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IMPACT OF THE GREEN REVOLUTION ON THE RAINFALL REGIME OF PUNJAB

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ABSTRACT : Climatge change at the regional level is a subject that has not received much attention. This paper studies the change in the rainfall amount and pattern in the post Green Revolution period in comparison with the pre Green Revolution period in the state of Punjab. The data used were from 1901-1991 for 28 stations. The study envisaged an increase in rainfall on the whole with areas of high rainfall experiencing a greater increase than the low rainfall areas. Extensive puddling for paddy during the hot dry months of May and June was expected to increase the rainfall in this season. As expected the rainfall did increase on the whole and there was a substantial seasonal increase. The spatial pattern of increase did not conform to expectations and the high rainfall areas did not post the expected increase and the low rainfall areas experienced substantial increases. This revealed a trend towards homogenisation of rainfall amounts in conjunction with the homogenised agricultural practices of the state.

INTRODUCTION

Climate change is the subject of intense research and speculation. Global warming is one aspect of this change. It is expected to result in a warmer and wetter climate. The 1990s were the warmest decade and 1998 was the warmest year since 1861 (IPCC, 2001). During the 20th century, temperature rose by 0.6° C; rainfall in tropical lands increased by 0.2 to 0.3 per cent per decade (Down to Earth, 2001). Extreme weather conditions are predicted for the near future. Most changes are related to anthropogenic activities and all life is likely to be affected.

Several studies have been undertaken to analyse the kind of changes that the Indian climate will be experiencing. A number of these relate to the interface between Indian agriculture and climate change with a focus on temperature changes (Seshu and Cady, 1984; Sinha, and Swaminathan, 1991; Achanta, 1993; Rao and Sinha, 1994; Aggarwal and Sinha, 1994). These studies state that an increase in temperature will result in decrease in yields of rice and wheat with the exception of Achanta, who concludes that rice yields could increase in the event of a rise in temperature. Some of these studies relate to the spatial patterns of the Indian monsoon. Parthasarathy, Rupakumar and Munot (1993), in their study of the Indian monsoon, have reveraled that no systematic trend exists over the last 100 years. Rupakumar *et al.* (1992) have however, shown that there are increasing trends in rainfall on the west coast and the central peninsula. This study also shows declining trends in rainfall for the northeast and northwest peninsula and northeast India. Lonergan (1998) has estimated an increase in

temperature in India in response to increased atmospheric carbon dioxide. An increase in the frequency of heavy rainfall events in South Asia are predicted (IPCC, 1998). Decadal trends in temperature, pressure and annual and seasonal rainfall have been made for the period from 1901-1986 (Srivastav, Dewan, Dikshit, Prakash Rao, Singh and Rao, 1992). This study shows a small warming trend for the country as a whole, with pressure values indicating a falling trend. The decadal variation in the seasonal and annual rainfall is within the statistical limits of one standard deviation.

Climate change and particularly, rainfall patterns, at the regional and local scale has not received much attention. This study is an attempt to redress this gap. It focuses on the state of Punjab, which is characterised by a semi-arid climate, is intensively cultivated, and heavily irrigated. Eighty four per cent of the geographical area of the state is under cultivation. Vast tracts of land under natural vegetation, marshes, wetlands and even river channels have been brought under cultivation. The area under irrigation is 96 per cent. The cropping pattern veered towards rice cultivation in the *kharif* season and wheat predominates during the *rabi* season. During the dry and hot months of May and June the entire state is converted into a vast lake due to paddy cultivation. During the post-harvesting period, the countryside is full of smoke from the fires burning the crop residues (Brar, 1999).

An effort has been made here to identify the changes in the rainfall regime of Punjab in the context of widespread landscape changes produced due to the Green Revolution. The study is placed in the context of changes in climate at the global level and the regional changes that have occurred in the state of Punjab. The extensive changes in landuse and irrigated area are expected to have ushered in a series of changes in the pattern of rainfall in the state. These could relate to a change in the total and the seasonal rainfall of the state, and a change in the amount of rainfall falling over different parts of the state. This paper sets out to investigate these points.

HYPOTHESES

- With extensive areas under crop cover and irrigation, it is hypothesized that there would be rise in the total rainfall in the state.
- The annual and seasonal rainfall is expected to increase more in the areas of high rainfall and less in areas of low rainfall.
- With extensive pudding for paddy during the months of May-June (which are otherwise the hottest and driest months), a substantial increase is expected in the amount of rainfall for these months.

METHODOLOGY

The data used in this analysis are from 1901-1991 for 28 stations that are scattered all over in Punjab. This data was collected from the India Meteorological Department at Pune and Chandigarh and Director Land Records, Jalandhar.

A comparison has been made for the mean values of rainfall for the pre (1901-66) and post (1967-91) Green Revolution periods for the following : annual rainfall, monsoon rainfall, winter rainfall, March-April rainfall (post-winter), May-June rainall (pre-monsoon), and October-November rainfall (post-monsoon). The monsoon rainfall covers the months of July, August, and September. The winter months comprise of December, January and February.

The mean values were calculated for these six sets of periods. These values were calculated by adding up the relevant months of each year individually and then taking the average for the required number of years. For example, to calculate the average for the monsoon rainfall, the readings for July, August and Spptember were totaled for each year and the average taken for the time periods under study : 1901-1991, 1901-1966 and 1967-1991.

These values were plotted on a map of Punjab to get the picture over space and time. A total of 24 maps were made. These include the annual and seasonal picture for the three periods under study and a set of maps depicting the change in rainfall amount in the post-Green Revolution peiod (1967-1991) over the pre-Green Revolution period (1901-1966). Weighted means were calculated for each period and season.

OVERALL DESCRIPTION : ANNUAL AND SEASONAL

The average annual rainfall for Punjab as a whole for the period 1901-1991 is 594.3 mm. The maximum amount of rain falls in the submontane north and northeast. Here it exceeds 800 mm and in the northern parts it even goes above 1000 mm. The rainfall decreases in a southwesterly direction with the arid southwest receiving less than 400 mm of rainfall (Map 1).

The wettest region in the state lies in the north that receives over 1000 mm of rainfall. The maximum amount of average annual rain is recorded at Madhopur. The northeast with over 800 mm of rain comes next. In this region lie stations like Tibri (964.6 mm average annual rainfall for 19901-1991), Hoshiarpur (918.3 mm), Dasuya (867.7 mm) and Gurdaspur (853.5 mm).

The driest region of Punjab is located in the southwest. The least amount of rain was recorded at Fazilka (average annual rain for 1901-1991 was 331.6 mm). Stations like Muktsar, and Jodhpur also receive low amounts of rainfall (less than 400 mm).

The central part of the state recorded an average annual rainfall of between 400 to 800 mm. This zone is transitional between the dry and the wet zones and it covers a major portion of the state. Towards the wet zone, the stations, such as Aliwal, Batala, Jalandhar, Samrala and Ludhiana, receive rainfall in excess of 700 mm. Closer to the southwest the stations in this zone have a reading close to 450 mm.

All the seasonal averages for the 1901-1991 period conform to the pattern of decreasing rainfall towards the southwest. The monsoon rainfall decreases from 700 mm in the north to less than 300 mm in the southwest (Map 4). The winter rain decreases from 100 mm to 50 mm in the same direction (Map 7). The march-April rain decreases from 60 mm to less thatn 40 mm; the May-June rainfall decreases from 80 mm to 40 mm; and the October-November rainfall decreases from 30 mm to less than 10 mm in the southwest. The decline is sharpest for May-June and October-November months.

LONG TERM CHANGE IN RAINFALL

This section discusses the change in average rainfall for the annual and seasonal periods. The comparison is made for the pre-and post-Green Revolution periods.

The rainfall in Punjab has increased on the whole. The annual rainfall increased in the post Green Revolutiong period by 39.6 mm (Table 1). The 600 and 800 average annual rainfall isohyets have moved in the direction of the southwest indicating an increase in amount of rainfall. The area encompassed by the 800 mm isohyet increase by 70 per cent in

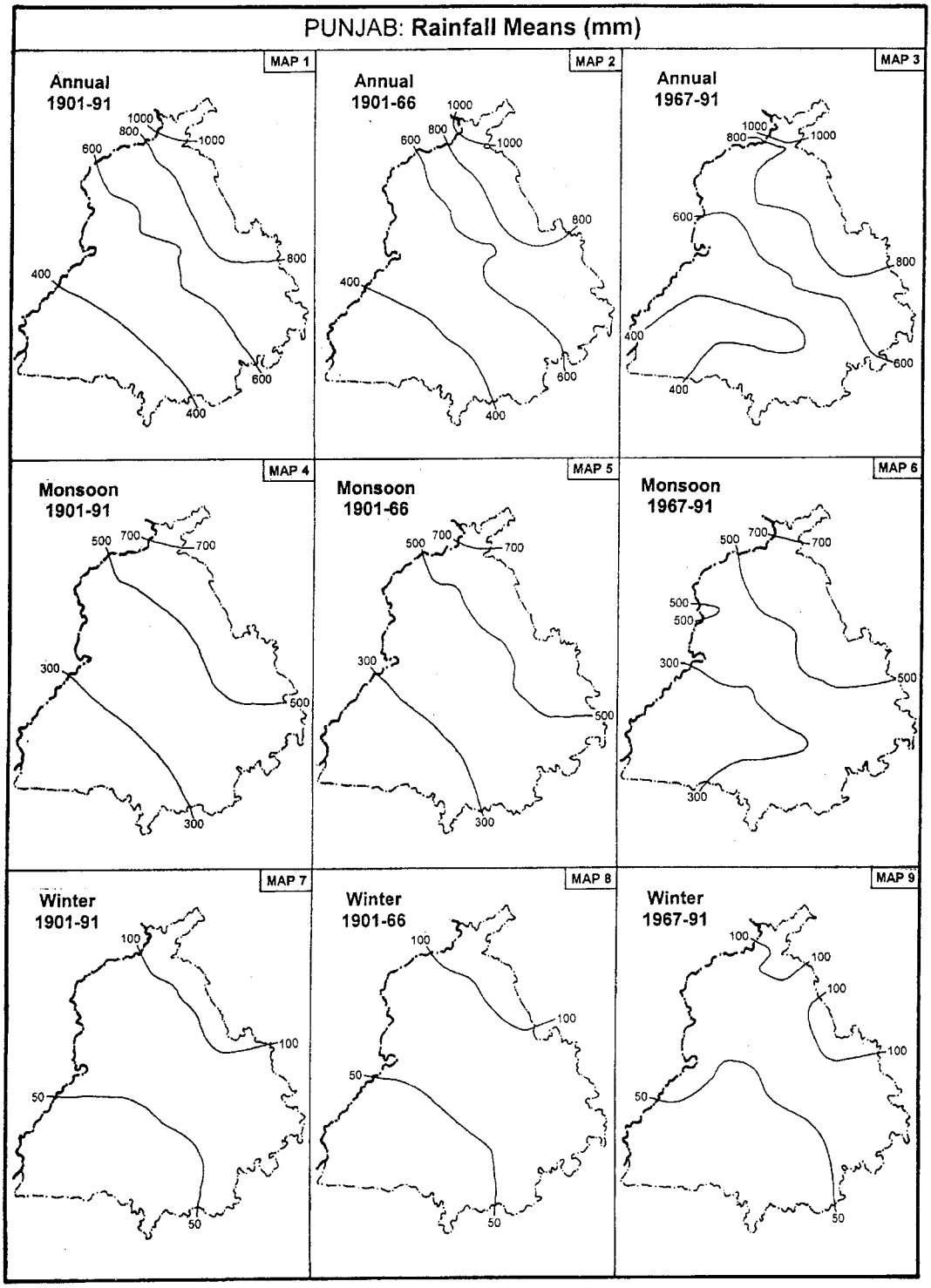

Fig. 1 : Punjab : Rainfall Means (mm) Map 1 to 9

Table 1

Punjab : Weighted means of rainfall (mm)

Period	1901-1991	1901-1966	1967-1991	Change 1967-1991 minus 1901-1966
Annual	594.3	578.0	617.6	+39.6
Monsoon (Jul, Aug, Sep)	413.0	405.5	421.1	+15.7
Winter (Jan, Feb, Dec)	69.4	68.0	68.2	+0.2
Mar-Apr	37.7	35.0	47.7	+12.6
May-Jun	55.5	49.2	65.6	+16.3
Oct-Nov	18.7	20.3	15.1	-5.2

the 1967-1991 period. The 600 mm isohyet has moved perceptibly to the southwest. There was a decrease of 25 per cent in area under 400 mm isohyet (Maps 2 and 3).

Punjab receives about 69 per cent of its rainfall during the monsoon period and 11 to 12 per cent during the winter rains. Nine per cent of the total rainfall is received during May-June and seven per cent in March-April. October-November account for three per cent of the annual rainfall. The increase in rainfall has been noted for all periods except October-November.

The maximum increase has been during the pre-monsoon (16.3 mm) followed by the monsoon (15.7 mm) periods. These two periods receive nine and sixty nine per cent of the total rainfall. The picture for May-June pre-monsoon period depicts the significant increases in rainfally in the post-Green Revolution period (Maps 14 and 15). In 1967-1991, the 80 mm isohyet covers most of the eastern part of the state, the 60 mm isohyet has shifted southwest wards and the 40 mm isohyet has disappeared.

The long-term averages of the monsson rainfall depict a squeezing of the area with 300-500 mm rainfall; area under 500-700 mm of rain has increased (Maps 5 and 6).

The March-April rainfall also records a substantial increase of 12.6 mm. Maps 11 and 12 depict a very clear southwards shift in the isohyets portraying a decided increase in the amount of rainfall.

Winter rainfall records a marginal increase of 0.2 mm. This is the second most important rainfall period of the state. The 50 mm isohyet has moved in a northeast direction and the 100 mm isohyet has shifted to the east (Maps 8 and 9).

The only period noting a decrease is pre-winter. Rainfall during October-November declined by 5.2 mm. the maps for this period depict a picture opposite to all other seasons. The 30 mm isohyet has disappeared in 1967-1991 and the 10 mm isohyet encompasses a much wider area (Maps 17 and 18).

The post Green Revolution changes : the regional and seasonal picture.

The regional and seasonal picture of change in the post Green Revolution period is one where

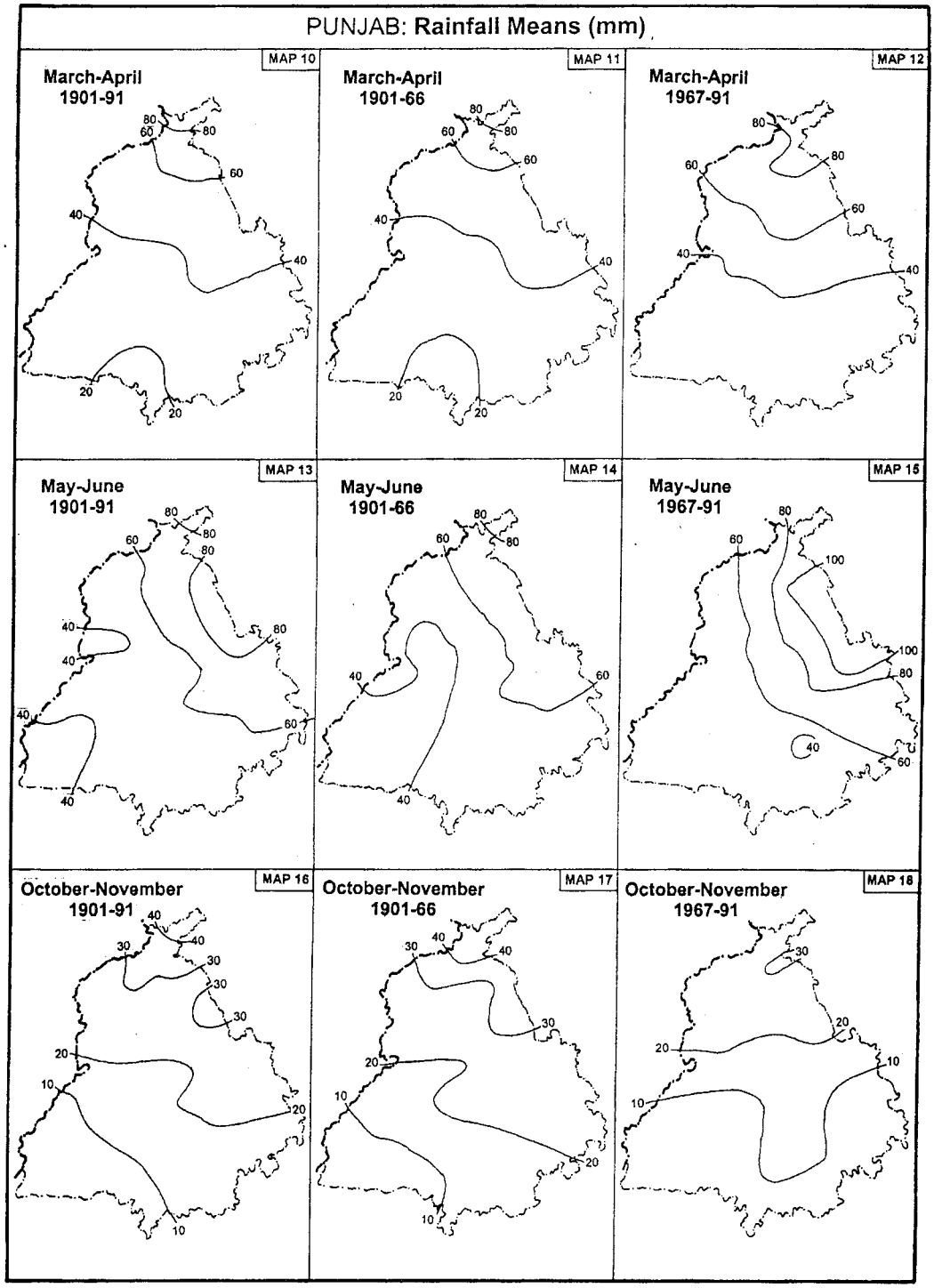

Fig. 2 : Punjab : Rainfall Means (mm) Map 10 to 18

the belt south of the River Sutlej and the northern parts emerge as areas of decline for annual and monsoon rainfall (Maps 19 and 20). The patterns of decline coincide for these periods.

The decrease in the north is significant because this was the area of maximum rainfall in Punjab. It covers the wettest parts of the state like Madhopur, Tibri and Gurdaspur. The central belt covering the stations of Moga, Jagraon, Ludhiana and Samrala is an intensively cultivated region and the area is considered to be the heartland of the Green Revolution. The significance of this decline is that it has occurred in that part of Punjab which had over 600-800 mm of rainfall.

Most of 'majha' and 'doaba' record increases in the annual and monsoon rainfall. The southwest significantly records increases for both these periods. The maximum increase in annual and monsoon rainfall was 233.7 mm and 172.3 mm at Nawanshahr. The maximum decrease in annual and monsoon rainfall was 187.9 mm and 127.1 mm at Gurdaspur.

The winter rainfall has recorded a decline in a major portion of the state (Map 21). The eastern and western parts record an increase. the decline and increase in the monsoon rainfall is much greater in amount than the decline and rise in winter rainfall. The maximum decrease in winter rainfall was at Gurdaspur (35.1 mm) and the maximum increase was at Garhshankar (27.7 mm).

Rainfall for the 4 dry months before the monsoon records an increase all over the state (Maps 22 and 23). this increase is quite high north of the River Sutlej for the March-April period. Most of the increase was in double figures with the maximum being 28.4 mm at Tibri. South of the Sutlej the increase remained in single figures. The pre-monsoon months of May-June record higher increases than the previous period with most stations recording a double digit increase. The maximum increase was 48.7 mm at Nawanshahr. Significantly, Fazilka in the dry southwestern corner, records a substantial increase in rainfall for March-April and May-June. An increase of 11.5 mm and 20.8 mm for these periods was recorded.

Table 2

Change in annual and seasonal averages of rainfall in post Green Revolution (1967-1991) period over the pre Green Revolution period (1901-1966)

Station	annual rainfall (mm)	monsoon rainfall (mm)	winter rainfall (mm)
Ajnala	+40.3	+16.1	-3.2
Aliwal	+30.2	+20.8	-7.9
Amritsar	+92.7	+68.7	-1.2
Batala	+87.2	+79.1	-15.5
Bhuchar	+197.1	+141.4	+17.5
Dasuya	+78.6	+39.0	-7.5
Fazilka	+96.5	+56.8	+4.9
Ferozepur Sadr	+9.2	-15.8	+10.0
Garhshankar	+67.7	+23.6	+27.7
Gurdaspur	-187.9	-127.1	-35.1
Hoshiarpur	+78.4	+34.6	-2.8
Jagraon	-42.4	-37.3	-11.7
Jalandhar	+20.5	-14.5	+0.7
Jodhpur	+81.8	+53.4	+0.4
Khara	+74.6	+24.7	-5.8
Lehal	-22.1	-1.4	-11.9
Ludhiana Observatory	-20.8	-15.8	-10.1
Madhopur	-35.9	-36.0	-4.6
Moga	-73.5	-58.9	-11.2
Muktsar	+5.0	-5.8	-0.2
Nakodar	+119.6	+86.2	-8.9
Nawanshahr	+233.7	+172.3	+10.1
Phillaur	+67.9	+54.3	-8.5
Ranike	-87.7	-56.2	-12.8
Samrala	-69.9	-50.0	-10.3
Tarn Taran	+62.6	+39.9	+1.5
Tibri	+14.7	-30.9	+9.0
Zira	+42.7	+19.6	-9.6

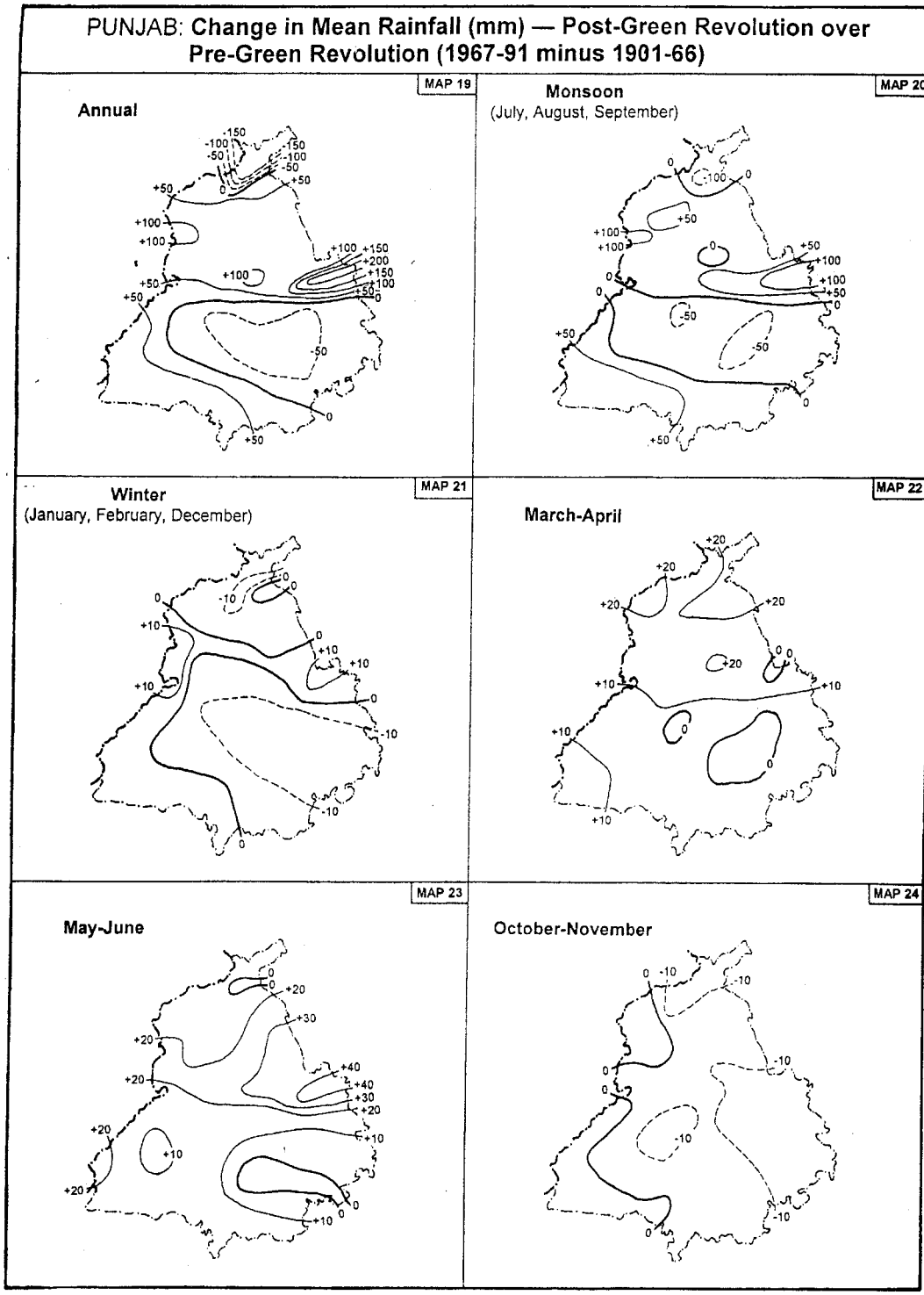

Fig. 3 : Punjab : Rainfall Means (mm) Map 19 to 24

The cool and dry months of October-November record significant declines all over the state (Map 24).

The picture that emerges from a study of the increase / decrease in annual and seasonal rainfall is revealing. A few stations record an increase in rainfall for all the six period under study. Bhuchar, Fazilka, Jodhpur, and Tarn Taran. Fazilka is the driest place in Punjab in terms of total annual rainfall received. It also receives that least amount of monsoon, winter, and pre-winter rainfall. Jodhpur in the vicinity is also equally dry. An increase in rainfall for these places is highly significant (Tables 2 and 3).

A comparison of the rainfall in the hot dry period and the cool dry period reveals significant rise in the former (Table 3). An analysis of tables 2 and 3 reveals that the pre monsoon (May-June) and post winter (March-April) rainfall has increased the maximum; there has been a decline in only 3 and 4 stations respectively. Additionally, the figures for increase are substantial as compared to the decline, which is marginal in most cases. The pre winter rainfall during October and November has declined in 21 of the 28 stations. The winter rainfally has also gone down in 19 places.

Conversely, there is one stations that records a decline in rainfall for all the periods : Ranike.

The annual rainfall has increased at 71 per cent of the places. Monsoon rainfall has increased at 57 per cent of the places.

Nawanshahr records the highest increase in annual rainfall (233.7 mm) and Gurdaspur records the maximum decline of 187.9 mm. The former posts dramatic increases for all periods except for October and November. At Gurdaspur rainfall decline is substantial during monsoon.

A trend towards homogenisation of rainfall amounts becomes apparent in this discussion. Change in seasonal averages of rainfall in

Table 3

Post Green Revolution (1967-1991) period over the pre Green Revolution period (1901-1966)

Station	Mar & Apr rainfall (mm)	May & Jun rainfall (mm)	Oct & Nov rainfall (mm)
Ajnala	+22.5	+3.0	+2.7
Aliwal	+17.9	+12.3	-12.9
Amritsar	+19.2	+5.7	+1.4
Batala	+20.5	+11.1	-8.0
Bhuchar	+10.2	+26.6	+1.7
Dasuya	+23.4	+29.1	-5.2
Fazilka	+11.5	+20.8	+2.4
Ferozepur Sadr	+0.4	+12.9	+1.0
Garhshankar	-4.7	+33.5	-12.2
Gurdaspur	+3.1	-6.8	-21.4
Hoshiarpur	+11.4	+30.1	-5.9
Jagraon	+3.7	+12.4	-9.7
Jalandhar	+20.9	+24.7	-11.3
Jodhpur	+8.2	+18.1	+0.1
Khara	+18.2	+26.2	-3.5
Lehal	+2.1	-0.1	-11.3
Ludhiana Observatory	+3.4	+17.5	-12.0
Madhopur	+23.4	1.1	-17.3
Moga	-5.1	+16.8	-15.2
Muktsar	+8.2	+6.2	-3.4
Nakodar	+13.6	+30.0	-5.7
Nawanshahr	+14.2	+48.7	-12.8
Phillaur	+14.0	+21.2	-13.6
Ranike	-2.9	-8.2	-6.9
Samrala	-5.1	+10.6	-17.5
Tarn Taran	+14.0	+4.7	+2.6
Tibri	+28.4	+10.2	-2.3
Zira	+17.7	+17.9	-3.1

Areas and periods of low rainfall have started to receive high amounts of rain. Some of the high rainfall areas have recorded considerable declines in rainfall amounts. The winter period,

which is the second most important rainfall season after the monsoon, posts significant declines in the state.

EXTREME VALUES

Average values do not always give a very clear picture of the real situation. Extreme values of rainfall present the entire range of high and low values. These are to be studied if the full implications of a particular rainfall regime are to be appreciated.

Table 4 shows that the station to record the highest ever rainfall during the study periods of 1901-1991 is Nawanshahr with 2467 mm in 1988. This was three times its normal rainfall. This is noteworthy. Madhopur is the station with the highest annual average rainfall (1354.2 mm) but in absolute terms it is at second place with 2223 mm. It is followed by Tibri 2213 mm, Dasuya 2013 mm, Hoshiarpur 2011 mm, Khara 1943 mm and Garhshankar 1860 mm.

Table 4

Highest amount of annual rainfall recorded in different stations in Punjab over the 1901-1991 period

Station	Highest Amount (mm)	Year
Nawanshahr	2467	1988
Madhopur	2223	1917
Tibri	2213	1988
Dasuya	2013	1988
Hoshiarpur	2011	1917
Khara	1943	1956
Garhshankar	1860	1976
Phillaur	1678	1984
Bhuchar	1593	1988
Gurdaspur	1554	1956
Aliwal	1547	1955
Batala	1526	1988
Lehal	1415	1933
Ranike	1400	1988
Ludhiana Observatory	1395	1917
Samrala	1317	1917
Jagraon	1291	1962
Tarn Taran	1287	1984
Amritsar	1277	1976
Jalandhar	1256	1950
Moga	1251	1973
Ajnala	1155	1976
Jodhpur	1126	1917
Nakodar	1122	1950
Zira	1090	1917
Ferozepur Sadr	967	1990
Muktsar	936	1950
Fazilka	845	1908

Table 5

Lowest amount of annual rainfall recorded in different stations in Punjab over the 1901-1991 period

Station	Lowest Amount (mm)	Year
Fazilka	37	1947
Bhuchar	39	1964
Jodhpur	64	1915
Ranike	67	1978
Moga	111	1968
Zira	115	1991
Lehal	126	1962
Muktsar	127	1947
Khara	154	1905
Jagraon	163	1969
Ferozepur Sadr	188	1946
Gurdaspur	201	1987
Tarn Taran	211	1932
Batala	211	1965
Ajnala	223	1902
Nakodar	239	1905
Ludhiana Observatory	240	1974
Samrala	244	1986
Phillaur	262	1969
Garhshankar	276	1918
Amritsar	283	1922
Jalandhar	300	1972
Aliwal	304	1989
Nawanshahr	312	1918
Dasuya	395	1934
Tibri	423	1918
Hoshiarpur	480	1949
Madhopur	543	1974

The year 1917 was a wet year with 6 stations recording their highest rainfall during this year : Hoshiarpur, Jodhpur, Ludhiana, Madhopur, Samrala, and Zira. The years 1988 and 1976 also received heavy amounts of rain with 5 and 4 stations recording their maximum rain during these years respectively.

Table 5 reveals that the lowest amount of rain to fall in Punjab from 1901-1991 was in Fazilka, 37 mm in 1947. The normal for this station was 331.6 mm. This conforms to its status of being the driest station in Punjab. Bhuchar follows with 39 mm of rainfall in 1964, Jodhpur 64 mm in 1915 and Ranike 67 mm in 1978. The year 1918 was a dry year with 3 stations along the hills recording their lowest rainfall : Garhshankar, Nawanshahr, and Tibri.

CONCLUSION

Punjab records an increase in annual rainfall of 39.6 mm in the post Green Revolution period. This supports the first hypothesis. However, the picture at the spatial scale was not uniform.

The increase is seasonally consistent and spatially uniform in the area of low rainfall, the southwest of Punjab. This area emerges as the area of increase in rainfall for all the periods under study. Fazilka and Jodhpur, which are among the driest stations of Punjab, post significant increases in rainfall. The north and northeast were identified as areas of high rainfall. In this region three pockets of change in the post Green Revolution period have emerged. The southern most end of this region, centering on Nawanshahr, experienced an increase that was substantial and the central part observed a moderate increase. The wet northern part, a region of over 1000 mm of rainfall, experienced a decline. Gurdaspur posts a maximum decline in average annual rainfall and also posted significant declines for all periods except for a marginal increase in the March and April rainfall. Madhopur, which recorded the highest average annual rainfall for 1901-1991, posted a decline for all periods except the hot and dry period.

Hence, we may state that the rainfall in the area of high rain did not increase and even decreased in parts. On the contrary, the areas of low rainfall posted significant increases. A trend towards homogenisation of rainfall amounts is observed with the rainfall of the southwest increasing and that in the north not increasing and even decreasing. This homogenisation was observed for the seasons too with the hot and dry period starting to get higher amounts of rainfall. The winter season, which is the second most important rainfall period after the monsoon, recorded only a marginal overall increase and posted significant declines in amounts spatially. This is in keeping with the homogenisation of agricultural practices, particularly irrigation, which has spread to the dry southwest in a big way. The second hypothesis was not fully substantiated.

The hypothesis relating to the rainfall increasing substiantially during May and June was validated fully. This period emerges with the maximum increase all over the state with the least number of stations recording a decline during the post Green Revolution period. This increase is to be seen in the light of the fact that this is the driest and hottest part of the year in this region.

It is evident that the rainfall regime in Punjab has undergone a change in the post-Green Revolution period in comparison with the pre-Green Revolution period. This change could be related to the wide ranging changes in land use and intensive and extensive irrigation.

The changes could also be viewed in the context of global warming and the ensuing climatic changes. This aspect requires a detailed investigation for an authentic answer.

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