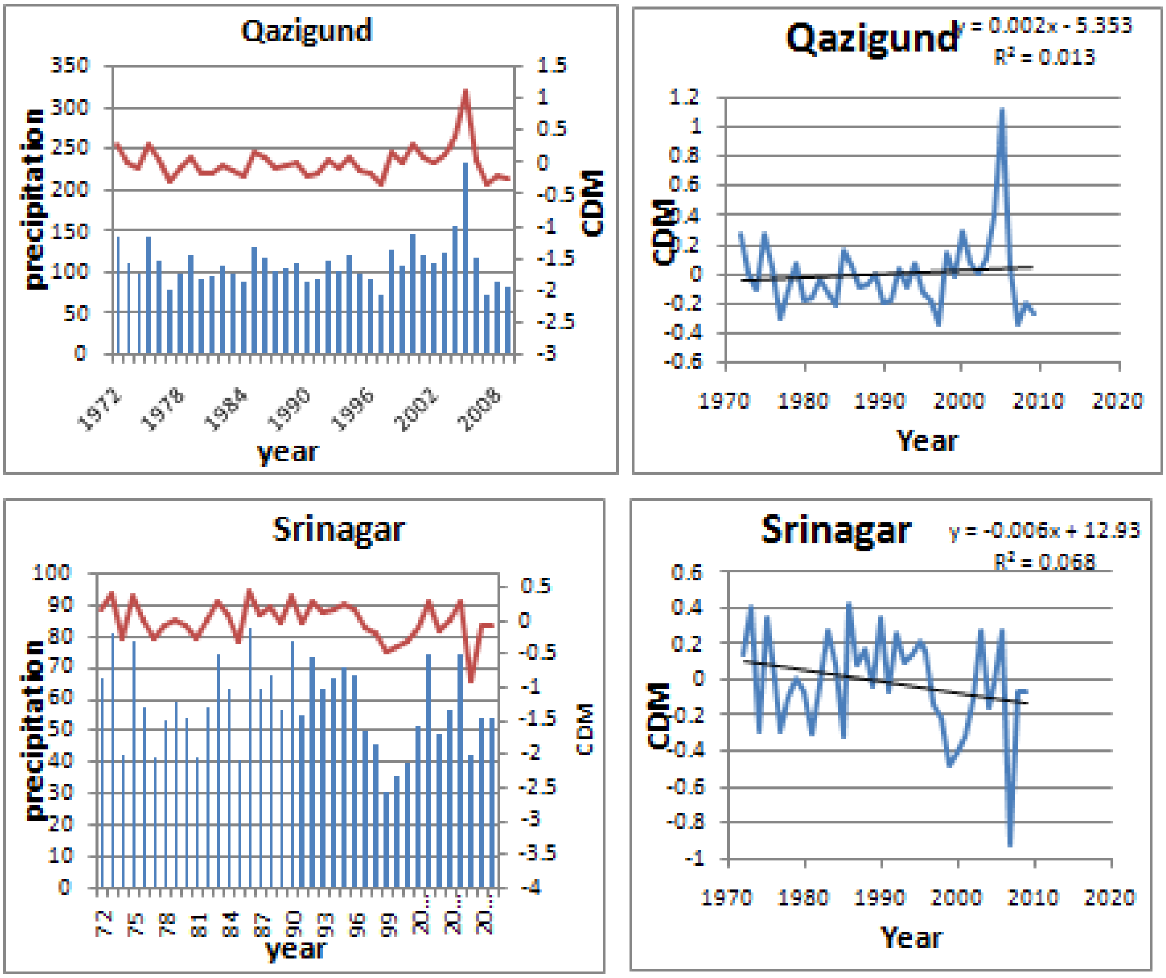
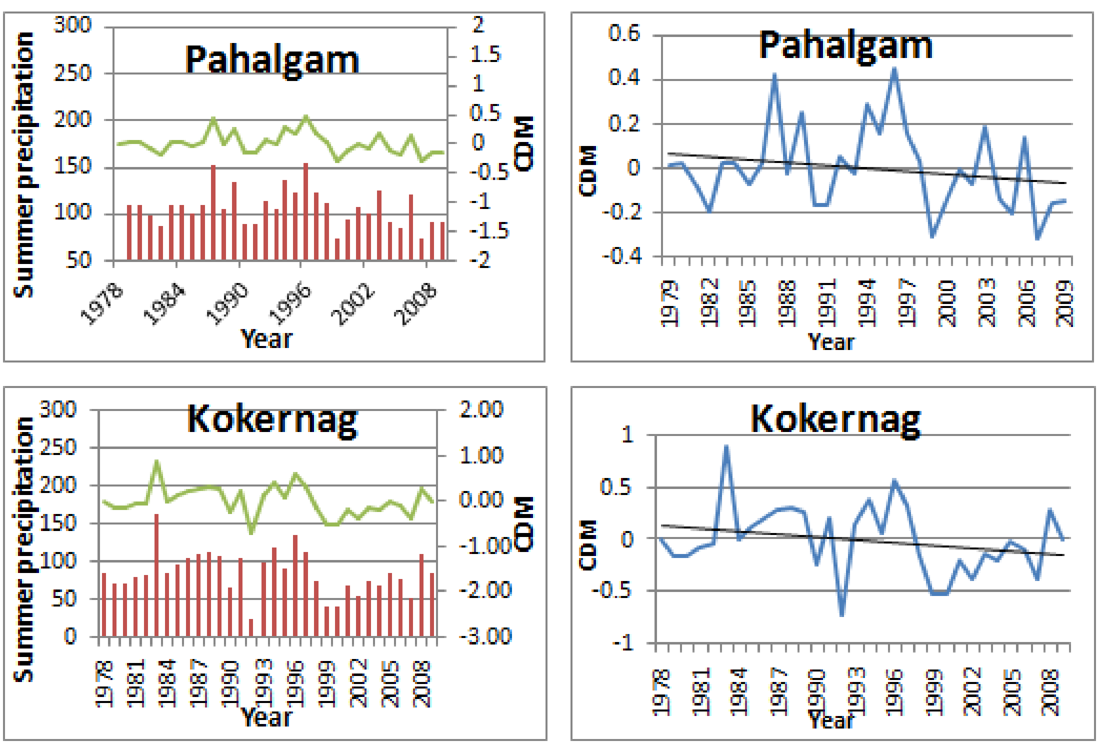


Fig 2: Trends of precipitation from 1972-2009. Right hand shows the deviation from the mean annual precipitation, with a least squares fitted trend and left hand shows annual precipitation with cumulative departure from mean plotted as a line.



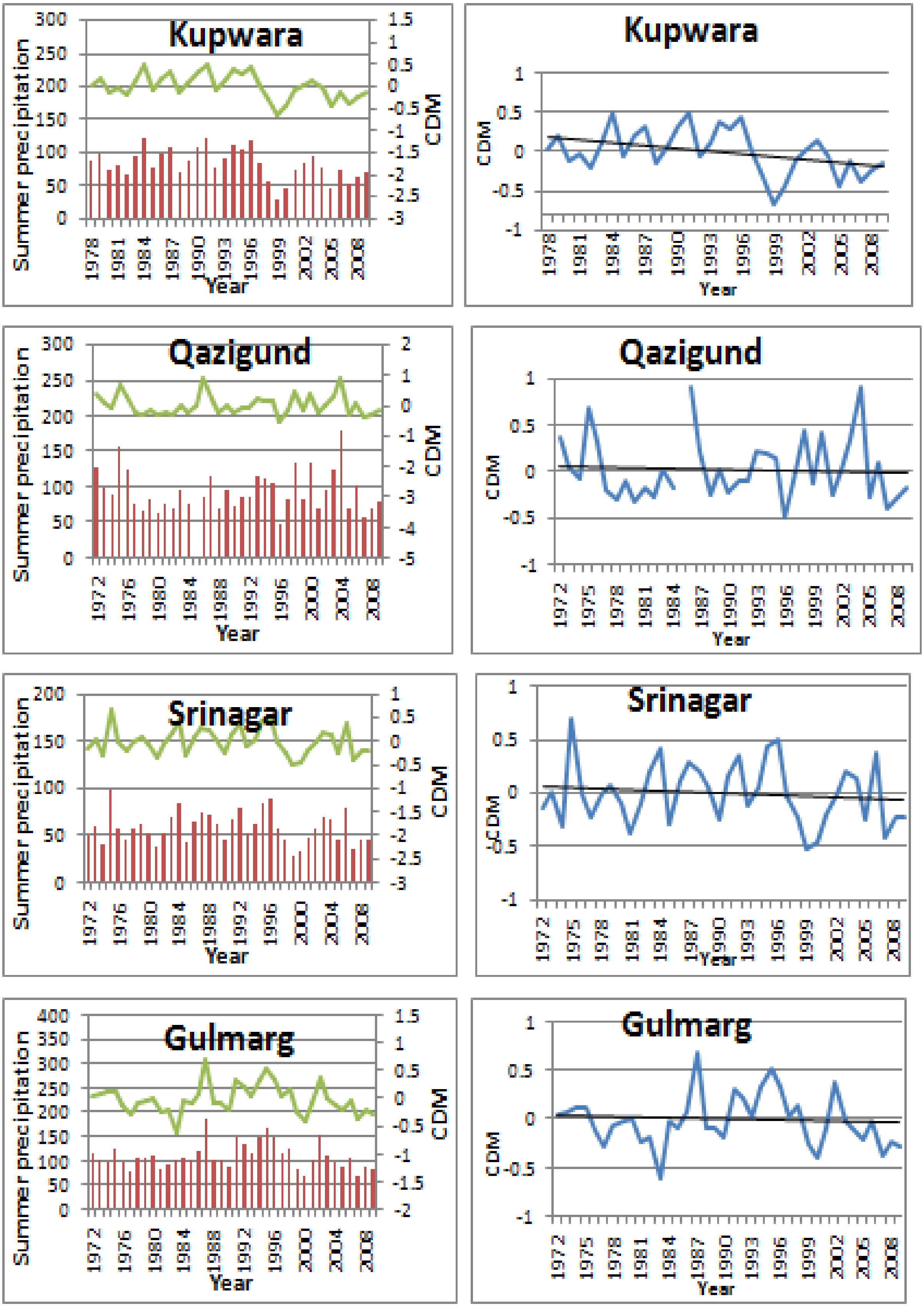
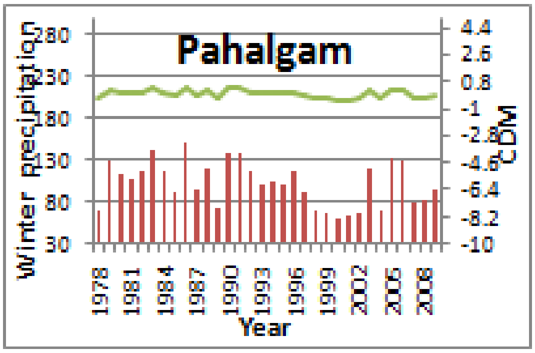
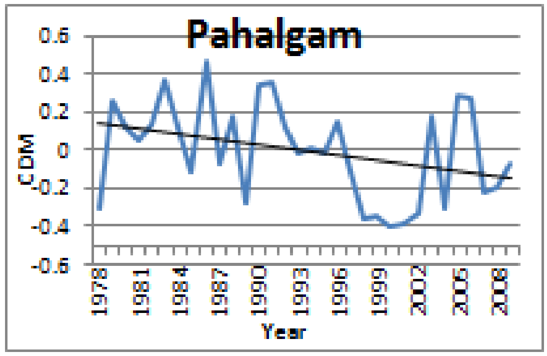
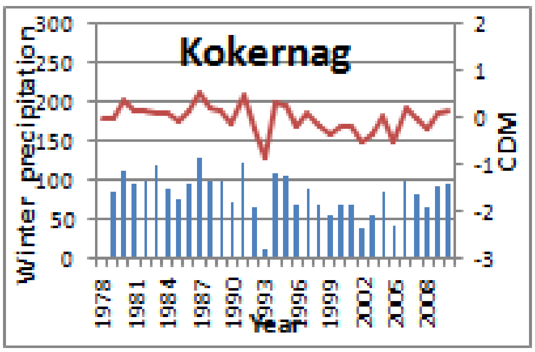


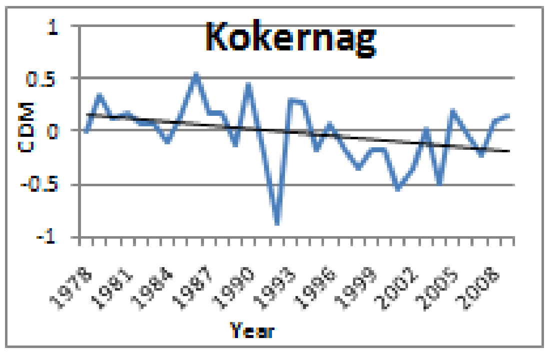
Fig 3: Trends of summer precipitation from 1972-2009. Right hand shows the deviation from the mean annual precipitation, with a least squares fitted trend and left hand shows annual precipitation with cumulative departure from mean plotted as a line.

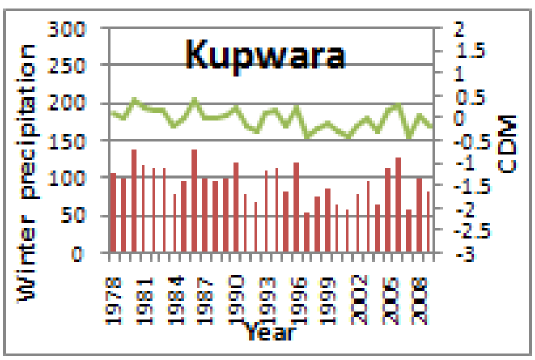
Wani Rashid A. and Khairkar V. P. (2012) found that trend for the month of December is showing an alarming declining trend; decreasing from 11.1 in 1970 to 8.5 in 2006 which is a clear signal of delaying of winter in the region. Most of the stations under study are found to be positively correlated for winter season but some are negatively correlated as well. Kokernag was found to be negatively correlated with Kupwara and Gulmarg for winter. Pahalgam was found to be strongly positively correlated with the other 5 stations except Qazigund for summer season. Also, Srinagar was found strongly positively correlated with Kokernag and Kupwara for summer season. Abrol, Y.P. et al (1996) made an attempt to look at the mean pattern of precipitation and surface air temperature variations over whole of South Asia and also to summarize the vast literature on climate change and variability over India providing the essential backgrounds. Baraonkar et al (1996) found significantly decreasing trends in both winter and summer precipitation in a record at Shimla from 1876 to 1982. Shresth et al (2000) found no distinction in long term trends in precipitation (mainly monsoon origin) from 1948 to 1994 in the Nepalese Himalaya. There is a sharp decreasing trend for the stations of Pahalgam, Kokernag and Kupwara which are located at the border and on hilly slopes. Though the trend is insignificant but is visible and the rainfall total of these stations is small but most variable.

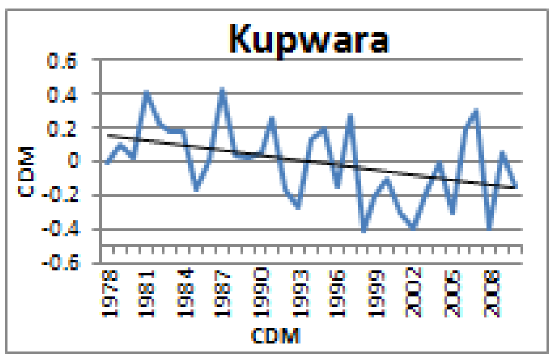


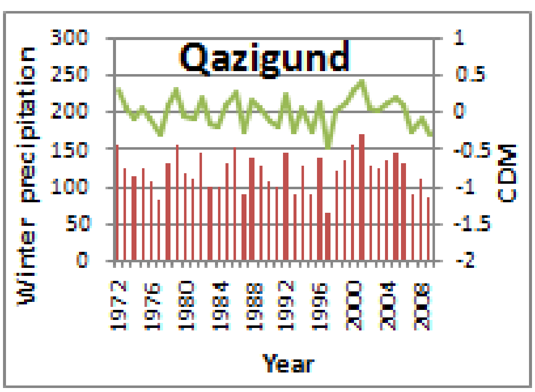


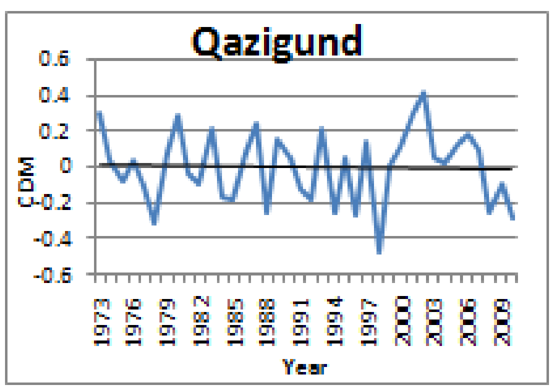












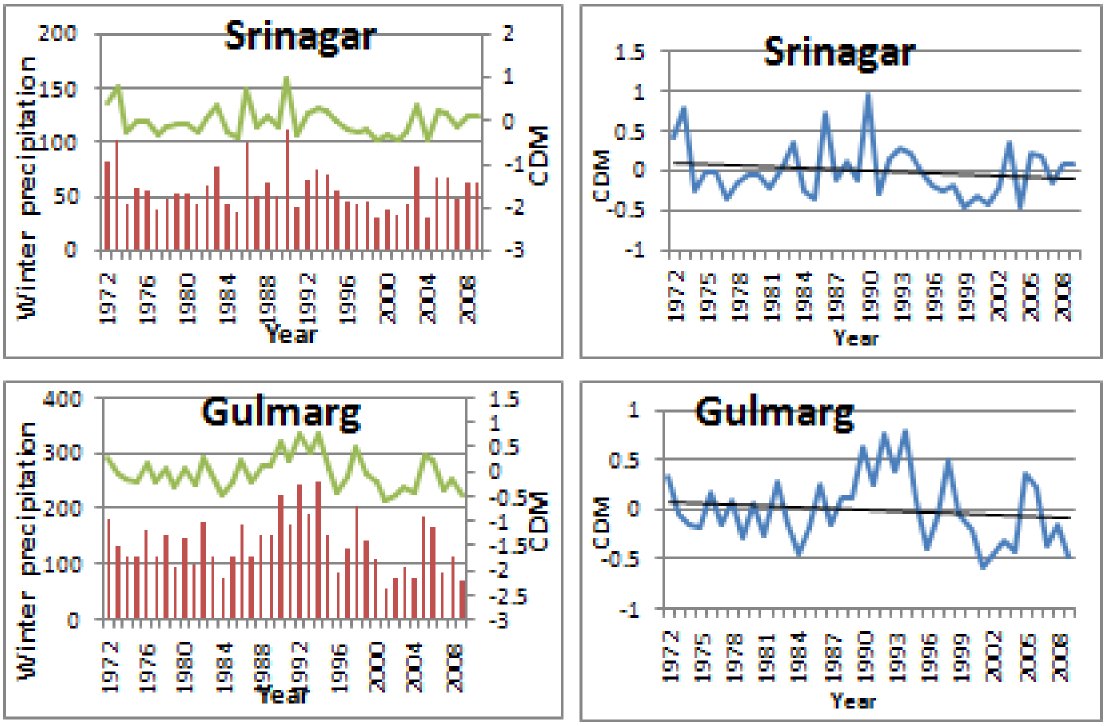


Fig 4: Trends of summer precipitation from 1972-2009. Right hand shows the deviation from the mean annual precipitation, with a least squares fitted trend and left hand shows annual precipitation with cumulative departure from mean plotted as a line.

Links to Teleconnections

Teleconnection generally refers to the linkage of seemingly unrelated climate anomalies over great distances. Traditional definition of the NAO define it as the difference in pressure between a station in Iceland and one in the Azores (Walker and Bliss, 1932). According to Wu et al. (2007), the winter anomalous circulation over the North Atlantic displays an equivalent barotropic structure, with a high pressure belt in the mid latitudes to the subtropics and a low pressure cap over the entire Arctic, resembling the positive phase of the Arctic Oscillation– North Atlantic Oscillation (AO–NAO). These patterns can extend completely around the globe, and during this circumglobal phase include a north-south dipole over the Atlantic that closely resembles the NAO (Branstator, 2002).

Table 3: Correlation between monthly average values of normalized sea level pressure difference over the Azores and Iceland (NAO) and monthly rainfall totals at various stations during the period 1978 -2010. Significant correlations are shown in bold and negative correlations are shown in italic.

	Gulmarg	Kokernag	Kupwara	Pahalgam	Qazigund	Srinagar
January	0.432	0.158	0.115	0.318	0.12	0.277
February	0.123	0.166	-0.042	-0.031	0.153	0.013
March	0.362	0.092	0.124	0.214	0.364	0.324
April	0.227	0.15	0.212	0.26	0.598	0.312
May	-0.201	-0.17	0.035	-0.004	-0.054	0.112
June	-0.148	0.13	0.334	-0.06	-0.047	0.033
July	0.65	-0.372	-0.31	-0.283	0.011	-0.121
August	0.093	-0.019	0.257	0.204	0.185	0.363
September	0.395	-0.368	0.30	-0.51	-0.997	0.451
October	-0.034	0.144	0.088	0.114	0.04	0.125
November	-0.285	0.324	0.569	0.348	0.29	0.629
December	0.27	0.317	0.313	0.194	-0.031	0.159

According to Raj et al., there exists a high correlation of the order of 0.87 based on the 100 year period (1901–2000) rainfall data between NEMR of Tamil Nadu and NEMR of the region covering Tamil Nadu as well as Kerala, CAP and Rayalaseema (Raj *et al* (2004). Significant correlation was obtained for some months as shown in table 3. Significant correlation between the NAO and monthly precipitation for the winter months from November to January and Mach to April particularly in Kokernag, Kupwara and Pahalgam for winter period and Qazigund and Srinagar for March and April. Hurrell (1995) has shown that during the winter half of the year, the oscillation provides a simple means of explaining much of the variability of surface temperature and precipitation patterns over Europe. There is a strong correlation between winter precipitation and NAO monthly average of the same period. There is an insignificant correlation between monthly NAO index and February, May, and June (except for Kupwara which is positively correlated with June NAO). Qian et al. (2003) observed a significant link between summer temperature over UK and the preceding later winter NAO index. Significant positive correlation between monthly rainfall/ precipitation and the monthly NAO was found for the Summer months of July, June and April. The highest positive correlation was found for Gulmarg station for the month of July. September was also significantly found positively correlated with the monthly NAO. Kokernag station was found positively correlated with the winter months of November and December. Kupwara was found positively correlated with the monthly NAO for the months of June, September and November. Pahalgam is also positively correlated with the monthly NAO for the months of January and November whereas Qazigund and Srinagar are found positively correlated for the spring months of March and April. Significant correlation was also witnessed by Srinagar for the months of August, September and November. According to Jhones et al. (1997), rainfall changes in the Karakoram region are related at least partially to the variability of the North Atlantic Oscillation index (NAO index). Sharma et. al. (2010) suggest that the ENSO and LNSO short term climate signal is one of the global teleconnections that cause perturbations in the performance of the SW monsoon over India in terms of subnormal and abnormal monsoon weather triggering droughts and flood situations, respectively. The influence of ocean surface patterns, such as those associated with the El Nino-Southern Oscillation (ENSO), have been noted as significant global teleconnections for atmospheric circulation and land surface climate [Glantz et. al., 1991].

Conclusion

Seasonal variations and trends have been assessed for the period 1975 to 2009. The total amount of rainfall was found to have decreased significantly at most of the stations during the winter period. There is spatially high correlation between summer and winter precipitation across the whole valley. There is highly significant downward trend for winter precipitation for Pahalgam whereas significant downward trend for summer precipitation was witnessed by Kokernag. Also, the annual precipitation trend for the stations of Kokernag, Kupwara and Pahalgam is showing an alarming increasing trend. Findings also suggest that there is a significant correlation between North Atlantic Oscillation and winter precipitation particularly during the period of September, November and December. Summer precipitation for most of the stations was found negatively correlated with the NAO. It can be deduced from the results that the major El Nino processes that start by the end of December in the eastern pacific contributed significantly to Kashmir Climate. According to Kenyon, J. and Hegerl G. C. (2007), the NAO/NAM has a significant response of temperature over Europe and Asia, and North America. The decrease in annual precipitation may be caused by climate change. Over the 20th century (1900 to 1995), there were relatively small increases in global land areas experiencing severe drought or severe wet conditions. In some regions, such as parts of Asia and Africa, the frequency and intensity of drought have been observed to increase in recent decades (Dore, 2005). The decrease in the total amount of rainfall especially during the winter season could create problems for the agriculture, forestry and energy sectors, public health and water resources.

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