MAUSAM, **57**, 3 (July 2006), 431-436

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Analysis of spatial patterns of trends in the frequency and intensity of Indian precipitation

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(*Received 19 February 2004, Modified 5 November 2004*)

सार – इस शोध पत्र में समूचे भारत के 129 मौसम केंद्रों के लिए 1910 से 2000 तक की समयावधि के दैनिक वर्षा के रिकार्डों को एकत्रित किया गया है । इसके बाद विभिन्न मौसम विज्ञानिक उपखंड़ों के लिए माध्य वार्षिक वर्षा के मानों के अनुसार इन केंद्रों को नौ भिन्न–भिन्न क्षेत्रों में बाँटा गया है । प्रत्येक क्षेत्र के लिए हर पाँच प्रतिशत के अंतराल पर कुल वर्षा और वर्षा की बारंबारता का विस्तृत विश्लेषण किया है । इन परिणामों से सामान्यतः भारत के लगभग सभी भागों में वर्षा की कमी का पता चला है जबकि केवल उत्तर पश्चिमी भागों में वर्षा में वृद्धि देखी गई है । वर्षा के प्रति सैंकड़ा वर्ग अंतरालों के अनुसार किए गए हमारे विश्लेषण से यह पता चलता है कि विशेष रूप से देश के आधे भाग पश्चिमी क्षेत्र में अतिवृष्टि की घटनाएँ बार–बार होती हैं । भारतीय वर्षा के स्थानिक आयामों पर प्रकाश डालने वाले हाउगटन इत्यादि (2001) के आई. पी. सी. सी. के वैज्ञानिक मूल्यांकन और अन्य अध्ययनों के साथ हमारे परिणाम व्यापक रूप से मेल खाते हैं ।

ABSTRACT. We assembled daily precipitation records for 129 weather stations spread all over India for the time period 1910 to 2000. Next we classified these stations into nine different regions according to the mean annual precipitation values for the different India meteorological sub-divisions. We conducted detailed analysis of total precipitation and the frequency of precipitation for each five-percentile interval for every region. In general, our results show a decrease in precipitation throughout much of India with only the northwest showing an increase. Our analyses by precipitation percentile class intervals show that the most extreme events have become more frequent, particularly in the western half of the country. Our results are broadly consistent with the IPCC Scientific Assessment by Houghton *et al*. (2001) and other studies focusing on the spatial dimensions of Indian precipitation over time.

Key words – Precipitation trends, Spatial patterns, Monsoon.

1. Introduction

The amount and timing of precipitation taking place in different parts of the Indian subcontinent have been the focus of research in many studies. The regional variations in the precipitation patterns in India are a result of a combination of factors both at the local and global level with the Himalayas in the north playing a major role in the spatial variability of the precipitation in the northern plains. The Indian subcontinent, even though a very small portion of the Earth's surface, has contrasting climates consisting of heavy precipitation in the far east to the desert type of climate in the northwest and in the interior of the continents. The efficient forecasting of the timing and quantity of precipitation occurring in the different parts of the subcontinent is of utmost importance in view of the heavy dependence of the Indian economy on the agricultural sector that in turn is predominantly decided by the performance of the monsoons.

The variability of the intensity and the frequency of precipitation occurring in India is a well-researched topic. Parthasarathy and Dhar (1976) analyzed the seasonal and annual precipitation of India from 1901 to 1960 found a significant increase of 5% in thirty year mean in the southwest monsoon and the annual precipitation. The observed increase in the winter monsoon was not statistically significant. Rupa Kumar *et al.* (1992) examined the trends in the total precipitation during 1871-1984, taking place in different parts of the Indian subcontinent, and found increasing trends in the precipitation all along the west coast and northwest India. Their study suggests a decreasing trend in the overall precipitation in eastern Madhya Pradesh and adjoining northeast. Kothyari and Singh (1996) in their study of the long-term trends over the Gangetic basin suggest that the precipitation variables had a decreasing trend starting in the 1960s. The results of their study showed that the rainfall variables had a decreasing trend and the temperature had an increasing trend. The decreasing trends in the precipitation variables were observed to have begun around the second half of the 1960s, and have implications for the Indian economy. Chhabra *et al*. (1997) studied the differences in the averages of rainfall during the periods 1931 to 1960 and 1961 to 1990 for a set of stations located throughout India. Their results indicate

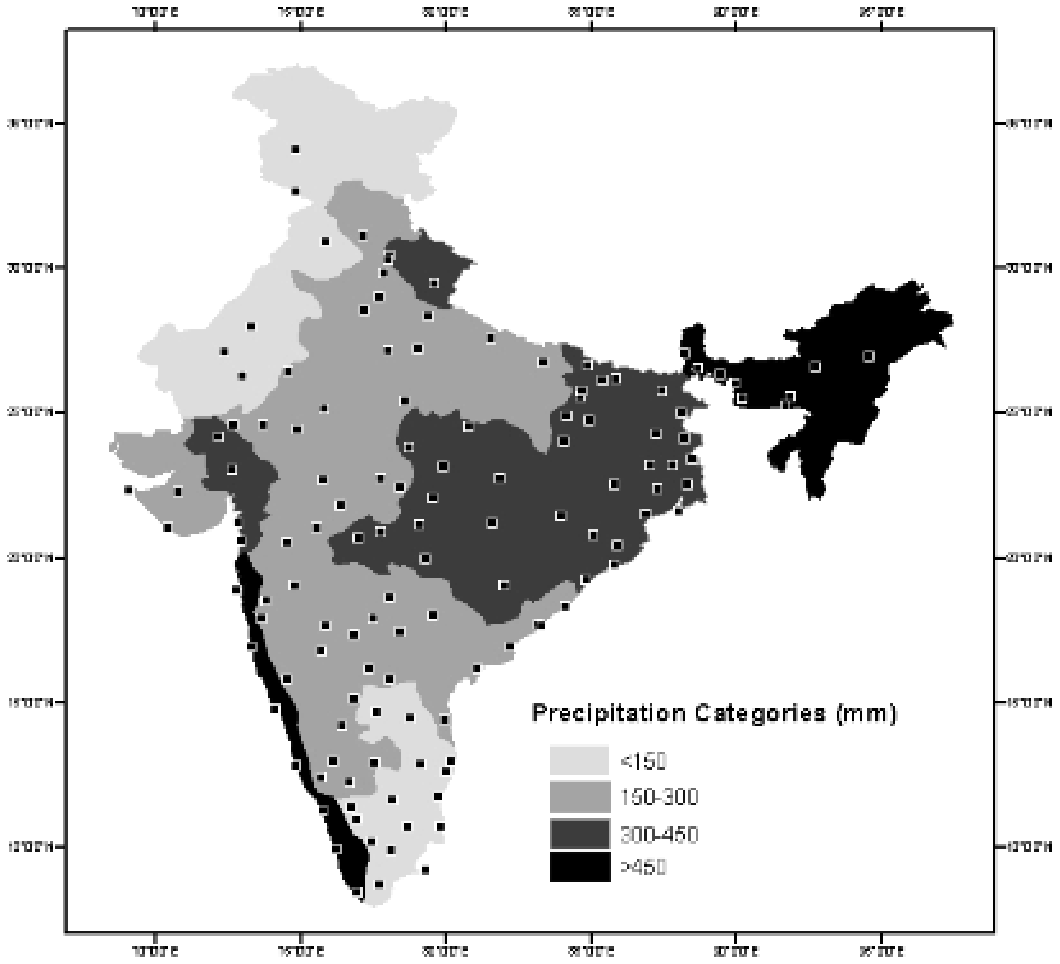

Fig. 1. Location of weather stations in India

a decrease in the precipitation in the hill stations and an increase in the precipitation in the urbanized/industrialized cities. Hulme and Viner (1998) found increase of up to 50% in precipitation in some regions of the Indian subcontinent, with a possible reduction in the dry season length by several months. Singh and Sontakke (2002) studied the fluctuations of important climatic parameters like precipitation amounts during 1829-1999 for the Indo Gangetic region. The main results of their study indicate a significant increasing trend in the summer monsoon precipitation in the western region from 1900, a significant decreasing trend from 1939 over the central part, and a significant decreasing trend over eastern part of the country. In an earlier study Sen Roy and Balling (2004) analyzed the trends in the patterns of extreme precipitation events from 1910 to 2000. Their results show an increasing trend over most of western India including most of Deccan plateau and a decreasing to a neutral trend over the eastern half of the country except the northeastern corner. Houghton *et al.* (2001) also show an increase in Indian precipitation, particularly in the western and northwestern areas of the country during 1900 to 1999. Most of the above studies suggest a decreasing trend in the precipitation over the Gangetic basin that is also agriculturally most significant region in the subcontinent. However there are no specific studies analyzing the trends in the spatial patterns of precipitation occurring in the different intensities from low to moderate to heavy precipitation over the years in the different parts of the subcontinent.

The present investigation is based on a study by Karl and Knight (1998) analyzing the trends in the occurrence of precipitation in various categories from 1910 to 1996 spread across the contiguous United States. Their study reports about a 10% increase in precipitation, which was

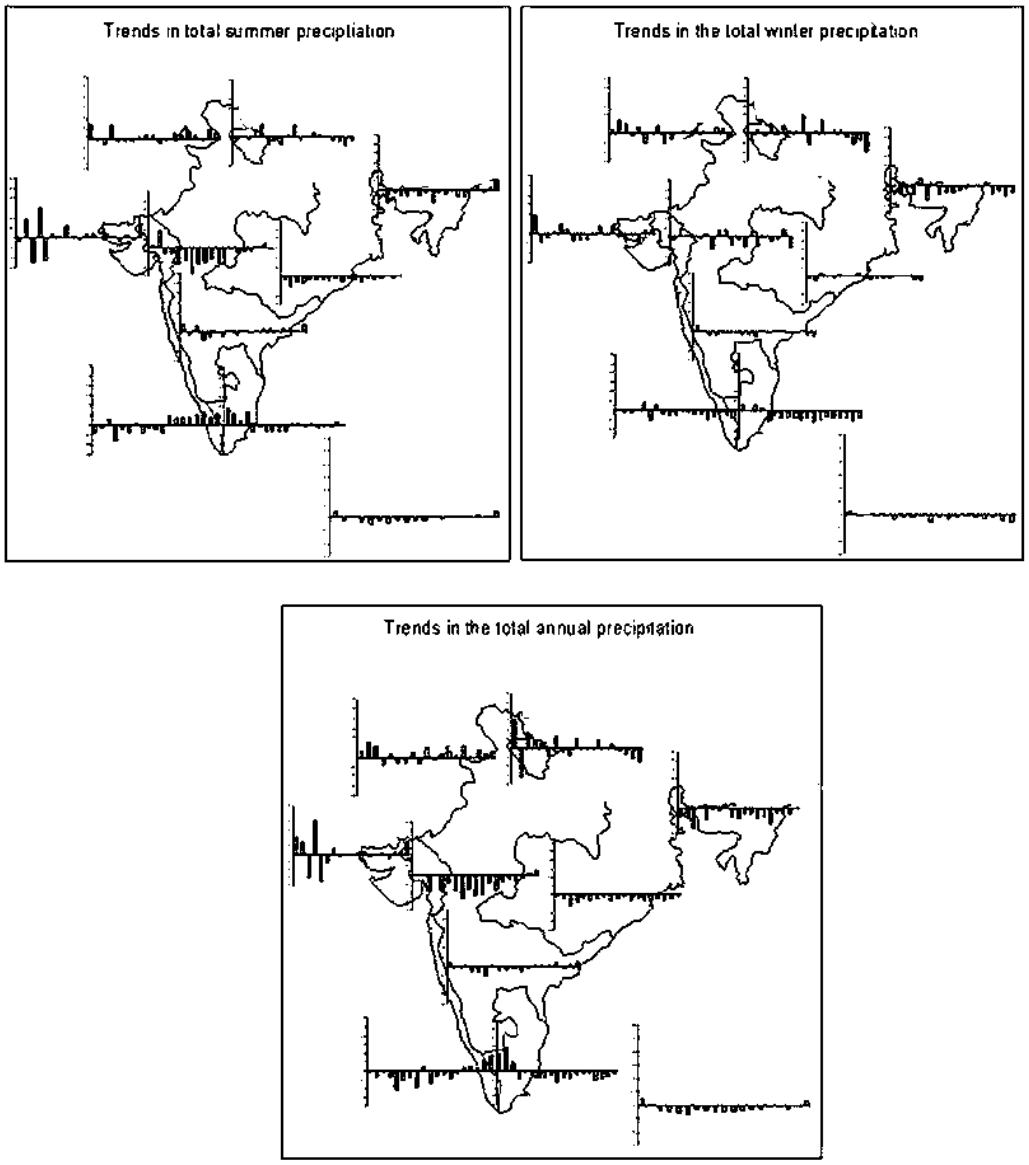

Fig. 2. Trends (1910-2000) expressed as the Pearson Product Moment Correlation also expressed as the regression coefficients for the total precipitation-taking place in each region classified by five percentile class intervals. Values plotted for each percentile interval is exclusive to that category. For instance the trends plotted for the 5th percentile represents the trend in precipitation between the lowest to the 5th percentile. The bar chart on the lower right represents the trends at the national level. The values on the ordinate axis extend between 0.6 to –0.3

mainly, attributed to the positive trends in the heavy and extreme daily precipitation events. In our analyses we have broadly adopted the methodology followed by Karl and Knight (1998) to study the spatial patterns in the precipitation events occurring in the different categories from low, moderate, to heavy precipitation events.

2. Data sources and methodology

The United States National Climatic Data Center's Global Daily Climatology Network database (#TD9101) has the daily precipitation data from 1910 to 1980 for 3838 stations in India. However, not all the stations had complete records and therefore we finalized a list of 133 stations which had less than ten percent of its data missing from 1910 to 1980.

The data for 1980 onwards till 2000 were procured from National Data Center of the India Meteorological Department for 130 of the 133 stations located in India. Next, the appropriate files were merged from the two sources for each station. The precipitation data for each

station were analyzed individually for any outliers or unusual precipitation values. On detailed examination it was found that the precipitation data for Sandbars weather station located in the Ganges delta region had an unnatural distribution with unusual outliers for certain years. As a result, 129 stations spread throughout India were finally used for the present analysis (Fig. 1). The data were also checked for the proportion of missing data; the years 1965 and 1970 to 1974 had a major proportion of missing data and therefore were dropped from the present analysis. All other years had less than 8.4% of missing data. The nearest neighbor statistic was derived for the distribution of stations as the ratio between the observed mean distance among the sites and the expected mean distance given a random distribution (Clark and Evans, 1954). The ratio of 1.30 for our network throughout India falls within the desirable "random to uniform" category.

In the present analysis, the meteorological subdivisions of India were grouped into nine broad regions on the basis of the mean annual precipitation received by each meteorological sub-division (Fig. 1). The mean annual precipitation values were taken into consideration to maintain uniformity and effective comparative analysis.

In analyzing the records, any day recording a precipitation event greater than 0.1 mm was considered as a precipitation event. The precipitation events were divided into five percentile interval categories from the 5^{th} to the 95^{th} percentile for each year, in terms of the number of rainy days and the total precipitation for individual percentile categories. The threshold values for each percentile category were determined on the basis of all the precipitation events over the entire study period. The values in each percentile category were exclusive to each percentile interval and not a cumulative score for all categories below it. These values were then used for classifying the precipitation events over the entire time period and determining the trends in the each percentile category. The Pearson product moment correlation coefficients were calculated using year as the independent variable and precipitation as the dependent variable, for individual five percentile interval categories. These coefficients were calculated to quantify the trend in the total amount of precipitation and the frequency of precipitation events for all 129 stations over the period 1910 to 2000. Finally, there were three matrices consisting of 129 rows representing the weather stations, with 19 columns consisting of the trend values for each five-percentile interval, for the total annual precipitation and the frequency of precipitation events. The three matrices were created for the annual precipitation, for the summer monsoon months of July and August, and for the winter rainy months of January and February. During the southwest summer monsoon season, July and August precipitation have been taken into consideration because during these two months most of the Indian subcontinent is under the grip of the southwest monsoons. Similarly, January and February are the months that have been taken into consideration during the northeast monsoons season, when most of the winter precipitation is received all over the country.

3. Analysis and results

The trend in the total precipitation occurring during July and August shows a tendency towards a slight decreasing trend over most of the subcontinent (Fig. 2). The declining trend is more pronounced in case of winter rains occurring during January and February. In case of both the annual total precipitation and the seasonal total precipitation, there is a decreasing trend in the low and moderate categories of precipitation in the northern part of the east coast extending into the Chota Nagpur plateau and parts of Chattisgarh state. However, the northeast region, consisting of the rainiest parts of the world and the southwestern part of the Indian peninsula show an increasing trend in the high intensity precipitation categories during the summer season. This trend in the summer precipitation is offset by substantial decreasing trends during the winter season for the northeast and the southwestern part of the peninsula, in the overall trends shown by the annual precipitation. In the northwestern region of India mainly comprising of the low precipitation region of arid desert of India, and all along the west coast there is an increasing trend in the high intensity precipitation categories in case of both seasonal and annual precipitation. Over Rajasthan and part of northwestern Himalayas, there is an increasing tendency in all categories of precipitation from low intensity to high intensity precipitation. The national level trends for the total amount of precipitation taking place exhibit similar declining trends for most categories of precipitation except for slight increasing trends in the high intensity categories occurring in the summer season, which is reflected in the annual trends at the national level.

We next analyzed the spatial pattern for the frequency of precipitation events (Fig. 3), which to a great extent show a similar pattern as that of the total precipitation. There is increasing trend in the frequency of precipitation all along the west coast mainly for the high intensity precipitation events. The northwestern region over Rajasthan and parts of northwestern Himalayas show increasing trends in case of all categories from low to moderate to high intensity precipitation events in a day. In the state of Uttaranchal located in the western Himalayas, the moderate events reveal an increasing trend during both the summer and winter rainy seasons. During the summer

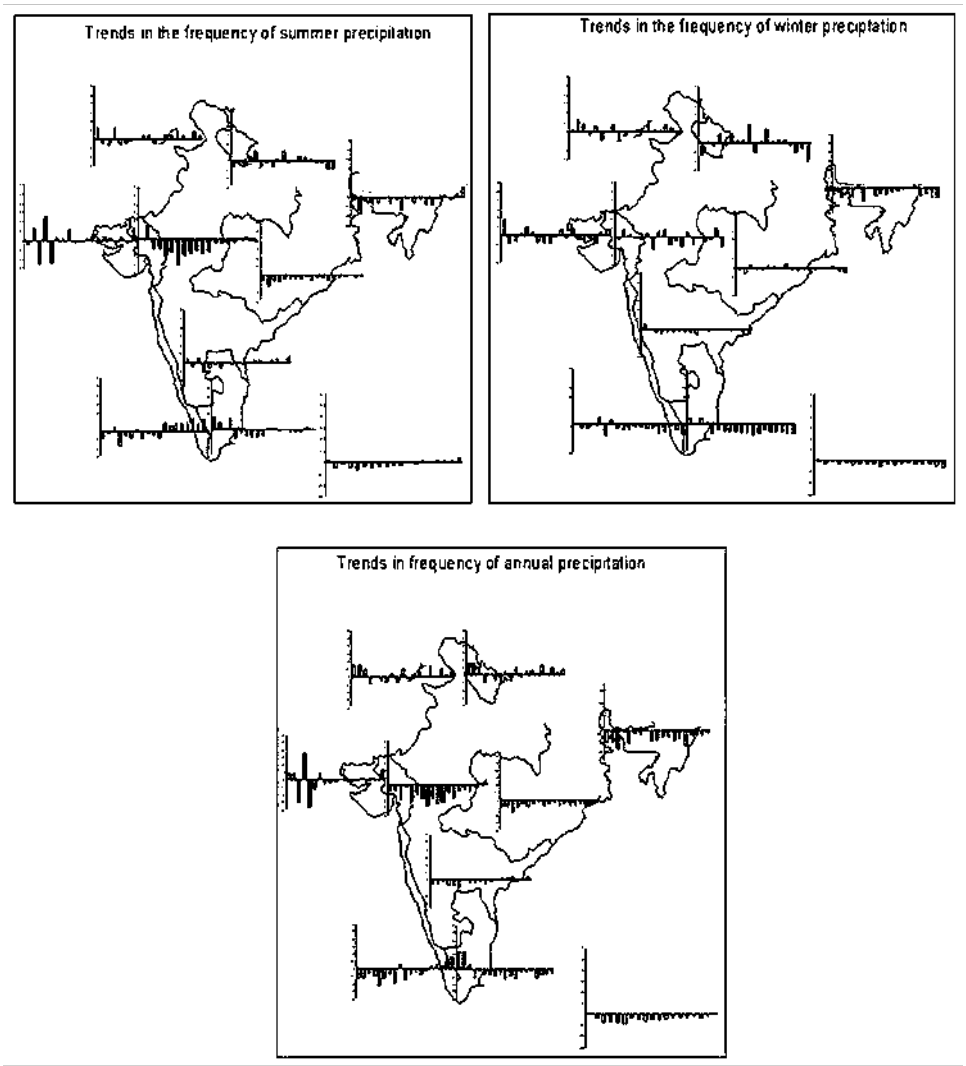

Fig. 3. The trends in the frequency of precipitation events, expressed in the same form as Fig. 2

monsoon season, in the northeastern region as well as the east coast of India, the number of days receiving very high intensity precipitation has increased over the years, more pronounced in case of the east coast. The eastern part of the country consisting of the Gangetic delta and the Chota Nagpur plateau, extending to the east coast, show significant decreasing trends in the frequency of all categories precipitation events. The decline is more pronounced in the case of the low intensity precipitation events than in case of the high intensity precipitation. There is also an increasing trend in the frequency of precipitation for the low intensity categories in the southeast over Tamil Nadu, and parts of Andhra Pradesh in both the seasons. The overall national trends for the frequency of precipitation over the entire subcontinent show a predominantly decreasing trend for all categories of precipitation except during summer, which shows an increase in the frequency of heavy precipitation events.

4. Discussion and conclusion

The trends in the precipitation occurring in each five-percentile intervals have been analyzed for the period 1910-2000 on a regional scale. The spatial trends in the frequency and the actual amount of precipitation taking place in the various categories may be summarized below :

(*i*) Overall the trends in the precipitation occurring in the two main rainy seasons and annually show a decreasing tendency. The declining trend is more pronounced during the winter season compared to the summer monsoon season mainly for the heavy precipitation events.

(*ii*) The northwestern part of the subcontinent, comprising of the arid and-semi arid regions of Rajasthan

and Gujarat, show a predominance of an increasing trend in all categories of precipitation events in both the seasons and annually.

(*iii*) Overall the entire west coast was found to be having positive trends especially in the heavy precipitation events. The increasing trends in the precipitation events in the west coast is indicative of the stronger impact of the Arabian Sea branch of monsoons during the south west monsoon season of July and August.

(*iv*) The increasing trend in the heavy precipitation events over the western part of the country also indicates the stronger influence of the intense low-pressure center forming over the northwestern part of the subcontinent over the resulting precipitation patterns.

(*v*) A point of concern however, is the overall neutral to decreasing trends in the precipitation events in the region extending from the northern part of the subcontinent to the interiors comprising of the Chota Nagpur Plateau and the foothills of the eastern Himalayas.

(*vi*) The increasing trend in the total amount and frequency of precipitation during summer over northeastern India may be attributed to the insignificant change in the number of depressions in the Bay of Bengal mentioned Lal *et al.* (1995).

(*vii*) We also analyzed the trends in total precipitation as a whole for the entire subcontinent. However, the correlation coefficient between year of record and annual precipitation total was very low at r = -0.02 and was not statistically significant.

We have analyzed the regional patterns of the trends in the precipitation occurring in low to moderate to high intensity events. The entire subcontinent was divided into nine precipitation regions according to the mean annual precipitation measurements calculated by the India Meteorological Department for each meteorological subdivision. The results show a decreasing tendency in most of the regions except for the northwestern part and the peninsular part of the country. The spatial patterns show a slight increasing trend in the high intensity precipitation events in the west coast and the northwest indicating the relative strengthening of the Arabian Sea branch of the southwest monsoon season compared to the Bay of Bengal Branch over the years. The east coast, which receives most of its precipitation from the northeast monsoon, showed a declining trend in the frequency and total amount of precipitation over the years. Our results are consistent with several earlier studies that include Kothyari and Singh (1996) and Singh and Sontakke (2002) indicating a declining trend in the precipitation events over the Gangetic plains. Singh and Sontakke (2002) also attribute this pattern to a westward shift in the precipitation activities and rainstorms attributed to global warming and associated changes in the general atmospheric circulation. The spatial patterns in precipitation revealed in this study are broadly consistent with future projections of climate presented in the most recent IPCC Scientific Report (Houghton *et al*., 2001).

References

Chhabra, B. M., Prakasa Rao, G. S. and Josm, U. R., 1997, "A comparative study of differences in the averages of temperatures and rainfall over the Indian stations during the periods 1931-60 and 1961-90", *Mausam*, **48**, 1, 65-70.

Clark, P. J. and Evans, F. C., 1954, "Distance to nearest neighbor as a measure of spatial relationships in populations", *Ecology*, **35**, 445-453.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. and Johnson, C. A. (Eds.), 2001, "*Climate Change*", The Scientific Basis. Cambridge, England : Cambridge University Press.

Hulme, M. and Viner, D., 1998, "A climate change scenario for the tropics", *Climatic Change*, **39**, 145-176.

Karl, T. R. and Knight, R. W., 1998, "Secular trends of precipitation amount, frequency and intensity in the United States", *Bull. Amer. Met. Soc*., **79**, 231-241.

Kothyari, U. C. and Singh, V. P., 1996, "Rainfall and temperature trends in India", *Hydrological Processes*, **10**, 357-372.

Lal, M., Cubasch, U., Voss, R. and Waszkewitz, J., 1995, "Effect of transient increases in greenhouse gases and sulphate aerosols on monsoon climate", *Current Science*, **69**, 752-763.

Parthasarathy, B. and Dhar, O. N., 1976, "A study of trends and periodicities in the seasonal and annual rainfall of India", *Indian J. Met. Hydrol. & Geophys*, **27**, 1, 23-28.

Rupa Kumar, K., Pant, G.B., Parthasarathy, B. and Sontakke, N., 1992, "Spatial and subseasonal patterns of the long-term trends of Indian summer monsoon rainfall", *International Journal of Climatology*, **12**, 257-268.

Sen Roy, S. and Balling, R. C., Jr., 2004, "Trends in extreme daily precipitation indices in India", *International Journal of Climatology*, **24**, 457-466.

Singh, N. and Sontakke, N. A., 2002, "On climatic fluctuations and environmental changes of the Indo Gangetic plains in India", *Climatic Change*, **52**, 287-313.