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Research Paper

Trend and frequency distribution of western disturbances and its impact on major crops of Solan district of Himachal Pradesh

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ABSTRACT

The study was conducted to examine the frequency and distribution of western disturbances (WD) and their effect on crops grown in Solan district of Himachal Pradesh. The daily rainfall data was collected for the period of 1971–2021. The results revealed that during the period of 50 years, the WD arrived as early as in the month of October and occurred as late as in May in the Solan district of Himachal Pradesh. The duration of WD persisted for 1 to 5 days. The number of WD with 1 day duration was found to be highest in May (89) and lowest during the month of November (21). The Man-Kendall and Sen's slope estimator analysed an annual increasing trend of Z=2.62 number of WD $year^{-1}$ and Q=0.47 number of WD $year^{-1}$. The deterministic coefficient explained the positive relationship between the number of WD and productivity at the development stage while showing a negative relationship at the maturity stage of different crops.

Key words: Western disturbance, Trend analysis, Man-Kendall, Frequency, Rainfall, Mid-hills

Western disturbances (WD) are driven by westerlies and are non- monsoonal precipitation. The term 'Western' refers to the direction from which WD originated with respect to India. Extra-tropical storms are a global phenomenon in which moisture is carried in the upper atmosphere, unlike their tropical counterparts, where the moisture is carried in the lower atmosphere. In the case of the Indian subcontinent, when the storm system encounters the Himalayas, the moisture sometimes sheds as rain. Winter western disturbances are more intense and occur more frequently. Western disturbances start declining in numbers after winter. They move over northern India in the months of April and May. According to Schiemann *et al.,* (2009) the westerly jet brought these disturbances to the Indian subcontinent is stronger in the south during the winter, so it makes sense to predict that winter WDs will occur more frequently and produce more precipitation. They are embedded in the southward propagating subtropical westerly jet stream and produce extreme precipitation over northern India, which is enhanced over the Himalayas because of orographic land-atmosphere interactions. During the post-monsoon and winter seasons, it is critical to meet the demand for water for agriculture, hydroelectric projects, drinking, etc. Precipitation caused by WDs is the major source of livelihood, mainly in North India. Winter precipitation associated with western disturbances is very important for rain-fed agricultural activities (Gill *et al*., 2013).

In the mid-hill zone of Himachal Pradesh, the annual rainfall showed a decreasing trend. Furthermore, a decreasing trend in rainfall for February and March has a determinant effect on the fruit quality (Mehta *et al.,* 2022). The frequency, duration and distribution of western disturbances may be favourable or unfavourable depending on their occurrence at different stages of crop growth, affecting overall grain yield (Gill and Kukal 2017; Gill *et al.* 2013; Gill *et al.* 2016). The amount and spatio-temporal distribution of rainfall due to WD is generally the single most important determinant of inter-annual fluctuations in overall crop production. Rabi crops, particularly wheat, were sown under rainfed conditions in Himachal Pradesh's mid-hill zone. Arrival of WD improve the soil moisture conditions which will help in field preparation and sowing crop. The rainfall during the months of October and November is favourable for sowing wheat crops. The WD provides the required moisture to the crops at different phenological stages. However, at the grain formation stages of crop, the higher frequency and duration of WD during March, April adversely affect the crop and reduce its quality as well as quantity. There is a very limited work available in respect of WD and their impact on crop productivity, especially in Himachal Pradesh. Therefore, we have studied the frequency and

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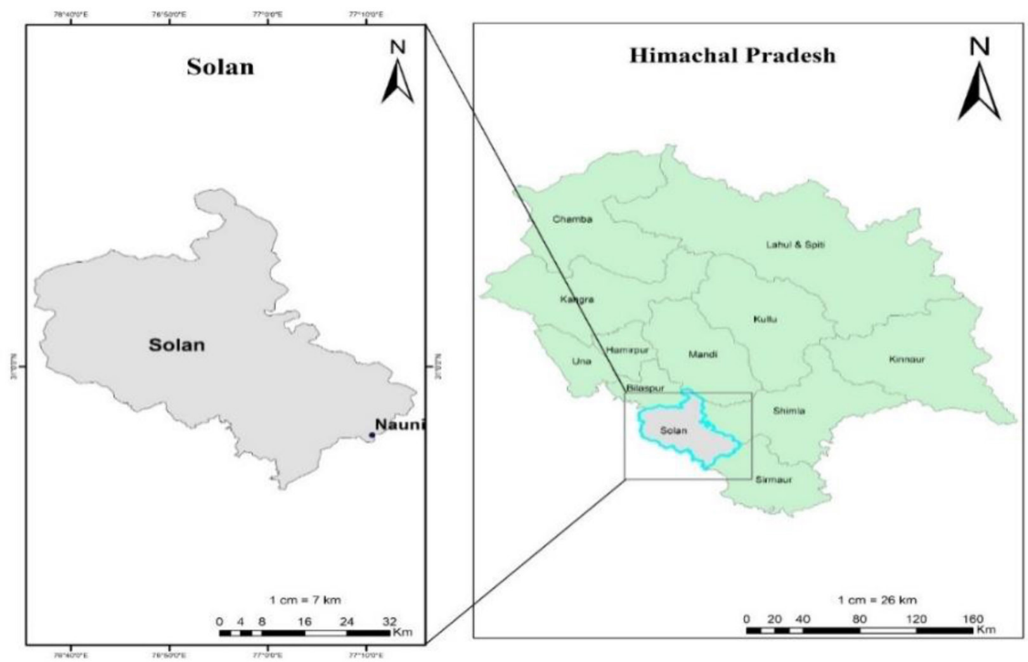

Fig 1: Map of study area

trend analysis of WDs and also their impact on crop production at the development and maturity stages of the crop.

MATERIALS AND METHODS

Experimental site

The daily rainfall and rainy days data of 50 years (1971-2021) was collected from Agromet observatory conducted in the Department of Environmental Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan (Fig. 1). The rainfall 2.5 mm per day and more was considered as a WD spell. If the spell was continued for one day that is WD spell of 1 day. If the spell was continued for two day that is WD spell of 2 days and so on if the spell was continued for five days, that is WD spell of 5 days like these categories are given.

Frequency and duration of western disturbances

The frequency of western disturbances was considered as the number of WD occurred during a month, season or year. The total number of WD was counted for each month, season & year whereas the frequency of occurrence of each duration was calculated for each month separately as:

Frequency = Total rainfall / Total numbers of WD; whereas WD/month is computed as,

WD/month = Frequency/ Average number of WD in month

Trend analysis

Trend analysis of WDs were carried out by using Mann-Kendall test (Mann, 1945) and Sen's slope estimator test (Sen, 1968). The Mann-Kendall test is fit for those data series where the trend may be assumed to monotonic perform two types of statistics depending upon the number of data values *i.e.* S- statistics is used if number of data values is less than 10 (Kumar and Jain, 2010). Being the data series more than 10 Z- statistics was used.

The statistics S is calculated as,

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(xj - xi)$$

where, $xjxj$ and $xixi$ are annual values in years j and I, j>i respectively, n is the number of data points and $sign(x_j - x_i)$ is calculated using equation

$$sgn(xj - xi) = \begin{cases} 1 & if xj - xi > 0 \\ 0 & if xj - xi = 0 \\ -1 & if xj - xi < 0 \end{cases}$$

The standard normal distribution (Z-statistics) is computed using equation

$$z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} if s > 0 \\ 0 \; if s = 0 \\ \frac{s+1}{\sqrt{var(s)}} if s < 0 \end{cases}$$

Statistically the significance of trend is assessed using the z- value. A positive value shows upward (increasing) trend while the negative value shows the downward (decreasing) trend.

Sen's slope estimator is used to determine the magnitude of the trend in data. This method considers temporal series data follow linear trend. If $X_p X_p$ & $X_q X_q$ are considered as values of time series data at m and n time as p > q. Positive Sen's slope indicates rising trend while negative Sen's indicates falling trend. The slope ($Q_i Q_i$) of data pairs is computed as

$$Q_i = \frac{X_p - X_q}{p - q}$$

The data on area and production of selected crops *viz*., wheat, barley and peach crop for last 30 years (1990-2020) for Solan district was collected from the Assistant Statistical office, Deputy Director of Agriculture and Horticulture, Shimla. To study the relationship of western disturbances with productivity of selected crop at different phenological stages the correlation and regression analysis were worked out.

RESULTS AND DISCUSSION

Characteristics of western disturbances

The different behavioural characteristics of western disturbances (WD) like onset, withdrawal, durations and amount of rainfall in WD were studied and analysed in the Solan district of Himachal Pradesh for the period from 1971–2021 (Table 1). The earliest date of the onset of western disturbances was observed on October 1, 1989, and the delayed onset was on January 1, 1985. The mean date of onset of WD in the study area was observed on November 2, 2002. The earliest date of withdrawal of WD was March 23, 1975 and delayed until May 31, 2020, and the median date of withdrawal was observed on May 22). The shortest duration of WD was observed on the 1/2th day, the longest was 6 days, and the mean duration was 3.25 days. The total shortest duration of WD was 123 days, and the total longest duration was 215 days, with a mean of 164 days. The rainfed regions are going to be affected more by the changing behaviour of rainfall as compared to the irrigation regions.

Frequency, duration and number of western disturbances

The number of WD with 1-day duration ranged from 21 to 89 (Table 2), being lowest in November (21) and highest in May (89). The maximum number of western disturbances with 5-day durations was observed in the month of March. The frequency of WD at Solan during the past 50 years indicated that it was maximum during December (26.77) and minimum during November (10.45). The WD received during physiological maturity and harvesting of the crop may cause a loss in crop yield because of lodging and shredding of grains, whereas the WD received during February month at the time of booting to heading stage is favourable for a higher grain yield of wheat.

Monthly amount of rainfall and number of western disturbances

The total number of WD had been observed highest in May (148), followed by March (130), with standard deviations of 1.77 and 1.39, and the CV of 49.10% and 43.99% indicated that rainfall was highest in these months at Solan (Table 3). The trend analysis of the number of WD showed an increasing trend in the months of October, November, December, January, February, April, and May. Where there was a decreasing trend in the month of March. The amount of rainfall received through WD experienced a negative trend in October, December, and March while the remaining months experienced a positive trend. The total amount of WD rainfall had been observed to be highest in February (70.13 mm), followed by March (69.17 mm), with a standard deviation of 57.25 and 52.90, and the lowest CV of 81.6% and 76.5% at Solan (Table 3). According to the results, the number of WD and amount of rainfall in the month of May were found to be highest as compared to the onset of western disturbances in the months of October and November. The lower

Table 1: Characteristics of western disturbance from the period 1971-2021

Western disturbance (WD)	Onset	Withdrawal
Earliest	October 1,1989	March 23, 1975
Delayed	December 31, 1985	May 31, 2020
Median	November 2	May 22
	Durations of single WD	**Total durations of WD**
Shortest	1/2th days	123 days
Longest	6 days	215 days
Median duration	3.25 days	164 days

Table 2: Frequency, duration and number of western disturbances occurred from the period of 1971-2021

Months	1-day	2-days	3-days	4-days	5-days	>5 – days	Total (WD)	Total RF (mm)	Frequency	WD per month
October	35	10	4	1	0	1	51	903	17.7	14.23
November	21	12	5	0	0	0	38	386.8	10.45	11.28
December	28	15	5	5	1	1	55	1258.4	26.77	21.11
January	52	43	16	4	1	0	116	2366.7	20.76	7.34
February	55	48	16	8	1	0	128	2875.5	23	7.37
March	55	38	21	8	4	4	130	2835.9	23.63	7.45
April	74	30	8	6	2	1	121	1716.9	14.55	4.93
May	89	37	14	7	1	0	148	2215.6	15.94	4.42
Total	409	233	89	39	10	7				

Table 3: Descriptive statistics of monthly number of WD and amount of rainfall received period of 1971-2021

Months	Total	Mean	SD (σ)	CV (%)	Slope (/year)	Trend
Number of WD						
October	51	1.24	1.32	106.01	0.01	↑
November	38	0.93	0.98	106.24	0.02	↑
December	55	1.27	2.07	72.74	0.01	↑
January	116	2.83	1.61	56.94	0.01	↑
February	128	3.12	1.4	44.84	0.02	↑
March	130	3.17	1.39	43.99	-0.02	↓
April	121	2.95	1.66	56.17	0.04	↑
May	148	3.61	1.77	49.1	0.04	↑
Amount of rainfall received						
October	903.0	22.02	45.2	205.1	-0.4	↓
November	386.8	9.43	15.46	163.9	0.12	↑
December	1259.3	30.71	42.23	137.5	-0.73	↓
January	2366.7	57.6	46.31	80.4	0.19	↑
February	2875.5	70.13	57.25	81.6	0.37	↑
March	2835.9	69.17	52.9	76.5	-0.29	↓
April	1716.9	44.18	41.02	92.8	0.21	↑
May	2215.6	56.73	42.23	74.4	0.48	↑

Table 4: Mann Kendall test and Sen's slope estimator trend analysis occurrence of western disturbance

Months	Z-Statistics	Q-Statistics	Trend
October	2.02	0.01	↑
November	1.82	0.01	↑
December	-0.75	0	↓
January	0.2	0.01	↑
February	0.66	0.02	↑
March	0	0	No trend
April	1.96	0.05	↑
May	0.43	0.02	↑
Total	**2.62**	**0.47**	↑

amount of rainfall in October and November may cause a delay in the sowing of wheat and affect the yield of the crop. Whereas, more rainfall in April and May and the occurrence of hailstorm events during physiological maturity and harvesting cause economic losses to the farmers. Mehta *et al.,* (2022) also concluded that an erratic rainfall pattern makes the cropping calendar shorter and affects agricultural practices. The farmers have also experienced for the last three decades that there is no rain when needed and more rain than normal when rain is actually not necessary.

Trend analysis by Mann-Kendall test statistics

The Mann-Kendall test and Sen's slope estimator were applied to the time series data from 1971–2021 for the study area. The results of the Mann-Kendall test and Sen's slope estimator are presented in (Table 4). The present investigation is supported by the study of Lal *et al*. (2022), who concluded that the number of heavy rainfall events is increasing in the Punjab region.

Relationship of number of WD with productivity of different crops

The relation between the number of WD during development and maturity stages and wheat, barley, and peach yields showed that water received through WD was beneficial at the development stage of each crop (Fig. 2). The present investigation is supported by the study of Kaur and Dhaliwal (2018), who concluded that increased rainfalls during the vegetative phase of wheat enhanced crop production in the Bathinda region of Punjab. Kingra (2016) also reported that the rainfall and number of rainy days during the reproductive growth period of wheat covering the months of February and March have been found favourable for higher grain yield in Punjab. Kaur and Hundal (2009) also reported that the heavy rainfall showers were received during the anthesis and grain-filling period of wheat crop had adverse effect on wheat yield.

The coefficient of determination explained the positive relationship between the number of WD and the yield of wheat, Barley and peach crops at the development stage. The variability of crop yield was explained by 62%, 34%, and 87% (Fig. 2) of the variation by the number of WDs received at the vegetative stage. While at the maturity stage, the coefficient of determination explained the negative relationship between the number of WD and yield at the maturity stage of both crops. The variability of crop yield explained 11%, 66%, and 39% (Fig. 3) of the variation by the number of WDs received at the maturity stage.

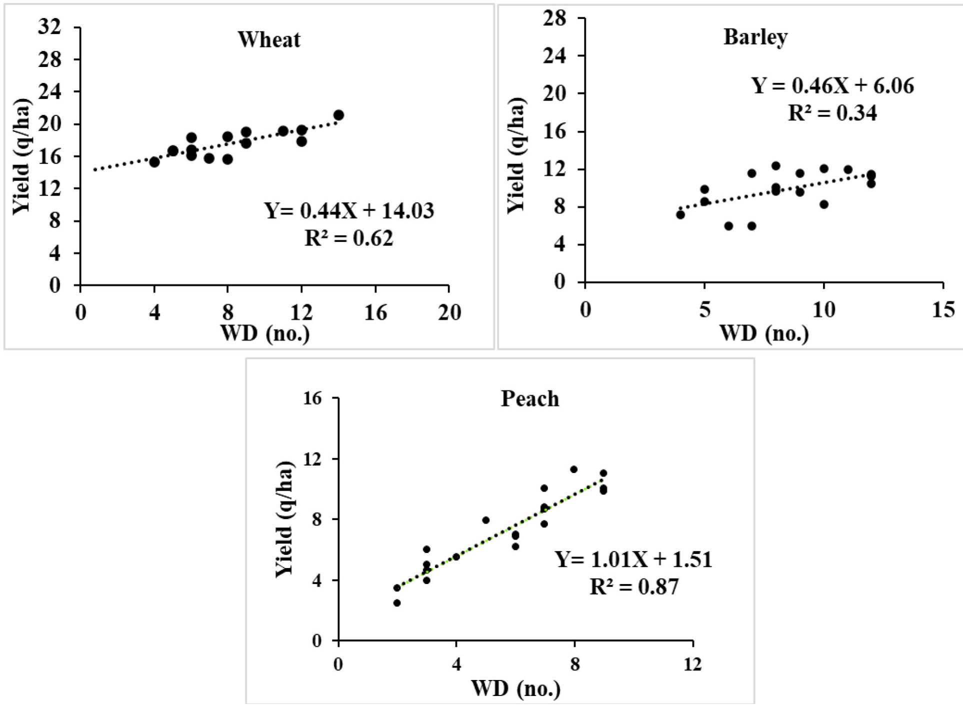

Fig 2: Effect of western disturbances at development stage (January - March) of selected crop from 1990-2020

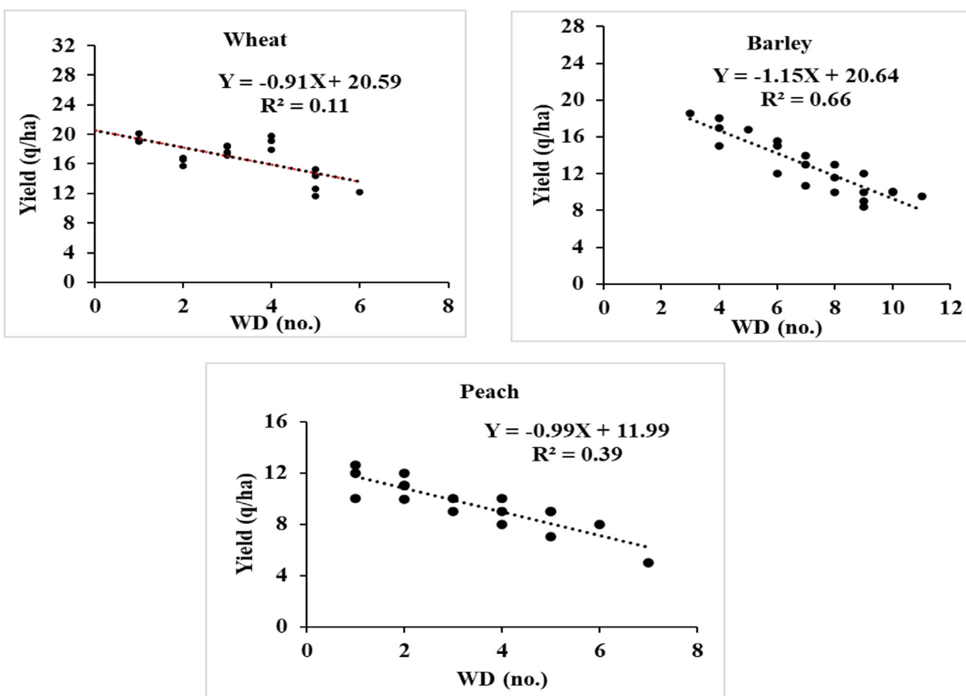

Fig 3: Effect of western disturbances at maturity stage (April-May) of selected crop from 1990-2020

CONCLUSION

The frequency and distribution of western disturbances were found to be favourable or unfavourable depending on their occurrence at different stages of crop growth and development. The trend in the total number of WDs was significantly increasing. The number of WDs that occurred at the growth and development stages of different crops was positively correlated with their production but negatively correlated at the maturity and harvesting stages.

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Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

Authors contributions: **P. Dadial**: Collection of data, analysis and manuscript writing; **M. Singh**: Guidance, supervision; **P. Mehta**: Guidance, supervision, manuscript writing.

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