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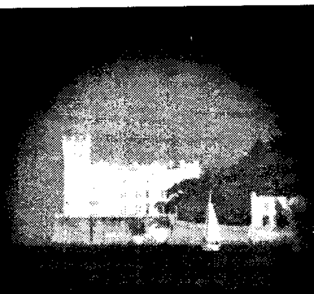

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THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

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Abstract

An attempt has been made here to investigate the local/regional monsoon rainfall behaviour in the meteorological sub-division # 13 comprising the areas of Haryana, Delhi and Chandigarh in India. The monthly monsoon rainfall data of 30 years (1970-99) of different locations in the region were used for the investigation. All locations except Delhi received more rainfall in monsoon season during the decade (1990-99) showing general increasing trend in the rainfall behaviour in recent times. The mean monsoon rainfall at various locations ranged between 324.8 mm at Sirsa and 974.9 mm at Chandigarh. The major amount of monsoon rainfall occurred during the month of July and August in the entire region. Monthly mean rainfall ranged between 37.5 to 144.9 mm (June), 130.6 to 298.2 mm (July), 92.6 to 313.6 mm (August) and 44.0 to 149.4 mm (September) at different locations. All the locations in the region exhibited overall increasing trend in monsoon rainfall over the period under study. All locations in the region received their lowest monsoon rainfall in the year 1987 which was a drought year and the season's rainfall ranged between 56.1 mm (Sirsa) and 290.0 mm (Delhi) during this year. Many of the locations observed clusters of fluctuations in their respective monsoon rainfall. The statistical summaries of historical data series (1970-99) gave rainfall information on various time scale. Such information acquires value through its influence on the decision making of the utlimate users.

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1. Introduction

Long term changes in precipitation on global/hemispheric scale are difficult to detect due to large spatio-temporal discontinuities and lack of observations over the oceanic regions. However, recent analyses of rainfall over the Northern Hemispheric land areas since the mid-nineteenth century (Houghton *et al.*, 1990) have indicated significant increase of rainfall in mid latitudes and concurrent decrease in low latitudes over the last 30-40 years. Regional manifestations of global scale climate change processes are very important because of their close link with the social and economic prosperity of the affected human population (Singh *et al.*, 2000).

The agroclimatic regional planning applied to agriculture and allied sectors is essentially a resource based planning. The regional approach to climate change/variability is in fact a quest to assess regional vulnerability, based on which appropriate response strategies can be evolved for maintaining ecological balance and sustainable development particularly under monsoon variability in semi-arid tropics. But most of the studies done so far have been based on the anticipated changes in climate related global parameters. Thus, in order to make a realistic impact assessment on regional scale, we need transition from global generalities to regional specifics.

The summer and winter monsoons constitute the most spectacular manifestation of regional anomalies in the general circulation of the atmosphere resulting from land-sea contrasts and geographical features. The monsoons of Indian sub-continent are described as ideal monsoons. The centers of action, air mass involved and the mechanism of precipitation of Indian monsoon are altogether different from other monsoon systems. India, with a population of 1 billion people is located in the central portion of south Asia and the summer monsoon, also known as south west (SW) monsoon, contributes about 75% of annual rainfall over most parts of the country. The country's agriculture, power generation and industrial production substantially depend on these rains.

For a country as vast as India, with inherent spatial variability of monsoon rainfall, there would almost always be some areas of deficient rains even in the best monsoon years (or some areas of flood even in worst monsoon). However, there are certain regional differences in the monsoon rainfall variability, which are of important consequences. The rainfall in meteorological sub-division consisting Haryana, Delhi and Chandigarh regions is received mainly between June-September as a result of SW monsoon. Since, monsoon fluctuations are of vital importance to agriculture, water supply and energy planning, numerous attempts have been made to develop techniques to predict monsoon rainfall and its variability. Virmani (1989) recommonded three types of annual rainfall variation viz., random yearly variation, trends in diminishing annual rainfall and oscillation in annual rainfall in a decade or two. The understanding of monsoon behaviour viz., annual, seasonal and intra-seasonal variability in a particular region is necessary to identify the optimal cropping strategies that ensure the sustainable ecological development (Sinha *et al.*, 1989).

1.1 Monsoon variability

Cheang (1993) carried out interannual variability study utilizing rainfall records of 41 years (1951-1991) and observed no clear indication of linear decreasing or increasing trend in the annual rainfall of 16 stations in Malaysia.

The monsoon variability studied in the global climate perspective (Verma, 1990) reported that monsoon variability in the recent decade was very large mainly due to ENSO. Recently, the Indian Climate Research Programme (ICRP), as formulated in the Science Plan of Department of Science and Technology (1996) envisages focus on the study of rainfall variability and its impact on agriculture.

Parthasarathy *et al.* (1993) made extensive studies on Indian monsoon variability and observed 12 regional/global circulation parameters affecting monsoon behaviour during the period from 1951-86. In regression equations 3 to 4 parameters were entered, explaining upto 80 percent of the variance depending upon the data period. Pant *et al.* (1996) reported statistically significant increasing long-term trend in mean annual precipitation over south Asian region.

Rajender Kumar and Desai (1999) analyzed Indian summer monsoon rainfall variability and concluded less interannual variability in the recent decade from 1987 to 1996 in comparison with the earlier decades.

1.2 Regional monsoon pattern

Sastri (1984) have reported that there were 20 drought years of different intensities during the 40 year period (1941-80) in Delhi region due to failure of SW monsoon. Rupa Kumar *et al.* (1992) examined spatial distribution of linear trend in the monsoon rainfall over the past century from a network of 306 stations and revealed contiguous areas but because of approximately equal areas under increasing and decreasing trends, the average series for the country becomes trendless. Singh *et al.* (1992) observed that the rising trend in the summer monsoon rainfall over north-west India is because of a westward shift in the monsoon rainfall activities and hypothesized that it is due to a rising trend in the northern hemisphere temperature and associated changes in the general circulation of the atmosphere.

Analyzing the 82 years (1901-1982) record of rainfall from 27 stations in Indain Punjab (Lal and Lakshmanaswamy, 1995) observed increasing trend both in annual and monsoon rainfall of Batala, Tanda and Nakodar stations. The rainfall pattern except winter rainfall does not suggest that the climate shift is occurring in Punjab. Chhabra *et al.* (1997) observed decreased rainfall over hill stations and increased rainfall over urban/industrialized cities during the periods 1931-60 and 1961-90.

Thus, the present study is intended to make realistic assessment on monsoon rainfall variability on local/regional scale particularly for the meteorological sub-division consisting Haryana, Delhi and Chandigarh regions of India.

2. Study area

The sub-division is situated in sub-tropics and extends from 27°38' to 30°55' N latitude and 74°27' to 77°36'E longitude (Fig.1). The altitude in the sub-division ranged between 215 to 261 meters above mean sea level. The region is land locked from all sides and mostly covers the Indo-gangetic plains. The various locations for the investigation along with their codes, coordinates and period of data used are presented in Table 1.

2.1 Climatic features of the region

The sub-division has semi-arid climate in the South-West and Gangetic plain environment in the remaining parts. The climate is generally very hot in summers and remarkably cold in winters. High temperatures of 45°C magnitude are recorded during the month of May in most parts of the sub-division, whereas, in winters the temperature goes down to –2 to –3°C for a few days. Most of the rainfall (75 to 80%) is received in SW monsoon season from June to September. Rainfall ranges from below 300 mm on the Rajasthan border and shows increasing trend towards the border adjoining Punjab and Himachal Pradesh where about 1200 mm of rainfall is received annually. About half of the sub-division can be classified as moisture deficit, whereas, the remaining half can be put in the category of adequate moisture status.

2.2 Data collection and their analysis

The mean monthly monsoon rainfall data for the period 1970-99 (30 years) at selected locations in the region were collected from Department of Agril Meteorology, CCS Haryana Agricultural University, Hisar, India and Meteorological Center, Chandigarh, India Meteorological Department.

The statistical methods/techniques used included the mean, standard deviation, standard error, coefficient of variation, trend analysis (moving average), comparative analysis (deviation from normal value).

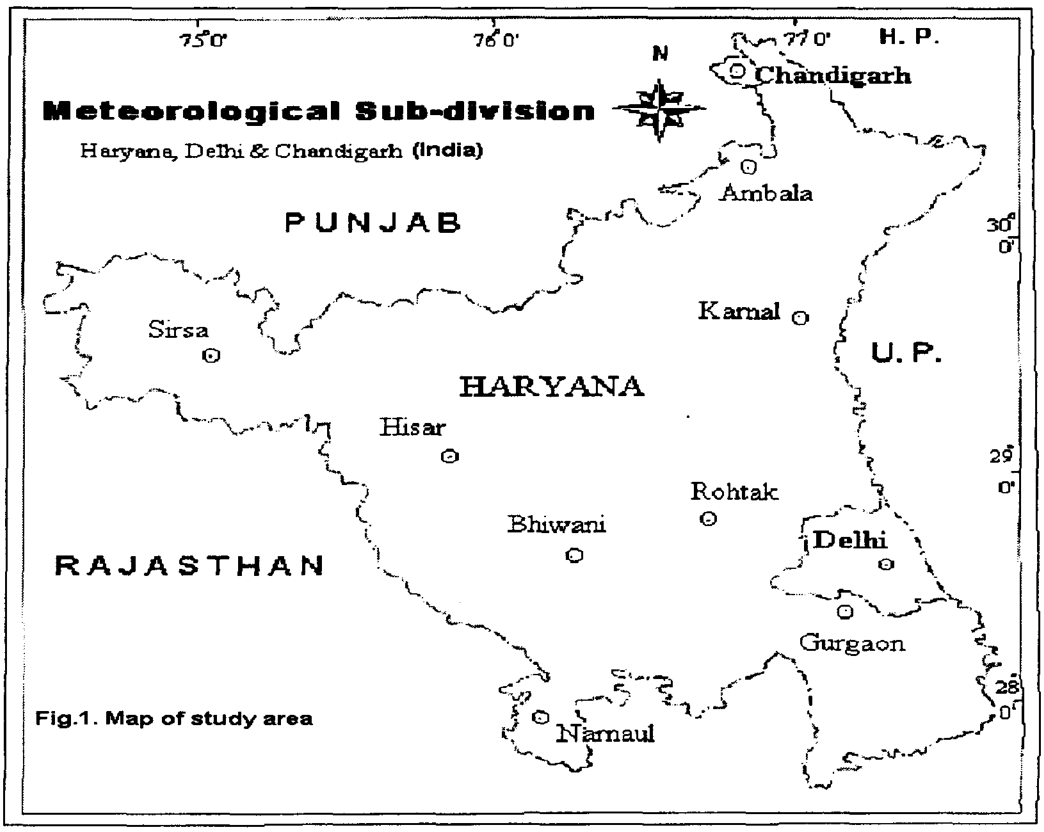

Fig.1. Map of study area

Table 1. Selected locations with their code, coordinates and period of data series used

S.No.	Locations	Code	Latitude °N	Longitude °E	Altitude m a.m.s.l.	Data series
1.	Sirsa	SRS	29°32'	75°27'	218	1970-99
2.	Hisar	HSR	29°10'	75°46'	215	1970-99
3.	Bhiwani	BHN	28°48'	76°08'	227	1970-99
4.	Narnaul	NRL	28°03'	76°06'	221	1970-99
5.	Rohtak	RTK	28°54'	76°35'	226	1970-99
6.	Gurgaon	GGN	28°28'	77°02'	230	1970-99
7.	Delhi	DEL	28°35'	77°10'	228	1970-99
8.	Karnal	KNL	29°43'	76°58'	245	1970-99
9.	Ambala	AMB	30°22'	76°47'	247	1970-99
10.	Chandigarh	CHD	30°40'	76°45'	261	1970-99

2.3 Rainfall analysis

The monsoon rainfall at different locations in the entire sub-division was analyzed using various indices/norms adopted at Indian Meteorological Department (IMD) and Indian Institute of Tropical Meteorology (IITM).

2.3.1 Monsoon rainfall index (MRI)

The overall situation at a location/region was indexed by expressing the monsoon rainfall in terms of the percent departure from its mean value (Parathasarathy *et al.*, 1992c).

$$MRI = 100 \times \frac{R_i - \bar{R}}{\bar{R}}$$

2.3.2 Monsoon rainfall categorization

As per the IMD norms (Biswas and Dutta, 1998), the rainfall in monsoon season was categorized as excess: rainfall 120 percent or more, normal: rainfall between 81 and 119 percent, deficient: rainfall between 41 and 80 percent and scanty: rainfall ≤ 40 percent of normal rainfall.

2.3.3 Rainfall category classification

Biswas and Dutta (1998) classified different rainfall categories as :

i) High – when probability > 70 percent

ii) Moderate – when probability ranged between 50 and 70 percent

iii) Low – when probability < 50 percent

iv)

2.3.4 Rainfall variability

Based on coefficient of variation (CV) Biswas and Dutta (1998) classified rainfall variability into four categories :

i) Low variability – when CV ranged between 15 and 19.9 percent

ii) Moderate variability – when CV ranged between 20 and 29.9 percent

iii) High variability – when CV ranged between 30 and 49.9 percent

v) Very high variability – when CV was $\geq$.50 percent

3. Results and discussion

3.1 Monsoon rainfall characteristics in the region:

3.1.1 Monsoon rainfall features

The mean monsoon rainfall in the entire sub-division ranged between 324.8 mm (Sirsa) and 974.9 mm (Chandigarh) during 1970-99. Rainfall observed in the recent 30 years (1970-99) was above the mean monsoon rainfall of long-term data series (Table 2). All locations in the entire sub-division observed increasing trend in monsoon rainfall over the period. Recently Ashrit and Rupa Kumar (1999) also reported general increasing trend in monsoon rainfall at different stations in India.

3.1.2 Monthly break-up of monsoon rainfall

A major amount of the monsoon rainfall occurred during the month of July and August in the entire region (Table 3). The probable date of onset of monsoon rains in the entire sub-division falls in the last week of June and the first week of July and the withdrawal takes place around middle of September. Therefore, July and August months constituted the period when monsoon was most active at all locations under study. The relative contribution of June and September months to the monsoon season's rainfall was considerably small when compared to the months of July and August. June month's contribution ranged between 10 and 19 percent, July contributed between 27 and 44 percent, August contributed between 23 and 38 percent and September contributed 12 to 22 percent in monsoon rainfall at different locations in the sub-division. Similar results indicating spatial and temporal rainfall variability and monthly contribution have been reported by Kothawale and Munot (1998).

3.1.3 Monthly monsoon rainfall features

Monthly mean rainfall in monsoon season at different locations (Table 4) ranged between 37.5 and 144.9 mm (June), 130.6 and 298.2 mm (July), 92.6 and 313.6 mm (August) and 44.0 and 149.4 mm (September). The rainfall variability was more in the months of June and September due to higher values of coefficient of variation (upto 149%) as compared to July and August (CV upto 70%). The rainfall variability in the entire sub-division was higher as compared to whole country. This may be attributed to the fact that the sub-division is situated on the farthest margin of SW monsoon domain in the Indian sub-continent. The high rainfall variability in monsoon season in the various regions was also reported by Parthasarathy and Mooley (1978), Biswas and Dutta (1998) and Kothawale and Munot (1998).

3.2 Monsoon rainfall trend in the region:

3.2.1 Five years moving average of rainfall

Monsoon rainfall trend was computed at different locations in the entire sub-division for the study period, using five years moving average and the trend, thus, observed have been depicted in Fig. 2 (A to L). All locations in the sub-division exhibited increasing trend over the period. The rainfall showed epochal fluctuations in the monsoon season. A significant increasing trend in monsoon rainfall was observed at most of the locations upto 1980. Thereafter, a decreasing trend was observed upto 1987. Subsequently, the monsoon rainfall showed consistently increasing trend at all the locations with little variations in their magnitude. The trend line of monsoon rainfall at Sirsa (Fig. 2 A) and country as a whole (Fig. 2 L) depicted almost static behaviour with marginal increments. These results corroborate the findings of Lal and Lakshmanaswamy (1998) and Ashrit and Rupa Kumar (1999) at different locations.

Table 2. Features of monsoon rainfall at different locations (1970-99) in the region.

Locations	Mean (mm)	SEm	CV	Long term mean (mm)
SRS	324.8	21.5	36	278.0
HSR	359.7	25.5	39	317.0
BHN	387.5	29.5	35	332.0
NRL	486.2	41.0	46	422.0
RTK	503.0	30.3	33	438.0
GGN	650.4	41.6	45	503.0
DEL	683.4	32.9	26	629.0
KNL	608.7	40.8	37	621.0
AMB	774.5	45.7	32	701.0
CHD	906.1	57.8	35	866.0
Sub Div	569.8	29.2	32	515.0
All Ind	841.7	15.4	10	880.0

Table 3. Monthly break-up (%) of monsoon rainfall at different locations in the region (1970-99).

Locations	June	July	Aug	Sept	Season's mean rainfall (mm)
SRS	14	40	33	13	324.8
HSR	14	36	34	16	359.7
BHN	10	40	38	12	387.5
NRL	13	36	37	14	486.2
RTK	10	38	36	16	503.0
GGN	12	33	36	19	650.4
DEL	11	32	37	20	683.4
KNL	14	34	37	15	608.7
AMB	14	37	31	18	774.5
CHD	16	33	35	16	906.1
Sub Div	13	36	35	16	569.8
All Ind	19	31	30	20	841.7

Table 4. Features of monthly rainfall (mm) during monsoon season at different locations (1970-99).

Locations	June			July			August			September		
	Mean	SEm	CV	Mean	SEm	CV	Mean	SEm	CV	Mean	SEm	CV
SRS	45.7	7.4	88	128.9	13.6	52	106.8	10.9	65	44.0	8.1	100
HSR	48.3	5.6	64	130.6	13.1	55	122.3	14.2	64	58.6	11.7	109
BHN	37.5	4.6	68	153.1	17.0	60	140.3	15.5	60	56.6	10.4	101
NRL	62.6	15.0	132	174.8	19.1	60	178.2	17.7	54	70.7	12.2	95
RTK	52.5	6.2	65	190.7	14.8	43	181.4	18.5	56	78.5	13.2	92
GGN	76.3	11.9	85	216.0	21.5	54	235.9	24.2	56	122.2	15.8	70
DEL	75.2	12.1	72	220.5	21.9	53	255.2	17.7	38	132.0	15.0	62
KNL	88.1	9.9	62	207.7	22.8	60	223.7	23.8	58	89.2	15.1	93
AMB	109.1	12.3	62	288.1	23.4	44	241.0	23.9	54	136.3	20.7	83
CHD	144.9	17.3	66	298.2	25.5	47	313.6	29.5	52	149.4	21.2	77
Sub Div	72.9	5.9	44	204.2	13.8	36	198.5	13.8	38	94.2	11.4	66
All Ind	163.4	5.9	20	262.1	5.9	12	250.7	5.3	12	165.6	6.4	21

Table 5. Monsoon rainfall range and index (MRI) at dfferent locations (1970-99).

Sr.No.	Locations	MRI	Monsoon rainfall range (mm)
1.	SRS	-82.7 to 53.2	56.1 to 504.1
2.	HSR	-82.3 to 84.0	63.5 to 665.6
3.	BHN	-74.7 to 61.9	98.0 to 627.6
4.	NRL	-68.4 to 153.8	153.4 to 1229.0
5.	RTK	-85.2 to 111.7	74.2 to 1065.0
6.	GGN	-84.6 to 58.3	100.1 to 1030.0
7.	DEL	-57.6 to 54.2	290.0 to 1053.8
8.	KNL	-64.6 to 85.8	215.3 to 1130.9
9.	AMB	-63.9 to 69.9	279.9 to 1315.7
10.	CHD	-69.6 to 94.1	275.7 to 1758.7
11.	Sub Div	-72.9 to 60.5	153.9 to 914.3
13.	All Ind	-22.4 to 14.9	652.9 to 962.7

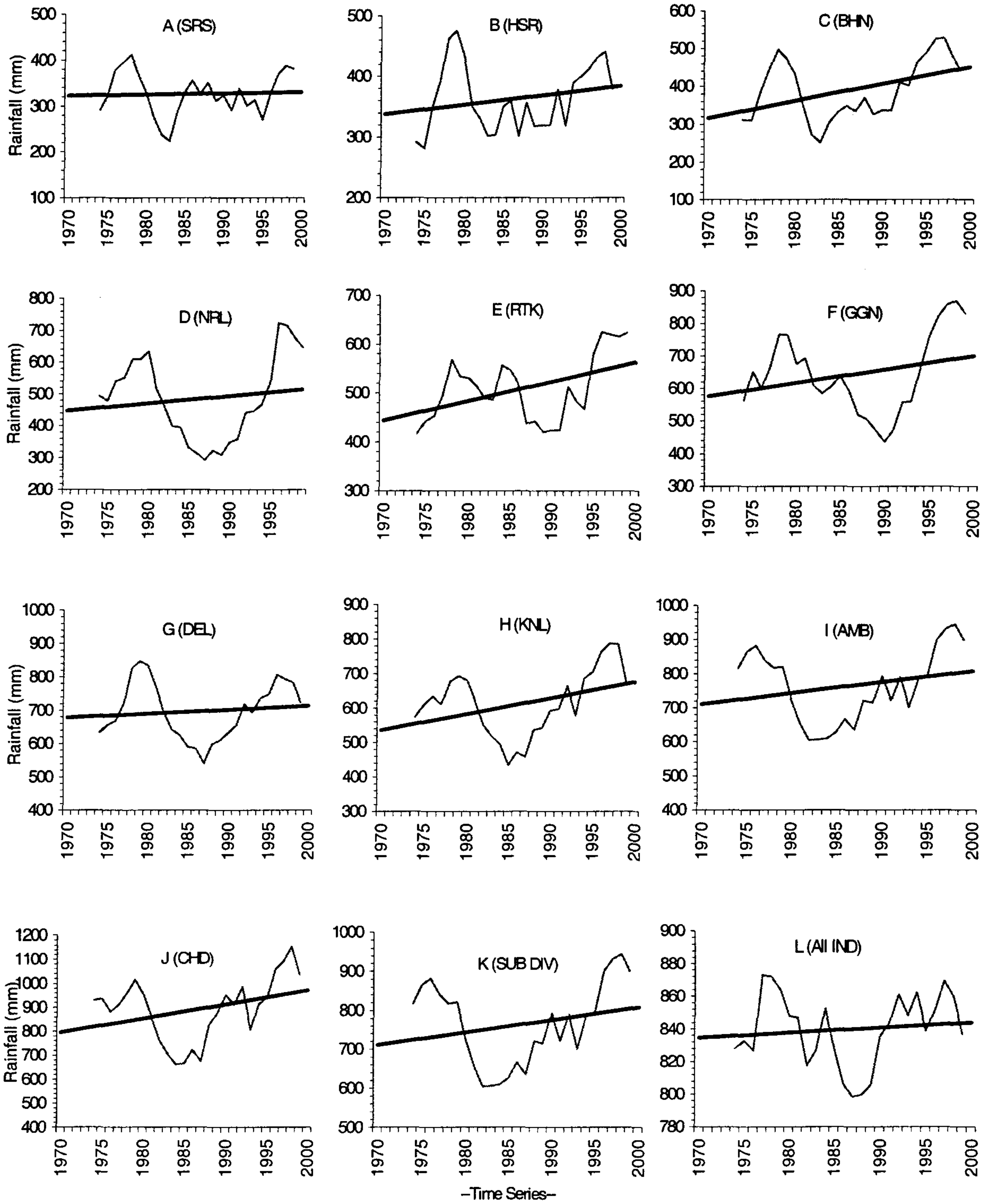

Fig.2. (A to L): Monsoon rainfall trend at different locations in the region

3.3 Rainfall variability in the region:

3.3.1 Monsoon rainfall index (MRI)

The rainfall variability based on MRI at different locations in the region have been given in Table 5. Hisar, Narnaul, Rohtak and Chandigarh showed broader range of MRI (>150). The MRI range at the remaining locations ranged between 111.8 (Delhi) and 142.9 (Gurgaon). This comparative narrow range of MRI was linked with lower rainfall variability as compared to the locations mentioned earlier with MRI (>150). The MRI range showed a decrease when it was computed over a larger area/region viz., sub-division, north-west India and country as a whole. It may be concluded here that the higher the MRI, more will be the rainfall and vice-versa. These results were also corroborated with the findings of Parthasarathy *et al.* (1992c).

3.3.2 Categorization of rainfall variability

Depending upon the coefficient of variation, the monthly monsoon rainfall could be categorized as very high and that of season as high. However, at All India scale, the variability in June, July and August was categorized as low, whereas, the September rainfall was categorized as moderate. The seasonal rainfall variability at All India scale was categorized as very low. Similarly, at location level the rainfall categories viz., excess, normal, deficient and scanty rainfall had low frequency of occurrence depending on the probability of these categories. The normal rainfall probability was categorized as high at All India scale because of 94 percent frequency of getting normal rainfall over the period under study. These results corroborate the earlier findings of Biswas and Dutta (1998).

3.3.3 Deviation/departure in monsoon rainfall

The percent deviation in monsoon rainfall from normal at different locations in the sub-division have been depicted in Fig. 3 (A to L).

The percent deviation at Sirsa was highest in 1990 and 1987 having positive and negative magnitudes, respectively (Fig. 3 A). At Hisar and Bhiwani (Fig. 3 B and 3 C), the maximum deviation was observed in 1988 (positive) and in 1987 (negative). At Narnaul (Fig. 3 D), the maximum deviation was observed in 1996 (positive) and in 1987 (negative). Rohtak and Gurgaon observed maximum deviation in 1995 (positive) and in 1987 (negative) as depicted in Fig. 3 E and 3 F, respectively.

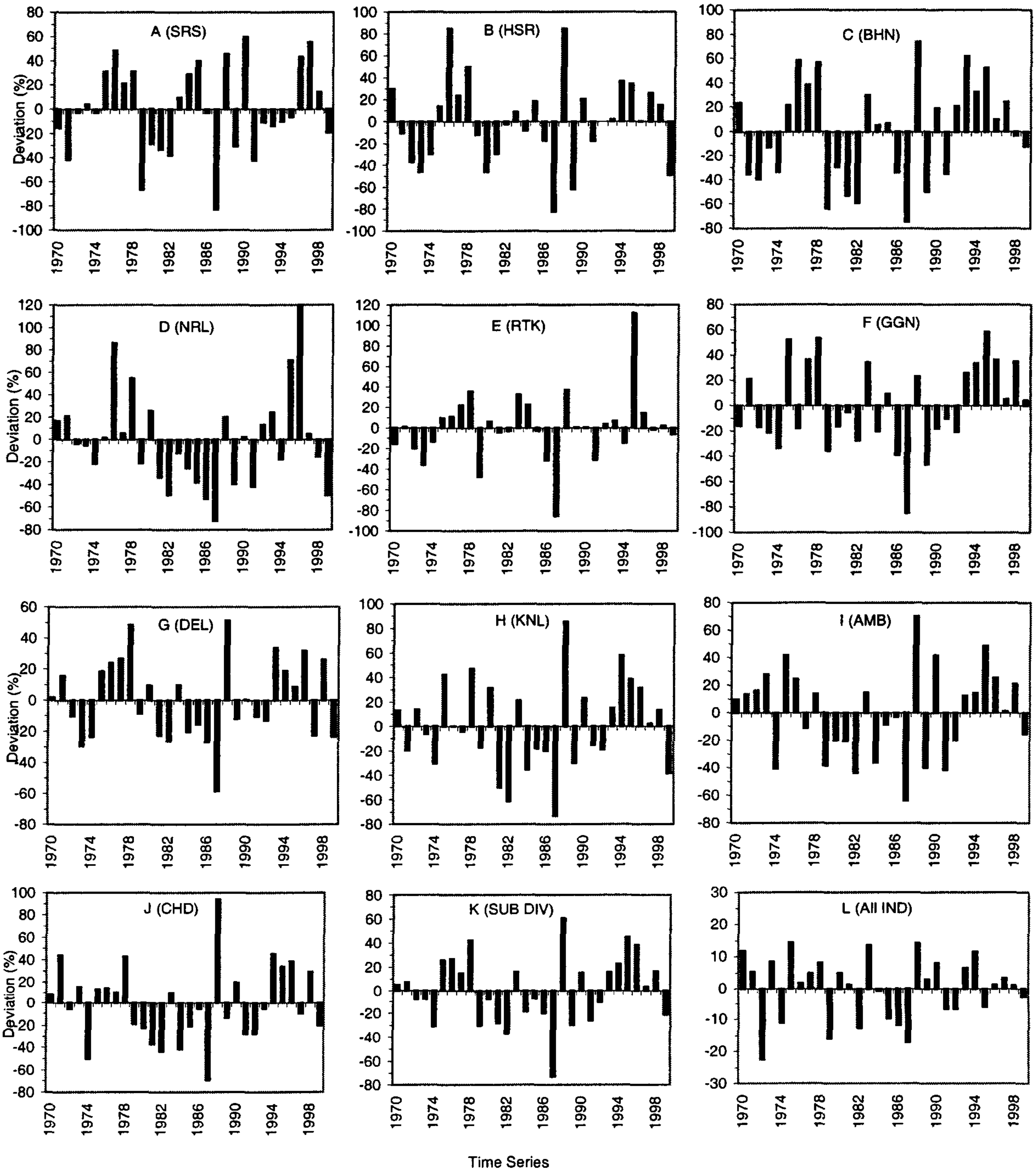

Fig.3. (A to L): Monsoon rainfall deviation from normal at different locations in the region

The other locations viz., Delhi, Karnal, Ambala and Chandigarh observed maximum deviation in 1988 (positive) and in 1987 (negative) as evident in Fig. 3 G to 3 J, respectively.

The deviation was observed maximum in 1988 (positive) and in 1987 (negative) at the regional/sub-divisional level (Fig. 3 K). The percent deviation of smaller magnitude was also observed maximum in 1988 (positive) and in 1973 (negative) at All India level (Fig. 3 L).

Many of the above locations also observed clusters of fluctuation in their monsoon rainfall as evident from their respective figures. These results corroborated with earlier findings of Parthasarathy *et al.* (1993) while studying Indian summer monsoon rainfall.

4. Conclusions

The salient findings of the investigation have been briefed here in the following text:

Sirsa station received the lowest (324.8 mm) and Chandigarh station recorded the highest (906.1 mm) rainfall during monsoon seasons, respectively. All locations except Delhi received more rainfall in the recent decade (1990-99) in monsoon season. Among the seasons, the contribution of monsoon season was maximum (77 to 82%) at all locations.

The monsoon season's mean rainfall at various locations ranged between 324.8 mm at Sirsa and 974.9 mm at Chandigarh over the period under report (1970-99). The major amount of monsoon rainfall occurred during the months of July and August in the entire region. July contributed about 27 to 44 percent and August's contribution was between 23 to 38 percent in monsoon rainfall at different locations in the region.

Monthly mean rainfall ranged between 37.5 to 144.9 mm (June), 130.6 to 298.2 mm (July), 92.6 to 313.6 mm (August) and 44.0 to 149.4 mm (September) at different locations in the whole region.

A significant increasing trend in monsoon rainfall was observed at many of the locations upto 1980. Thereafter, a decreasing trend was noticed upto 1987. Subsequently, the monsoon rainfall showed consistently increasing trend with little variation in magnitude at all locations. Hence, all locations in the region exhibited overall increasing trend in monsoon rainfall over the period (1970-99). The highest rainfall in June ranged between 97.0 mm at Bhiwani (1978) and 419.0 mm at Narnaul

(1996). July's highest rainfall ranged between 265.2 mm at Sirsa (1974) and 602.1 mm at Chandigarh (1994). In August, the range of highest rainfall varied between 198.0 mm at Sirsa (1976) to 640.0 mm at Gurgaon (1995). In September, the highest rainfall ranged between 170.0 mm at Sirsa (1988) to 488.7 mm at Chandigarh (1988). Monsoon season's highest rainfall ranged between 504.1 mm at Sirsa (1997) and 1758.5 mm at Chandigarh (1988).

All locations in the entire sub-division received their lowest rainfall in the year 1987 which was a drought year and the rainfall received ranged between 56.1 mm (Sirsa) and 290.0 mm (Delhi).

Hisar, Narnaul, Rohtak and Chandigarh showed a broader range of monsoon rainfall index (MRI) which was linked with the higher rainfall variability.

On the sub-divisional scale including all locations, the percent deviation in monsoon rainfall was maximum in 1988 (positive) and in 1987 (negative), respectively. Many of the locations observed clusters of fluctuations in their respective monsoon rainfall.

The statistical summaries of historical data series (1970-99) gave rainfall information on various time scale. Such information acquires value through its influence on the decision making of the users.

Thus the results can be summarised in the following broadly drawn important conclusions:

- Most of the locations received more rainfall in monsoon season in the decade (1990-99) showing general increasing trend in rainfall pattern in recent times.
- Monsoon season's contribution was maximum (77 to 82%) in annual rainfall among the seasons.
- The major amount of the monsoon rainfall occurred in the months of July and August in the entire region.
- The overall increasing trend in monsoon rainfall was observed at all locations in the sub-division over the period under investigation.
- Spatial and temporal rainfall variability in monsoon season observed was quite high in entire region.

Information on the minimum assured and maximum possible monthly and monsoon season rainfall for each location will be useful for water harvesting/hydrological projects and planning of agricultural operations based on which appropriate response strategies can be evolved for maintaining ecological balance and sustainable development particularly under monsoon variability in semi-arid tropics.

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