Vol. 21, No. 2, pp. 424-434 (2021)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Arrival, Withdrawal and Duration of Western Disturbances in Different Districts of Punjab

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ABSTRACT

The historical weather data on rainfall (mainly number of western disturbances (WD), duration of WD and number of day rain occurs during the WD) for different districts representing different agroclimatic zones i.e. sub-montane undulating zone [Ballowal Saunkhri (1984-2019), central plain zone (Amritsar (1970-2019), Ludhiana (1970-2019) and Patiala (1970-2019) and south-west zone (Bathinda (1977-2019) and Faridkot (1977-2019)] were analysed from October to May in Punjab, India. The chances of arrival of WD in all the six districts of Punjab was found maximum during the month of October and withdrawal was observed during May month. Mean, standard deviation and coefficient of variation for western disturbances, duration of western disturbances, number of days rain occurs and rainfall for all six stations were also calculated and found that it was higher in February and March months in all the districts. The decade wise total WD and average rainfall was also worked out for six stations and the results revealed that total WD for Ludhiana (170), Patiala (164) and Ballowal Saunkhri (171) were higher during second decade but for Amritsar (188) these were higher during third decade. Similarly, average rainfall was higher during second decade for Ludhiana (39.6 mm), Patiala (44.4 mm) and Amritsar (55.4 mm). It has been found that total number of WD's were higher during first decade in Faridkot while for Bathinda it was higher during third decade.

Key words: Western disturbance, agroclimatic regions, rainfall, number of rainy days, Punjab

Introduction

The winter weather systems that move across northwest India from west to east during the period from October to May are called Western disturbances (WD) as these are embedded in the westerlies. Thunderstorms associated with the so-called Western Disturbances may occasionally occur. Increased rainfall during different critical stages of wheat crop (crown root initiation, flowering, and physiological maturity) results in higher yield than dry years, while high temperature during reproductive stage reduces the yield (Kalra *et al.*, 2008). This fact is also true for other crops. Temperatures as well as rainfall are two important weather parameters affecting growth of *rabi* crops. A well distributed winter rainfall (15-20 cm) is a necessity for the rainfed regions. Overall it was stated that, the temperature is likely to rise more during the winter season (*rabi*) as compared to the rainy season (*kharif*) and this will severely affect the yield of *rabi* season crops. In the region, the monsoon (June-September) and winter season (December-March) rainfall contributes about 80% and 20% of the annual precipitation, respectively

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(Gill *et al.*, 2017; Yadav *et al.,*2012). Winter precipitation is very important for the production of *rabi* crop and particularly the wheat crop, as it provides moisture and maintains low temperature for the crops which is vital for the growth of the plants.

Precipitation caused by WD during the months of October and November is favourable for the sowing of wheat crop in areas lacking in the irrigation facilities. The amount of rainfall depends upon the intensity and duration of western disturbances. At the same time, a WD provides required moisture to the wheat crop at different phenological stages during its life cycle. Reproductive stage of wheat crop passes through the months of February and March under Punjab conditions. Moisture deficiency during this stage has detrimental effect on the grain yield of wheat crop (Satter *et al*., 2016). Apart from rainfall, temperature has a great impact on the grain formation and development stage of the wheat crop under irrigated as well as under rainfed conditions. Rainfall with variable amount and regularity can affect the crop growth curve and yield of wheat.

The arrival and withdrawal of western disturbance determines the moisture availability to the winter crops as well as modifies the prevailing weather. The frequency and duration of western disturbances may be favourable and unfavourable depending on their intensity and stage of crop growth. These weather systems during winter season results in a large temporal and spatial variation in crop yield (Gill *et al.*, 2013; Gill *et al.*, 2015). Therefore, understanding the behaviour of western disturbance in these parts of Punjab bears great importance.

Materials and Methods

Data collection

In the present study, historical weather data for six stations of Punjab, was collected for the period from October to May as per the availability *i.e.* for Amritsar (1970-2019), Ballowal Saunkhri (1984-1209), Bathinda (1977-2019), Faridkot (1977-2019), Ludhiana (1970-2019) and Patiala (1970-2019) from Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University Ludhiana, different Research Stations of PAU, and India Meteorological Department. The data have been analyzed to study the arrival, withdrawal and duration of western disturbances at different locations, Mean, standard deviation and coefficient of variation for western disturbances, duration of western disturbances, number of days rain occurs and rainfall for all six stations were analysed.

Table 1. Location of study sites in Punjab

District	Latitude	Longitude
Amritsar	31°31′56″	74°52′25″
Ballowal Saunkhri	31°06′27″	76°29′70″
Bathinda	30°35′19″	75°01′12″
Faridkot	30°72′57″	74°81′89″
Ludhiana	30°54′33″	75°48′22″
Patiala	30°19′38″	76°24′00″

Mean

Monthly as well as seasonal mean of rainfall were calculated by simple arithmetic mean method. The monthly as well as seasonal mean of rainfall from October to May were also calculated.

Standard Deviation

The standard deviation (SD, is used to quantify the amount of variation or dispersion of a set of data values. A low standard deviation indicates that the data points are close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

Coefficient of variation

The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean. It shows the extent of variability in relation to the mean of the population.

$$C.V = \frac{\sigma}{\bar{X}} * 100$$

Where
σ = standard deviation
$\bar{X}$ = mean of data

Duration of Western Disturbance

It is the period during which western disturbance remains active and causes cloudiness and

precipitation. Active WD may be defined as the one, which produces cloud as well as rainfall. Trace is also taken into account as light rainfall also affects the microclimate of the crops. Normally, one rainy day is counted when 2.5mm rainfall occurs during 24 hours. But in the present study, one rainy day was taken if light rainfall or trace occurred during 24 hours.

Results and Discussion

Arrival and withdrawal of western disturbances (WD) during rabi season (October-May) in different districts of Punjab

The onset and withdrawal of western disturbances in different districts of Punjab from 1970- 2019 has been presented in Table 2.

Amritsar

The data in Table 2 indicates that during the period of 49 years (1970-2019), the WD arrived during the month of October (36 years) followed by November (8 years), December (2 years) and January (3 years). It means the probability of onset of WD in October month is 73.4% followed by November (16.3%), December (4.0%) and January (6.1%), respectively. Out of 49 years, there were 44 years in which WD remained active upto May month and only for 5 years the withdrawal has occurred during the month of April. This depicts that there was 89.7% chances that WD may remain active upto the month of May and only 10.2% during the month of April.

Ballowal Saunkhri

The data in Table 2 indicates that during the period of 35 years (1984-2019), the WD arrived during the month of October (23 years) followed by November (3years), December (5years) January (3 years) and February (1 year). It means the probability of onset of WD in October month is 62.8% followed by November (8.5%), December (14.2%), January (8.5%) and February (2.8%), respectively. Out of 35 years, there were 33 years in which WD remained active upto May month and for 1 year the withdrawal has occurred during the months of February and April. It indicated that there was 94.2% chances that WD may remain active upto the month of May and only 3.1% during the month of April.

Bathinda

The Table 2 indicates that during the period of 42 years , the WD arrived during the month of October (27 years) followed by November (7 years), December (3 years), January (4 years) and February (1 year). It means the probability of occurrence of WD in October month is 64.3% followed by November (16.6%), December (7.1%), January (9.5%) and February (2.3%), respectively. Out of 42 years, there were 35 years during which WD remained active upto May month and only for 1, 2 and 4 years the withdrawal has occurred during the month of February, March and April, respectively. It indicated that there was 83.3% chances that WD may remain active upto the month of May and only 2.3, 4.7 and 9.5% during the month of February, March and April, respectively.

Faridkot

The data in Table 2 indicates that during the period of 19 years (2000-2019), the WD arrived during the month of October (9 years) followed by November (1 years), December (5 years) and January (4 years). It means the probability of onset of WD in month of October is 47.3% followed by November

Table 2. Arrival and withdrawal of WD (%) at different locations in Punjab during *rabi* season

Location	October	November	December	April	May
Amritsar (1970-2019)	73.4	16.3	4.0	10.2	89.7
Ballowal (1984-2019)	62.8	8.5	14.2	3.1	94.2
Bathinda (1977-2019)	64.3	16.6	7.1	9.5	83.3
Faridkot (2000-2019)	47.3	5.2	26.3	5.2	94.7
Ludiana (1970-2019)	53.0	24.4	12.2	14.2	85.7
Patiala (1970-2019)	61.2	14.5	12.5	6.2	85.7

(5.2%), December (26.3%) and January (21.0%), respectively. Out of 19 years, there were 18 years in which WD remained active upto May month and only for one year the withdrawal has occurred during the month of April. It indicates that there was 94.7% chances that WD may remain active upto the month of May and only 5.2% during the month of April.

Ludhiana

The data in Table 2 indicates that during the period of 49 years (1970-2019), the WD arrived during the month of October (26 years) followed by November (12 years), December (6years) and January (5years). It means the probability of onset of WD in October month is 53.0% followed by November (24.4%), December (12.2%) and January (10.2%), respectively. Out of 49 years, there were 42 years in which WD remained active upto May month and only for 7 years the withdrawal has occurred during the month of April. It indicated that there was 85.7% chances that WD may remain active upto the month of May and only 14.2% during the month of April.

Patiala

The data in Table 2 indicates that during the period of 49 years (1970-2019), the WD arrived during the month of October (30 years) followed by November (7 years), December (6 years) and January (6 years). It means the probability of onset of WD in October month is 61.2% followed by November (14.5%), December (12.5%) and January (12.5%), respectively. Out of 49 years, there were 42 years in which WD remained active upto May month and only for 3 years and 4 years the withdrawal has occurred during the month of March and April. It indicates that there was 85.7% chances that WD may remain active upto the month of May and only 6.1 and 6.2% during the month of March and April, respectively. It has been observed that the WD never occurred during the monsoon months especially during July and August months and roughly the start of December and April, could be considered appropriate boundaries for a 'western disturbance' season (Kieran *et al*., 2017).

Decadal variation in total number of WD and average rainfall during rabi season (October-May)

The analysis of total number of western disturbances WD and total rainfall RF was done for Amritsar during the years 1970-2019 (Fig.1a). The total number of western disturbances ranged from 139 to 188 and being highest (188) during 1990-99 and the lowest (139) during 2010-2019. The seasonal total rainfall ranged between 1194 to 2333 mm and being highest (2333 mm) during 1980 -89 and the lowest (1194 mm) during 1970-1979.

At Ballowal Saukhri, (Fig. 1b) the total number of western disturbances was between 100 to 135. The highest number of WD was found in decade III (135) whereas the lowest was in the decade IV. The average rainfall ranged between 1850 to 1106 mm. The highest (1850 mm) was in the decade III and the lowest (1106 mm) was in the decade IV.

The total number of western disturbances WD ranged between 90 to 129 at Bathinda (Fig. 1c). The highest (129) was in the decade II and the lowest (90) was in the decade III. The total rainfall ranged from 1217 to 785 mm and was highest (1217 mm) in II decade whereas, the lowest (785 mm) was observed in the decade IV.

At Faridkot (Fig. 1d) number of WD during decade I and decade II was 89 and 70, respectively. Average rainfall was highest in decade I (532 mm) and lowest (673 mm) in decade II.

At Ludhiana (Fig. 1e) the total number of western disturbances ranged between 127 to 170. The highest number of WD was in decade II (170) and the lowest was in decade V (127). The total rainfall ranged from 1642 to 1045 mm and was highest (1642 mm) in the decade II whereas the lowest (1045 mm) was in the decade I.

At Patiala (Fig. 1f) the total number of western disturbances ranged from 106 to 164 and was highest (164) in the decade 1980-1990 whereas, the lowest (106) was observed in the decade I. The Average rainfall ranged from 1840 to 1048mm and was highest in decade II whereas, the lowest (24.7 mm) was observed in IV decade.

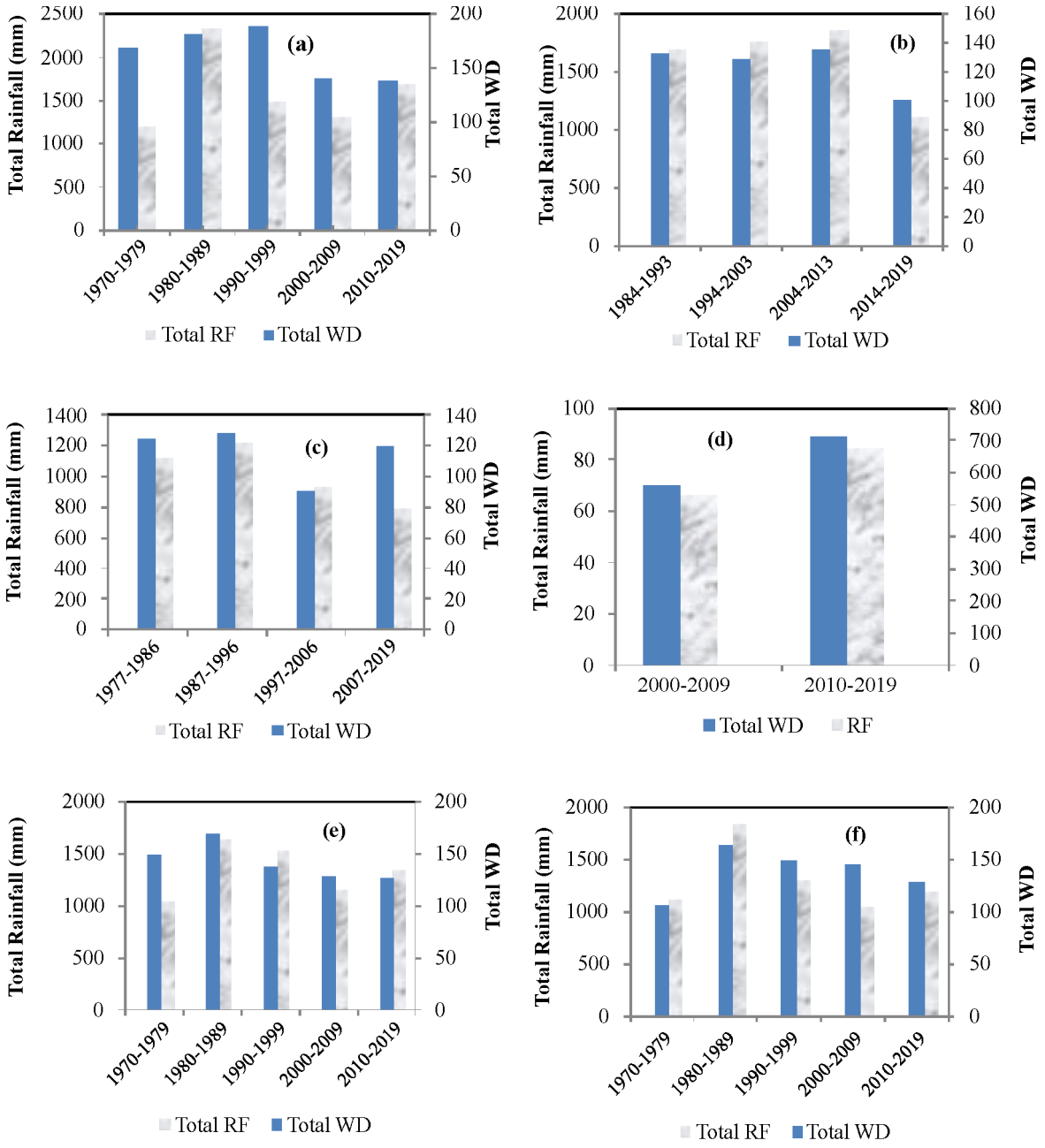

Fig. 1. Total number of western disturbance and average rainfall at different locations in Punjab i.e. Amritsar (a), Ballowal Saunkhri (b), Bathinda (c), Faridkot (d), Ludhiana (e) and Patiala (f)

Statistical parameters of western disturbances at different locations

The statistical analysis of different rainfall components has been shown in Table 3.The analysis of 49 years (1970-2019) rainfall data of Amritsar indicates that the number of WD per month was highest (3.0) in the month of February and lowest (0.6) in month of November. The duration of WD was highest (6.4) in March and lowest (1.9) in November month (Table 3).The number of monthly number of day rain occurs was highest (3.6) in March month and lowest (1.2) in November month, whereas monthly rainfall was highest (37.8 mm) in month of March and lowest (6.3mm) in month of November. The coefficient of variation of WD ranged between 66.8 to 141.9% during October to May being highest

Table 3. Number and duration of WD, number of day rain occurs (RD) and rainfall at different locations in Punjab during *rabi* season

Month	Number of WD			Duration of WD			Number of day rain occurs			Average rainfall		
	No	SD	CV (%)	Days	SD	CV (%)	No	SD	CV (%)	RF (mm)	SD	CV (%)
Amritsar												
October	1.0	1.2	116.0	2.3	4.2	183.3	1.3	1.4	110.7	15.0	25.7	171.3
November	0.6	0.8	141.9	1.9	3.6	190.7	1.2	1.7	146.0	6.3	10.4	165.7
December	1.0	1.2	124.1	2.8	4.5	162.2	1.4	1.4	98.2	11.0	14.3	129.8
January	2.1	1.8	88.5	4.2	4.2	101.7	2.3	1.2	50.9	26.8	27.4	102.4
February	3.0	2.3	77.0	5.7	5.3	94.1	3.3	3.9	117.6	35.9	31.2	87.1
March	3.2	2.2	66.8	6.4	6.1	94.3	3.6	4.4	120.7	37.8	35.1	92.8
April	2.0	1.8	90.0	5.1	5.6	111.2	2.6	1.5	57.0	23.7	31.6	133.1
May	1.9	1.7	89.9	4.6	5.0	109.1	2.9	1.8	61.1	20.9	22.9	109.6
Ballowal Saunkhri												
October	1.1	1.3	127.6	1.7	1.9	111.0	1.3	1.3	102.7	23.7	46.5	196.2
November	0.7	1.1	161.2	1.0	1.5	151.5	0.7	0.9	137.8	5.9	12.1	203.4
December	1.1	1.1	101.6	2.1	1.9	89.2	1.4	1.1	76.5	23.0	40.2	174.3
January	2.4	1.7	70.1	3.9	2.2	55.9	2.2	0.9	41.4	35.8	32.7	91.3
February	3.3	2.5	74.0	5.6	2.8	49.9	2.7	1.1	39.5	38.8	32.5	83.6
March	2.8	2.0	69.8	5.2	3.1	58.9	2.7	1.4	52.7	32.4	30.5	94.0
April	1.9	1.7	88.6	3.7	2.5	67.3	2.3	1.3	55.8	17.8	15.6	87.8
May	2.9	2.3	78.0	5.0	2.6	53.2	3.2	1.6	51.1	33.2	27.4	82.6
October	1.1	1.3	127.6	1.7	1.9	111.0	1.3	1.3	102.7	23.7	46.5	196.2
Bathinda												
October	0.7	1.0	134.0	1.1	1.1	107.0	1.6	2.8	178.9	11.3	17.2	153.0
November	0.4	0.7	164.1	0.7	1.3	175.7	1.1	2.2	206.5	4.0	8.4	207.8
December	0.6	1.0	134.0	1.0	1.1	107.0	2.2	2.8	178.9	7.1	17.2	153.0
January	1.3	1.2	93.5	1.6	1.1	66.7	2.4	1.7	73.1	15.0	17.4	115.8
February	2.1	1.7	78.9	2.0	1.4	69.8	3.2	2.2	67.9	26.4	27.5	104.3
March	1.7	1.7	103.3	2.0	1.5	72.8	3.0	2.5	82.6	19.1	25.5	133.1
April	1.1	1.6	145.2	1.7	1.4	85.9	2.3	2.2	97.1	13.9	1.9	86.7
May	1.4	1.5	109.5	1.8	1.5	83.8	2.2	21.4	154.2	18.9	26.4	139.8
Faridkot												
October	0.1	0.4	282.8	0.6	0.9	146.6	0.5	0.8	151.2	5.3	13.3	251.3
November	0.3	0.5	185.2	0.4	0.5	138.0	0.4	0.5	138.0	2.5	4.3	172.7
December	0.5	0.8	151.2	1.0	1.1	106.9	0.8	0.7	94.3	4.6	6.3	137.3
January	1.3	1.0	82.8	2.1	1.7	81.3	1.6	1.1	65.3	8.8	6.7	75.8
February	1.8	1.8	104.7	3.0	2.3	77.7	2.3	1.8	77.9	22.1	25.0	113.1
March	2.0	1.8	88.6	3.0	2.8	94.3	2.3	1.8	81.4	35.9	50.4	140.5
April	1.6	0.9	56.4	2.4	0.9	38.6	1.8	0.7	40.4	19.0	15.6	82.1
May	1.5	1.1	71.3	1.9	1.6	82.8	1.8	1.4	79.4	18.7	22.8	122.2

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Ludhiana												
October	1.0	1.2	121.9	1.2	1.7	139.8	0.7	1.1	154.1	10.8	22.3	207.0
November	0.8	1.0	122.8	1.2	1.6	134.5	0.6	0.9	151.6	6.1	13.4	219.1
December	1.3	1.0	77.8	1.9	1.5	81.8	1.2	1.2	103.0	15.0	22.3	148.5
January	2.1	1.1	53.5	3.5	2.1	61.4	2.3	1.5	65.8	27.8	23.8	85.8
February	2.6	1.3	50.5	4.3	2.7	64.4	2.7	2.1	78.1	33.0	30.8	93.2
March	2.5	1.7	66.7	4.2	3.2	77.4	2.2	2.0	94.2	23.1	22.2	96.5
April	2.2	1.3	61.0	3.0	2.1	70.6	1.7	1.5	89.7	18.4	22.5	122.1
May	2.4	1.7	69.8	3.3	2.6	80.0	1.9	1.8	93.7	23.0	24.8	107.7
Patiala												
October	0.7	1.2	161.5	1.3	1.8	139.1	0.9	1.1	115.9	10.4	20.3	195.5
November	0.6	1.2	184.5	1.2	1.7	142.8	0.8	1.0	126.7	7.1	15.8	223.4
December	1.1	1.2	114.5	1.8	1.5	85.0	1.2	1.0	83.9	16.8	27.3	162.9
January	2.0	1.5	76.5	3.3	2.1	64.1	1.9	1.1	56.8	27.3	28.4	104.0
February	3.0	2.3	77.5	4.0	2.6	66.9	2.5	1.5	60.0	29.4	24.7	84.0
March	2.1	2.2	102.5	4.3	3.1	72.1	2.6	1.7	65.1	26.1	29.6	113.5
April	1.9	2.3	122.3	3.0	2.2	75.4	2.1	1.3	64.4	18.4	36.4	197.6
May	1.8	1.8	103.0	3.5	2.8	80.9	2.5	1.6	63.9	22.6	31.3	138.6

(141.9%) in November month and lowest (66.8%) in March month. The coefficient of variation of duration of WD was highest (190.7%) in November month and lowest (94.1%) in the month of February. Similarly, the coefficient of variation of RD was highest (146.0%) in November month and lowest (50.9%) in January month, whereas coefficient of variation for rainfall was highest in month of October (171.3%) and lowest (87.1%) in February month. The variability of WD, duration of WD, number of day rain occurs and rainfall revealed that it was high for all these three parameters in the early growth stages of wheat crop whereas it was low during active growth and reproductive stage of wheat crop.

The analysis of rainfall data (1984-2019) at Ballowal Saunkhri, indicates that the number of WD per month was highest (3.3) in the month of February and lowest (0.7) in the month of November. The duration of WD was highest in February (5.6) and was lowest (1.0) in November month. The number of monthly number of day rain occurs was highest (2.7) in February and March month and lowest (0.7) in November month, the monthly rainfall was highest (38.8 mm) in the month of February and lowest (5.9 mm) in the month of November. The coefficient of variation of WD ranged between 69.8 to 161.2% during (October to May) being highest (161.2%) in November month and lowest (69.8%) in March month. The coefficient of variation of duration for WD was highest (151.5%) in November month and lowest (49.9%) in the month of February. The coefficient of variation of RD was highest (137.8%) in November month and lowest (39.5%) in February month, whereas coefficient of variation for rainfall was highest in month of November (203.4%) and lowest (83.6%) in February month. The variability of WD, duration of WD, number of day rain occurs and rainfall was high in the early growth stages of wheat crop whereas it was low during active growth and reproductive stage of wheat crop.

The analysis of rainfall data (2000-2019) at Faridkot, indicates that the number of WD per month was highest (2.0) in the month of March and lowest (0.1) in the month of October. The duration of WD was highest in February and March (3.0) and lowest (0.4) in November month. The number of monthly number of day rain occurs was highest (2.3) in February and March month and lowest (0.4) in November month, whereas, monthly rainfall was highest (35.9 mm) in the month of February and lowest (2.5 mm) in the month of November. The coefficient of variation of WD ranged between 56.4 to 282.8% during October- May, being highest (282.8%) in October month and lowest (56.4%) in

April month. The coefficient of variation of duration of WD was highest (146.6%) in October month and lowest (38.6%) in the month of April. Similarly, the coefficient of variation of RD was highest (151.2%) in October month and lowest (40.4%) in the April month, whereas coefficient of variation for rainfall was highest in the month of October (251.3%) and lowest (75.8%) in January month. The variability of WD, duration of WD, number of day rain occurs and rainfall was high in the early growth stages of wheat crop whereas it was low during active growth and reproductive stage of wheat crop.

The analysis of rainfall data of Ludhiana for a period of 49 years (1970-2019) indicates that the number of WD per month was highest (2.6) in the month of February and lowest (0.8) in month of November. The duration of WD was highest in February (4.3) and lowest (1.2) in October and November. The number of monthly number of day rain occurs was highest (2.7) in February month and lowest (0.6) in November month, whereas monthly rainfall was also highest (33 mm) in month of February and lowest (6.1mm) in the month of November.The coefficient of variation of WD ranged between 50.5 to 122.8% during (October to May) being highest (122.8%) in November month and lowest (50.5%) in February month. The coefficient of variation of duration of WD was highest (139.8%) in October month and lowest (61.4%) in the month of January. Similarly, the coefficient of variation of RD was highest (154.1%) in October month and lowest (65.8%) in January month, whereas coefficient of variation for rainfall was highest in the month of November (219.1%) and was lowest (85.8%) in January month. The variability of WD, duration of WD, number of day rain occurs and rainfall was high in the early growth stages of wheat crop whereas it was low during active growth and reproductive stage of wheat crop.

The analysis of rainfall data (1970-2019) at Patiala, indicates that the number of WD per month was highest (3.0) in the month of February and lowest (0.6) in the month of November. The duration of WD was lowest in November (1.2) and highest (4.3) in March month. The number of monthly number of day rain occurs was highest (2.6) in March month and lowest (0.8) in November month, whereas monthly rainfall was highest (29.4 mm) in month of February and lowest (7.1mm) in the month of November. The coefficient of variation of WD ranged from 76.5 to 184.5% during October- May, being highest (184.5%) in November month and lowest (76.5%) in January month. The coefficient of variation of duration of WD was highest (142.8%) in November month and lowest (64.1%) in the month of January. The coefficient of variation of RD was highest (126.7%) in November month and lowest (56.8%) in January month, whereas coefficient of variation for rainfall was highest in month of November (223.4%) and was lowest (84.0%) in February month. The variability of WD, duration of WD, number of day rain occurs and rainfall was high in the early growth stages of wheat crop, whereas, it was low during active growth and reproductive stage of wheat crop.

The analysis of rainfall data from 1977 to 2019 years, for Bathinda indicates that the number of WD per month was highest (2.1) in the month of February and lowest (0.4) in month of November. The duration of WD was highest (2.0) in February and March and was lowest (0.7) in November month. The number of monthly number of day rain occurs was highest (3.2) in February month and lowest (1.1) in November month, whereas monthly rainfall was also highest (26.4 mm) in month of February and lowest (4.0mm) in month of November.

The coefficient of variation of WD ranged between 78.9 to 164.1 per cent during October to May being highest (164.1%) in November month and lowest (78.9%) in February month. The coefficient of variation of duration of WD was highest (175.7%) in November month and lowest (66.7%) in the month of February. Similarly, the coefficient of variation of RD was highest (206.5%) in November month and lowest (67.9%) in February month. The coefficient of variation for rainfall was highest in the month of October (207.8%) and lowest (86.7%) in April month. The variability of WD, duration of WD, number of day rain occurs and rainfall was high in the early growth stages of wheat crop whereas it was low during active growth and reproductive stage of wheat crop.

Decadal variation of rainfall during withdrawal of WD (February, March and April)at different locations

At Amritsar (Table 4) the average decadal rainfall in the month of February ranged between 26.7 to 40.0 mm being highest (40.0 mm) in 2nd and 5th decade and lowest (26.7 mm) in 1st decade. For March month average decadal rainfall was highest (64.9 mm) in 2nd and lowest (27.9 mm) in 4th decade. The average decadal rainfall in the month of April ranged between 13.3 to 45.1 mm being highest (45.1 mm) in 2nd decade and lowest (13.3 mm) in 1st decade. The coefficient of variation for the month of February month was highest (122.1mm) in 5th decade and lowest (50.1mm) in 3rd decade. During March coefficient of variation ranged between 45.1 to 118.6% being lowest 45.1 in IIIrd decade. The coefficient of variation for the month of April ranged between 64.2 to 132.2% being highest (132.2%) in IVth decade and lowest (64.2) in Vth decade.

At BallowalSaunkhri (Table 4) the average decadal rainfall for the month of February ranged between 28.3 to 46.0 mm being highest (46.0 mm) in 4th decade and lowest (28.3 mm) in 1st decade. During March month average decadal rainfall was highest (34.8 mm) in 4th and lowest (20.0 mm) in 1st decade. The average decadal rainfall for the month of April ranged between 13.9 to 19.8 mm being highest (19.8 mm) in 3rd decade and lowest (13.9 mm) in 2nd decade. Similarly coefficient of variation for month of February month was highest (94.0 mm) in 4th decade and lowest (68.8 mm) in 2nd decade. During March month coefficient of variation ranged between 62.5 to 95.3% being highest (62.5mm) in 2nd decade and lowest (95.3 mm) in 1st decade. The coefficient of variation for month of April ranged between 90.1 to 102.9% being highest (102.9%) in 2nd decade and lowest (90.1) in 3rd decade.

At Bathinda (Table 4) the average decadal rainfall for the month of February ranged between 15.8 to 38.3 mm being highest (38.3 mm) in 2nd decade and lowest (15.8 mm) in 4th decade. During March month average decadal rainfall was highest (32.3 mm) in 1st and lowest (11.5 mm) in 3rd decade. The average decadal rainfall for the month of April ranged from 5.6 to 21.6 mm being highest (21.6 mm) in 1st decade and lowest (5.6 mm) in 3rd decade. Similarly coefficient of variation for month of February was highest (110.9 mm) in 3rd decade and lowest (81.6 mm) in 1st decade. During March month coefficient of variation ranged between 73.7 to 157.9% being highest (157.9 mm) in 4th decade and lowest (73.7 mm) in 2nd decade. The coefficient of variation for month of April ranged between 108.1 to 184.4% being highest (184.4%) in 3rd decade and lowest (108.1) in 4th decade.

At Faridkot (Table 4) the average decadal rainfall for the month of February ranged between 19.6 to 27.5 mm being highest (27.5 mm) in 1st decade and lowest (19.6 mm) in 2nd decade. During March month average decadal rainfall was highest (29.2 mm) in 2nd and lowest (19.2 mm) in 1st decade. The average decadal rainfall for the month of April ranged between 7.0 to 15.3 mm being highest (15.3 mm) in 2nd decade and lowest (7.0 mm) in 1st decade. Similarly coefficient of variation for month of February month was highest (117.6 mm) in 1st decade and lowest (116.9 mm) in 2nd decade. During March month coefficient of variation ranged between 94.5 to 159.4% being highest (159.4mm) in 2nd decade and lowest (94.5 mm) in 1st decade. The coefficient of variation for month of April ranged between 64.0to 103.4% being highest (103.4%) in 2nd decade and lowest (64.0%) in 1stdecade.

At Ludhiana (Table 4)the average decadal rainfall for the month of February ranged between 1.4 to 20.6 mm being highest (20.6mm) in 3rd decade and lowest (1.4 mm) in 1st decade. During March (Table 4) it ranged between 1.7 to 13.7 mm being highest (13.7) in 2nd decade and lowest (1.7 mm) in 5th decade. The average decadal rainfall for the month of April ranged between 5.5 to 23.6 mm being highest (23.6mm) in 3rd decade and lowest (5.5mm) in 4th decade. Similarly coefficient of variation for month of March ranged between 126.2 to 190.9% being highest in 2nd decade and lowest in Ist decade. The coefficient of variation for month of April ranged between 86.9 to 158.1% being highest in IIIrd decade and lowest in Vth decade.

At Patiala (Table 4) the average decadal rainfall for the month of February ranged between 25.1 to 31.6 mm being highest (31.6mm) in 5th decade and lowest (25.1 mm) in 4th decade. During March month average decadal rainfall was highest (32.6 mm) in

Table 4. Decadal variation of rainfall in February, March and April at different locations of Punjab

Year	Decade	February			March			April		
		Mean (mm)	SD	CV (%)	Mean (mm)	SD	CV (%)	Mean (mm)	SD	CV (%)
					Amritsar					
1970- 79	I	26.7	14.1	52.7	33.1	33.6	101.7	13.3	15.9	119.2
1980-89	II	40.0	28.5	71.4	64.9	47.0	72.5	45.1	57.2	126.8
1990-99	III	35.6	17.8	50.1	28.9	13.0	45.1	16.6	13.5	81.1
2000-09	IV	37.7	42.0	111.5	27.9	25.2	90.4	13.4	17.7	132.2
2010-19	V	40.0	48.9	122.1	33.1	39.2	118.6	31.5	20.2	64.2
Mean		36	30.3	81.5	37.5	31.6	85.6	23.9	24.9	104.8
					Ballowal Saunkhri					
1984-93	I	28.3	22.9	81.1	20.0	19.0	95.3	17.1	17.6	102.8
1994-03	II	36.4	23.4	68.8	29.8	18.7	62.5	13.9	13.5	102.9
2004-13	III	38.3	32.4	85.0	21.6	18.7	90.9	19.8	18.3	90.1
2014-19	IV	46.0	42.3	94.0	34.8	31.8	90.8	18.0	17.6	97.9
Mean		37.2	30.2	82.2	26.5	22	84.8	17.2	16.7	98.4
					Bathinda					
1977-86	I	25.0	21.9	81.6	32.3	31.5	102.2	21.6	34.1	169.8
1987-96	II	38.3	36.4	94.9	13.2	9.5	73.7	16.8	20.6	131.7
1997-06	III	27.6	28.8	110.9	11.5	12.0	105.3	5.6	10.5	184.4
2007-19	IV	15.8	15.8	100.1	17.9	20.8	157.9	12.1	13.6	108.1
Mean		26.6	25.7	96.8	18.7	18.4	109.7	14.0	19.7	148.5
					Faridkot					
2000-09	I	27.5	32.3	117.6	19.2	18.2	94.5	7.0	4.5	64.0
2010-19	II	19.6	22.9	116.9	29.2	46.6	159.4	15.3	15.8	103.4
Mean		12.3	27.6	117.2	24.2	32.4	126.9	11.1	5.1	83.7
					Ludhiana					
1970- 79	I	1.4	2.0	141.7	5.8	7.3	126.2	10.3	13.9	135.2
1980-89	II	12.6	16.7	132.6	13.7	26.1	190.9	21.7	24.6	113.3
1990-99	III	20.6	42.3	205.0	6.3	10.4	164.0	23.6	37.3	158.1
2000-09	IV	10.7	15.6	145.8	2.7	4.4	164.8	5.5	5.7	103.1
2010-19	V	9.4	12.6	134.1	1.7	2.7	158.8	15.6	13.5	86.9
Mean		10.9	17.8	151.8	6.0	10.2	160.9	15.3	19	119.3
					Patiala					
1970-79	I	30.6	24.2	79.0	16.9	23.3	137.9	7.7	11.2	145.1
1980-89	II	30.2	23.9	79.2	31.4	32.0	101.9	34.3	71.4	208.0
1990-99	III	30.2	18.8	62.3	24.6	29.1	118.5	18.5	28.0	151.0
2000-09	IV	25.1	28.2	112.3	26.3	32.8	124.9	15.6	19.1	122.2
2010-19	V	31.6	33.3	105.3	32.6	34.4	105.5	15.3	12.5	81.7
Mean		73.6	25.6	87.6	26.3	30.3	117.7	18.2	28.4	81.7

5th and lowest (16.9 mm) in 1st decade. The average decadal rainfall for the month of April ranged between 7.7 to 34.3 mm being highest (34.3 mm) in 2nd decade and lowest (7.7 mm) in 1st decade. Similarly coefficient of variation for month of February month was highest (112.3 mm) in 4th decade and lowest (79.0 mm) in 1st decade. During March month coefficient of variation ranged between 101.9

to 137.9% being highest (137.9 mm) in 1st decade and lowest (101.9 mm) in 2nd decade. The coefficient of variation for month of April ranged between 81.7 to 208.0% being highest (208.0%) in 2nd decade and lowest (81.7) in 5th decade. It has been found that the western disturbances mostly occurred during the winter season during the *rabi* season (October - April), the occurrence of rainfall is very much needed so that farmer can make arrangement for sowing of wheat crop otherwise he has to apply pre-sowing irrigation and after that also different irrigations for the growth of the crop. The purpose of this study is to analyze the rainfall distribution patterns during *rabi* crops sowing (October- December) and afterwards (Gill *et al*., 2017). Rainfall during the pre-sowing period is pre-requisite for land preparation as well as for moisture conservation for *rabi* planting. Low rainfall is likely to give a poor crop and also overexploitation of groundwater otherwise if water requirement would be fulfilled through rainfall then groundwater can be conserved.

Conclusion

From this study it was observed that maximum time the onset of WD mostly occurs during the month of October in whole of Punjab. The intensity of occurrence of WD during October month is highest in NW region (Amritsar) and lowest in SW region (Faridkot) of Punjab. During most of the times the withdrawal of WD occurs during the month of May in Punjab. At most of the places the number of total WD has shown decreasing trend with time. The implementation of an appropriate strategy for rainwater harvesting will generate the possibilities of increase in the amount and intensities of rainfall that in turn, will improve the augmentation phenomena of ground water reservoir.

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Received: September 22, 2021; Accepted: December 26, 2021