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Trend study of Meteorological Parameters and Crop Yield in Solan District of Western Himalayan State

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Abstract:
The study was carried out to examine the trends of important weather parameters and their effect on the production of cereal crops in Solan district of Himachal Pradesh. The descriptive statistics and regression analysis revealed no significant trend in all the selected weather parameters in annual, seasonal and monthly basis for the period (1984 – 2011). In Regression analysis cubic and quadratic functions (non significant) were found to be the best fit. Sen's estimation analysis indicated increasing trend of maximum temperature by 2.95°C, minimum temperature by 0.50°C and decreasing trend of rainfall, relative humidity and sunshine hours. Analysis of relationship of crop yields to time in regression analysis did not show any significant trend. However, Sen's estimate showed increasing trends for selected crops. There was no significant correlation of individual weather parameters with crop yields but in case of multiple regression analysis some effects were observed indicating thereby that crops yields are influenced by combinations of weather parameters.

Keyword: Meteorological parameters, climate change, trend, crop yield

1.0 Introduction:

Global warming is likely to cause major changes in various weather variables such as temperature, absolute humidity, precipitation and global solar radiation etc. (Mimi *et al*., 2010). The air temperature indicates climate changes both on global and regional scale (Jones *et al.*, 1992). Some aspect of climate change such as longer growing seasons and increased temperature may be beneficial in cold regions but there will be some adverse impacts, including reduce water availability, greater water need, and more frequent extreme weather events. The Intergovernmental Panel on Climate Change (IPCC, 2007a) has projected that increase in temperature is expected to be in the range of 1.8 to 4.0°C by the end of 21st century. For the Indian region (South Asia), the IPCC projected rise in temperature will be 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future human activities (IPCC, 2007*b*). The rise in temperature will be higher during the winter (*Rabi*) than in the rainy season (*Kharif*). These climatic changes are expected to increase the pressure on Indian agriculture as projected that there is a probability of 10-40% loss in crop production in India by 2080-2100 due to global warming (Rosenzweig *et al*., 1994; Fischer *et al*., 2002, IPCC, 2007b). The global mean surface temperatures (GMSTs) are projected to rise in future at a similar rate for the four Representative Concentration Pathways (RCP) scenarios.

Various studies indicated that significant climatic changes are observed over different region (Sinha *et al.,* 1998a). The air temperature over the wheat growing region was higher by 1.7°C over period of 15 days (January 16 to February 1). The actual temperature rise was 2.3°C to 4.5°C in the major wheat producing region of Punjab and Haryana (Sinha *et al*., 1998). Through these studies they projected the serious effects of regional temperature on productivity of major crops in India like wheat and rice. The predicted changes in global temperature can increase the frequency of mountain hazards and reduce agricultural production. The impact of climate change can be more severe in the Himalayas (Mishra, 2012). Taoyuan *et al*. (2014) concluded that the temperature change contributed positively to total yield growth by 1.3% and 0.4% for wheat and rice, respectively, but negatively by 12% for maize and the impacts of precipitation change were marginal. According to NCAR, the climate change has substantially increased the prospect that crop production will fail to keep up with rising demand in the next 20 years. Nkulumo *et al*. (2014) found that the impacts of climate change on crop yields in Southern Africa varied area to area and crop types.

The simulation of climate change on maize yields over the period 2008–2030 showed that a combination of changes in temperature and precipitation can either bring positive or negative effects on maize yields (Xiang *et al*., 2011). Liangzhi *et al*. (2009) found that a 1^{o}C increase in temperature during wheat growing season reduces wheat yields by about 3–10%. Tianyi *et al*. (2008) found that there was an inconsistency in the observed correlation between rice yields and the occurrence of ENSO events during various periods from 1960 to 2004 in most provinces. The analysis indicates that policymakers should recognize that the climate change would change the productivity of factors, so a regional and crop-specific total-factor-adaptation model is recommended (Li *et al*., 2014). The study conducted by Branka *et al*., (2014) showed that each year during the growing season, the crops were exposed to some degree of water deficit. The average water deficit in June, July and August was 48 mm, 98 mm and 88 mm, respectively. Christian *et al*., (2010) found that potatoes and tomatoes should be fully irrigated during initial phase, however, during the later stages less irrigation might be applied without causing significant yield.

In India, agriculture is dependent on the south-west monsoon as evident from the fact that the net irrigated area of the country is 60.9 million hectares from a total net sown area of 140.3 million hectares thereby making the agriculture sector in India very sensitive to any changes in rainfall pattern. The impact of overall deficit of 23% in rainfall during the south-west monsoon in 2009-10, which adversely affected *Kharif* production, is reflected in the agriculture GDP growth rate which shows a decline of 0.2 per cent as against the previous year's growth rate of 1.6 per cent **(**Aggarwal, 2008). Recent reviews indicated that change in climate has greater influence on crop production. Therefore it is very important to study the impacts of changing climatic conditions on the productivity of cereal crops so that adaptation measures can be under taken. Keeping in view of this a study was carried to find out the trend pattern of weather variables and their correlation with crops. The rainfall pattern has changed with the change in climate, but the crop yield does not fall sharply. The crop yield was unaffected by rainfall significantly. The study also revealed that there is no trend in rainfall in the region (Aggarwal, 2013).

2.0 Methodology:

The Western Himalayan state of Himachal Pradesh situated between North Latitude: 30^{0} 22' $40^{''}$ to 330 12' $40^{''}$ N and East Longitude 75^{0} 47' 55" E to 79^{0} 04' 20" is hilly and mountainous area with altitude ranging from 350 to 6,975 meter above mean sea level. It receives on an average 1,323 mm total annual rainfall and temperature varies from -20^{o}C to 45^{o}C. The agricultural sector of Himachal Pradesh has adopted a diversification approach that demands for a focus on the production of off-season vegetables that include potato, ginger, soyabean, oilseeds, and pulses. The farmers focus more upon generating the cash crops for more revenue earning as it suits the agro-climactic conditions in Himachal Pradesh. The main cereals cultivated in Himachal Pradesh are wheat, maize, rice, and barley.

The Solan district of Himachal Pradesh falls in low and mild-hill region. The district is situated between 76^{o} 42' to 77^{o} 20' East longitude and 30^{o} 05' to 31^{o} 15'North latitude. The altitude of the district ranges from 300 to 3,000 meters above means seal level. The climate of the district is sub tropical to sub temperature. The temperature ranges from 0^{0}C to 39^{0}C. The district receives an average rainfall of 1,164 mm, mostly during monsoon. Total geographical area is around 1,936 km^2 and contributes 3.49 percent of the total area of the state. The net area sown in the district is 39,997 hectare out of which 28,366 hectare is sown more than once. The major cereal crops in the district is maize which is occupying about 25,130 hectare of land out of which 4,386 (17%) is under irrigation and wheat which is covering about 24,000 hectare of land out of which 7,500 hectare (31%) is under irrigation.

The weather parameters *viz.,* maximum temperature, minimum temperature, rainfall, sunshine hours, wind speed and relative humidity data of 27 years (1984-2011) were collected from Department of Environmental Science, Dr Y S Parmar University of Horticulture & Forestry, Nauni (Solan), India and crops yield data of maize, rice and wheat for the period (1996 - 97 to 2010 – 11) were collected from State Agriculture Department, Government of Himachal Pradesh, India. The analysis was conducted to investigate the probable linkage between the selected weather parameters and cereals viz., maize, wheat and rice so that the impact of weather parameters on production can be revealed for annual, seasonal, monthly and weekly basis. To enhance the predictability of the results the meteorological data were divided into three period i)1984 -1993; ii) 1994-2003; iii) 2004-2011and the overall period data (1984-2011) were analyzed. The average of each weather data during the whole growing period of each crop was calculated, i.e. maize (May – October), wheat (October – April) and rice (June – October). To find out the effect of weather parameters on crops yields, each crop yields was correlated with individual weather parameter, there after the combinations of all the parameters were correlated with yields to find out their combined effect on crop yields.

The yield of each crop over the period of time was computed to find out the trend over the study period. Statistical and economic analysis has been carried out using Statistical Package for social Sciences (SPSS). Karl Pearson's coefficient between weather parameters viz., maximum temperature, minimum temperature, rainfall, sunshine hours, wind speed and relative humidity was worked out. Different functions viz., linear, power, inverse, quadratic, cubic, compound, growth, exponential and logistic were fitted to find out the trend of weather parameters over the period of time as well as the relation of cereal crop yields with weather parameters. The best fitted equations were selected on the basis of R^2 value.

Sen's Method:

In non-parametric statistics, the Theil–Sen estimator is a method for robust linear regression that chooses the median slope among all lines through pairs of two-dimensional sample points. It can be computed efficiently, and is insensitive too outliers; it can be significantly more accurate than simple linear regression for skewed and heteroskedastic data, and competes well against non-robust least squares even for normally distributed data in terms of statistical power.

3.0 Results and Discussion:

The study revealed that annual mean maximum temperature during the study period varied between 23.46^{o}C to 27.19^{o}C. The lowest mean maximum temperature (23.46^{o}C) was recorded in the year 1985 and highest mean maximum temperature (27.19^{o}C) was recorded in the year 2006 (Fig.1.). The maximum temperature range was 16.4 to 39.5^{o}C. The coefficient of variation ranged between 15.55% - 27.19%, indicating that maximum temperature was more consistent in the year 2006 (15.55%) and less consistent (27.19%) in the year 1984. For assessing the normality assumption, the Skewness value was observed far away from zero and Kurtosis value was also far away from three. Therefore the yearly maximum temperature data did not show normality assumptions (i.e Skewness = 0 and Kurtosis = 3). No particular trend was observed in annual analysis for maximum temperature under study period.

The Annual mean minimum temperature varied between 7.75^{o}C which was recorded in the year 1985 to 14.82^{o}C recorded in the year 1986. The minimum temperature range was -3.6 to 19.0^{o}C. Coefficient of variation, a statistical measure of the dispersion of data points in a data series around the mean, ranged between 44.32 % recorded in 1987 to 76.45% recorded in the year 1985 (Fig.2.). The Skewness, varied between 0.0 - 0.18. Skewness of zero was recorded in the year 1994 which indicates normality assumptions while in other years Skewness was far away from zero. Kurtosis varied from -0.79 to -1.37 with negative values for all the years.

The annual variation of rainfall during the study period varied between 526.10 mm which was recorded in the year 1984 to 2552.0 mm which was recorded in the year 1988. The coefficient of variation ranged between 276.48 % - 517.64% (Fig.3.). This indicates that rainfall was more consistent in the year 1996 (276.48%) and less consistent in the year 2009 (517.64%). The normality assumption as assessed by Skewness and Kurtosis did not show any normality as Skewness value was observed far away from zero and Kurtosis was also away from three, meaning there by no particular trend of rainfall was observed.

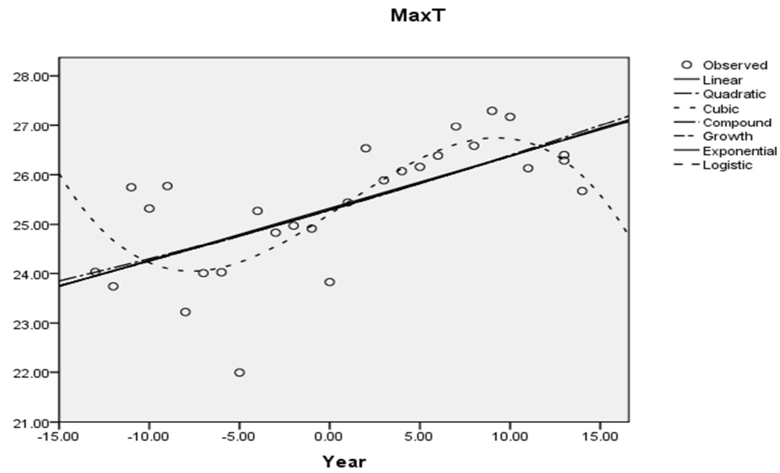

Fig. 1. Maximum temperature variation with time on annual basis

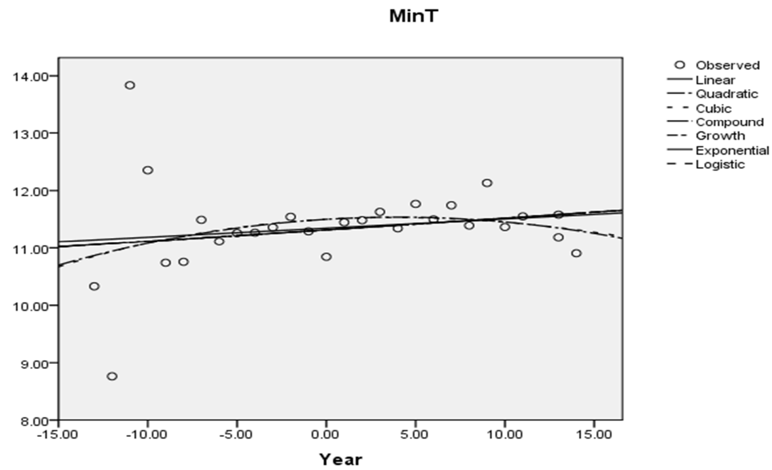

Fig. 2. Minimum temperature variation with time on annual basis

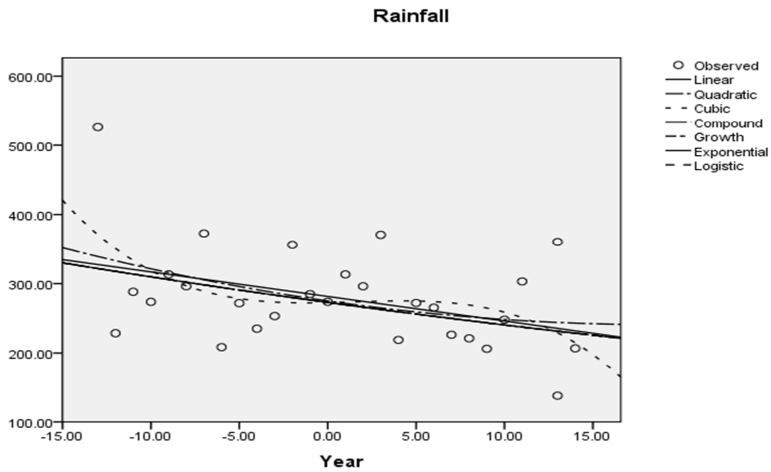

Fig. 3: Rainfall variation with time on annual basis

Analysis revealed that mean relative humidity varied between mean values of 51.72% recorded in the year 1989 to 64.68% registered in the year 1997. Relative humidity range was 18 to 100%. The coefficient of variation ranged from 23.23% to 42.43% indicating thereby relative humidity was more consistent in the year 2004 (23.23%) and less consistent (42.43%) in the year 1989. The year which registered the lowest outlier relative humidity as shown by Skewness was 1996 with value of - 0.01 while the year 1986 recorded the highest outlier with value of 0.59. In case of Kurtosis the year 1987 recorded the lowest outlier with value of 0.02 and the highest outlier was recorded in the year 2011 with value of -1.36, indicating there by no normality assumption observed for relative humidity under the study period.

The results of variability analysis revealed no significant trend in all the selected weather parameters on annual, seasonal and monthly basis. The Skewness values were observed far away from zero except in 1994 for annual maximum temperature and 1997 for maximum temperature during spring season. Kurtosis values were also far away from 3 for all the periods thereby indicating no normality assumption. Regression analysis also did not show statistical significant trends for the selected weather parameters except for maximum temperature which shows statistical significant cubical trend with R^2 value of 0.6 while for other weather parameters the R^2 value varied between 0.06 – 0.4. Cubic and quadratic functions (non significant) were noted to be the best fit.

The season wise analysis showed that there was no explicit linear trend between weather parameters and time. Similar behaviors of increasing and decreasing trends were observed in all the season as the cubic function showed to be the best fit. However, an examination of R^2 values showed that some fraction of variations in weather parameters can be explained by change in time in each season. Maximum temperature recorded the highest R^2 values in each season on general analysis except monsoon/summer. The highest R^2 value of 0.52 was recorded in spring season, followed by winter with R^2value of 0.45. Rainfall recorded the lowest R^2 values in each season except in monsoon/ summer where it recorded the highest R^2 value (0.23). In case of minimum temperature winter and spring seasons recorded the highest R^2 value of 0.15.

Comparison between season's shows that spring has the highest R^2 value (0.52) for maximum temperature, winter and spring recorded the highest R^2 value (0.15) for minimum temperature and monsoon recorded the highest R^2 value (0.23) for rainfall. The analysis also revealed that monsoon recorded the lowest R^2 value (0.14) for maximum temperature, where autumn has the lowest R^2 value (0.07) and 0.04 for minimum temperature and rainfall respectively. Though no any significant trends observed for any weather elements under the study period but season of spring and winter showed much variation in both maximum and minimum temperature compared to autumn and summer.

The month-wise average maximum temperature varied between 17.8°C to 31.52°C. The maximum mean temperature was highest (31.52°C) in month of May and maximum mean temperature was lowest (17.8°C) in month of January. The months which recorded highest maximum temperature as shown in upper limits of range are the months of June (39.5°C), April (35.8°C) and May (35°C). The coefficient of variation ranged between 8.23% - 21.43% indicating thereby maximum temperature was more consistent in the month of August (8.23%) and less consistent (21.43%) in the month of February. The average minimum temperature varied between 2.16°C to 19.61°C. The minimum mean temperature was highest (19.61°C) in month of July and the minimum mean temperature was lowest (2.16°C) in month of January. The months which recorded lowest temperature as shown by range are the months of January (-3.6°C), February (-2.8°C) and December (-2.7°C). The coefficient of variation ranged between 112.91% - 8.13%. Results showed that Solan district received highest amount of rainfall during the months of July and August. The highest average of rainfall (8.24mm) was recorded in July. The months which received less amount of rainfall were October – January and April. Month of November recorded the least average rainfall of 0.38 mm. The month-wise average relative humidity varied between 45.17% - 82.12%. The maximum mean relative humidity (82.12%) was found in month of August and the minimum relative humidity (45.17%) was found in month of April.

The regression equations for selected weather parameters over the period of time for annual data for predicting the weather variables have been presented in Table 1.

Table 1. Regression equations for selected weather parameters over the period of time for annual data

Parameter	Period	Fitted Equation	R^2
Maximum Temperature (X_1)	1984-1993	$X_1 = 24.849 - 0.636t - 0.085t^2 + 0.04t^3$ (0.30) (0.06) (0.02)	0.46
	1994-2003	$X_1 = 25.253 + 0.394t + 0.26t^2 - 0.013t^3$ (0.17) (0.032) (0.01)	0.66
	2004-2011	$X_1 = 26.845 - 0.177t - 0.042t^2 + 0.005t^3$ (0.17) (0.04) (0.02)	0.65
	1984-2011 **(Overall)**	$X_1 = 25.28 + 0.237t + 0.003t^2 - 0.001t^3$ (0.05) (0.003) (0.00)	0.60
Minimum Temperature (X_2)	1984-1993	$X_2 = 11.727 - 0.232t - 0.085t^2 + 0.025t^3$ (0.39) (0.07) (0.03)	0.23
	1994-2003	$X_2 = 11.313 + 0.09t + 0.015t^2 - 0.005t^3$ (0.07) (0.01) (0.004)	0.34
	2004-2011	$X_2 = 11.611 - 0.055t - 0.015t^2 - 0.002t^3$ (0.144) (0.04) (0.02)	0.42
	1984-2011 **(Overall)**	$X_2 = 11.503 + 0.0017t - 0.002t^2 + 1.499*10^{-5}t^3$ (0.05) (0.003) (0.00)	0.06
Rainfall (X_3)	1984-1993	$X_3 = 269.724 + 17.447t + 6.388t^2 - 2.506t^3$ (21.1) (3.90) (1.37)	0.54
	1994-2003	$X_3 = 309.103 - 4.555t - 2.266t^2 + 0.232t^3$ (14.34) (2.65) (1.37)	0.16
	2004-2011	$X_3 = 235.631 + 17.084t + 0.926t^2 - 1.314t^3$ (33.44) (8.48) (0.93)	0.07
	1984-2011 **(Overall)**	$X_3 = 272.608 + 0.54t + 0.162t^2 - 0.035t^3$ (4.05) (0.23) (0.03)	0.21
Sun shine hours (X_4)	1984-1993	$X_4 = 7.258 - 0.061t - 0.013t^2 + 0.004t^3$ (0.22) (0.04) (0.02)	0.02
	1994-2003	$X_4 = 7.006 + 0.229t + 0.017t^2 - 0.012t^3$ (0.08) (0.02) (0.02)	0.59
	2004-2011	$X_4 = 6.347 - 0.077t + 0.042t^2 - 0.002t^3$ (0.15) (0.04) (0.02)	0.41
	1984-2011 **(Overall)**	$X_4 = 7.102 - 0.01t - 0.002t^2 + 0.00t^3$ (0.03) (0.002) (0.00)	0.23
Wind speed (X_5)	1988-1999	$X_5 = 5.143 + 0.1t - 0.022t^2 - 0.011t^3$ (0.31) (0.05) (0.016)	0.13
	2000-2010	$X_5 = 3.547 - 0.290t + 0.26t^2 + 0.012t^3$ (0.05) (0.01) (0.002)	0.89
	1984-2011 **(overall)**	$X_5 = 4.382 - 0.172t + 0.00t^2 + 0.001t^3$ (0.07) (0.01) (0.001)	0.40
Relative humidity (X_6)	1985-1994	$X_6 = 62.207 + 3.713t + 0.595t^2 - 0.112t^3$ (5.42) (1.002) (0.35)	0.23
	1995-2004	$X_6 = 59.965 - 0.882t + 0.221t^2 + 0.03t^3$ (0.63) (0.12) (0.04)	0.58
	2005-2011	$X_6 = 56.956 + 1.158t + 0.526t^2 - 0.164t^3$ (0.95) (0.2) (0.13)	0.74
	1984-2011 **(overall)**	$X_6 = 65.92 - 1.202t - 0.049t^2 + 0.008t^3$ (0.69) (0.04) (0.01)	0.15

Figures in parentheses are standard error of estimates

The analysis of effect of weather parameters on crops yields revealed that most of individual weather parameters did not show any significant impact on crops yields. However, combined weather parameters showed significant effect on selected crops which indicates that crop yields are influenced by combinations of weather parameters (Table 2).

Table 2. Multi-linear function for crop yields with selected weather parameters

Crop	Equation	R^2
Wheat	$Y = 3120.8 + 12.320X_1 - 112.8X_2 + 9.562X_3 + 35.887X_4 - 443.563X_5 - 3.256X_6$ (149.68) (230.98) (5.28) (148.49) (199.47) (20.20)	**0.7**
Rice	$Y = 9111.167 - 17.673X_1 - 174.832X_2 + 2.101X_3 + 147.805X_4 - 45.492X_6$ (133.39) (298.42) (2.96) (117.69) (32.336)	**0.6**
Maize	$Y = 3168.781 - 70.865X_1 + 101.420X_2 + 1.152X_3 - 154.492X_4 - 151.322X_5 + 9.044X_6$ (179.69) (357.41) (1.973) (131.76) (206.96) (36.24)	**0.5**

Table 3: Point value for the chart of Sen's estimate (s) for annually averaged maximum temperature over study period **(^{o}C)**

Year	Annual average maximum temperature	Sen's estimate/(s)	Actual error	95 % fiducial limits
1984	24.03	23.97	0.06	23.19 - 24.68
1985	23.74	24.08	-0.34	23.35-24.74
1986	25.75	24.19	1.56	23.52 - 24.81
1987	25.32	24.30	1.02	23.68 - 24.87
1988	25.77	24.41	1.37	23.85 - 24.94
1989	23.22	24.52	-1.29	24.01 - 25.00
1990	24.01	24.63	-0.62	24.18 - 25.07
1991	24.02	24.74	-0.71	24.34 - 25.13
1992	21.99	24.84	-2.85	24.51 - 25.20
1993	25.27	24.95	0.32	24.67 - 25.26
1994	24.83	25.06	-0.23	24.84 - 25.33
1995	24.97	25.17	-0.20	25.00 - 25.39
1996	24.92	25.28	-0.37	25.17 - 25.46
1997	23.83	25.39	-1.56	25.33-25.52
1998	25.44	25.50	-0.06	25.50 - 25.58
1999	26.53	25.61	0.92	25.65 - 25.66
2000	25.89	25.72	0.17	25.71 - 25.83
2001	26.07	25.83	0.25	25.78 - 25.99
2002	26.16	25.94	0.22	25.84 - 26.16
2003	26.39	26.05	0.34	25.91 - 26.32
2004	26.98	26.16	0.82	26.49 - 25.97
2005	26.59	26.27	0.32	26.04-26.65
2006	27.30	26.37	0.92	26.10 - 26.82
2007	27.18	26.48	0.69	26.17 - 26.98
2008	26.13	26.59	-0.46	27.15 - 26.23
2009	26.29	26.70	-0.42	26.30 - 27.31
2010	26.40	26.81	-0.41	26.36 - 27.48
2011	25.67	26.92	-1.25	26.43 - 27.64

Table 4: Point value for the chart of Sen's estimate (s) for annually averaged minimum temperature over study period **(°C)**

Year	Annual average minimum temperature	Sen's estimate/(s)	Actual error	95 % fiducial limits
1984	10.33	11.10	-0.77	10.74-11.46
1985	8.76	11.12	-2.37	10.79-11.46
1986	13.84	11.14	2.69	10.84-11.45
1987	12.35	11.16	1.19	10.89-11.45
1988	10.74	11.18	-0.44	10.93-11.45
1989	10.76	11.20	-0.44	10.98-11.44
1990	11.49	11.22	0.28	11.03-11.44
1991	11.11	11.24	-0.12	11.08-11.43
1992	11.26	11.25	0.01	11.13-11.43
1993	11.27	11.27	0.00	11.17-11.43
1994	11.36	11.29	0.07	11.22-11.42
1995	11.55	11.31	0.24	11.27-11.42
1996	11.29	11.33	-0.03	11.32-11.42
1997	10.84	11.35	-0.50	11.37-11.41
1998	11.45	11.37	0.09	11.41-11.41
1999	11.49	11.38	0.10	11.41-11.46
2000	11.63	11.40	0.23	11.40-11.51
2001	11.35	11.42	-0.07	11.40-11.56
2002	11.77	11.44	0.33	11.40-11.61
2003	11.50	11.46	0.04	11.39-11.66
2004	11.75	11.48	0.27	11.39-11.70
2005	11.40	11.50	-0.10	11.39-11.75
2006	12.13	11.51	0.62	11.38-11.80
2007	11.37	11.53	-0.16	11.38-11.85
2008	11.55	11.55	0.00	11.38-11.90
2009	11.19	11.57	-0.38	11.37-11.94
2010	11.58	11.59	0.00	11.37-11.99
2011	10.91	11.61	-0.70	11.36-12.04

Maximum temperature showed negative effects in maize and rice as high temperature induces stress to plants by reducing water resources that are essential for crop growth as Lal *et al*. (1998) has also found same results. Sen's estimate which depicts the trends by stabilizing the data in the form of median values was used because the common method of regression analysis could not point any trend of weather parameters during the study period. In this analysis maximum and minimum temperatures showed increase of 2.95°C and 0.5°C respectively (Table 3 and Table 4). Wheat yield showed positive relations with maximum temperature in the present study as Neenu *et al*. (2013) have also explained that in mid to high latitudes increases in temperature my result to increase in yield but with diminishing effect when the temperatures changes is greater than 3°C.

Increase in temperature might be due to natural and anthropogenic forcing. Study by *Gallo et al. (1999)* showed that anthropogenic forcing such as land-use and land cover including agriculture pattern, urbanization, deforestation etc. may significantly modify the temperature because of modification of interactions between land surface and atmosphere. Another possible influence of temperature rise may be due to increase of greenhouse gas concentration which has showed already the evidence of affecting temperature worldwide.

The results of the present study corroborate with the finding of Dimri (2012) who found a warming trend over the western Indian Himalayas, with the greatest observed increase in maximum temperature (1.1-2.5^{o}C). The present findings resemble with the findings of Kumar *et al.* (2010) who conducted a study in Kashmir valley by analyzing rainfall data of five stations for the period 1903-1982 and showed that three stations experienced a decreasing trend in annual rainfall (Table 5).

Table 5: Point value for the chart of Sen's estimate (s) for annually averaged rainfall over study period **(mm)**

Year	Annual average rainfall	Sen's estimate/(s)	Actual error	95 % fiducial limits
1984	526.10	310.11	215.99	272.68 - 357.00
1985	228.56	307.32	-78.76	272.70-350.56
1986	288.21	304.52	-16.31	272.72-344.12
1987	273.77	301.73	-27.96	272.73-337.67
1988	313.28	298.93	14.34	272.75-331.23
1989	296.15	296.14	0.01	272.77-324.79
1990	372.69	293.34	79.35	272.79-318.35
1991	208.54	290.55	-82.01	272.81-311.90
1992	271.84	287.75	-15.92	272.82-305.46
1993	235.10	284.96	-49.87	272.84-299.02
1994	253.25	282.17	-28.92	272.86-292.57
1995	356.18	279.37	76.81	272.88-286.13
1996	284.87	276.58	8.29	272.90-279.69
1997	273.77	273.78	-0.01	272.91-273.25
1998	313.28	270.99	42.29	266.80-272.93
1999	296.15	268.19	27.96	260.36-272.95
2000	370.73	265.40	105.33	253.92-272.97
2001	218.89	262.60	-43.72	247.48-272.99
2002	272.15	259.81	12.34	241.03-273.01
2003	265.42	257.02	8.40	234.59-273.02
2004	226.33	254.22	-27.90	228.15-273.04
2005	221.18	251.43	-30.25	221.70-273.06
2006	206.19	248.63	-42.45	215.26-273.08
2007	248.14	245.84	2.30	208.82-273.10
2008	303.15	243.04	60.10	202.38-273.11
2009	137.90	240.25	-102.35	195.93-273.13
2010	360.42	237.45	122.96	189.49-273.15
2011	206.75	234.66	-27.91	183.05-273.17

In case of sunshine hours the present study indicated the decreasing trend during the study period this collaborates with the study of Pathak *et al.* (2003) reported the negative trend in solar radiation in indo-Gangetic plains of India. Relative humidity also showed decreasing trend which might be due to increase of temperature and decrease of rainfall. Non-linear and non significant relationship of crop yield, with individual weather parameters were observed in the weather parameters for all the selected crops. However, in multiple regressions analysis effects were observed indicating thereby that crops yields are influenced by combinations of weather parameters instead of a single weather parameter. Rainfall showed a significant positive effect on all the selected crops. Maximum temperature showed positive effect in case of wheat, negative effect in case of maize and rice, and sunshine hours showed a positive effect on rice and wheat.

Sen's estimate showed the increasing trend of cereal crops in the study areas. This may be due to improved variety of seeds, innovative technology of irrigation, use of fertilizers etc. The agriculture in India has shown an increase in average agricultural output per hectare in last 60 years. There was an extreme event of minimum temperature recorded -3.6^{0}C during 2012-13 in the study area as predicted by IPCC, 2013 that it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.

The relationship between the yields data of maize with the individual selected weather parameters showed that quadratic function found to be the best fit for the relationship between maize yields with maximum temperature, sunshine hours and wind speed, while cubic function showed to be the best fit in relationship with rainfall and minimum temperature. Only the relationship between maize yield and sunshine hours showed significant trend (R^2 = 0.51). Both quadratic and cubic equations indicate non-linear relationship between maize yields with selected weather parameters. The relationship between wheat yields with selected weather parameters revealed quadratic function to be the best fit for wheat yield with relation to maximum temperature with R^2 value of 0.03, minimum temperature with R^2 value of 0.08 and relative humidity with R^2 Value of 0.07. Cubic function showed to be the best fit for the relationship of wheat yield with sunshine hours with R^2 value of 0.01 and wind speed with R^2 value of 0.45, while inverse function showed the best fit in relation to rainfall. Only the relationship between wheat yields and rainfall showed significant trend (R^2=0.51). Quadratic function found to be the best fit for rice yield with relationship to maximum temperature with R^2 value of 0.01, sunshine hours with R^2 value of 0.3 and wind speed with R^2 value of 0.6. While cubic function found to be the best fit of rice yield with relation to minimum temperature with R^2 value of 0.04 and rainfall with R^2 value of 0.24. In case of relative humidity compound function showed to be the best fit with R^2 value of 0.14.

Rainfall showed positive effect to all the crops i.e with increases in rainfall crops yield were also increasing. These results provide the evidence that rainfall is very important for crop productions especially in rain fed area like Solan as it is the main source of water. Related studies by Saito *et al*. (2006) observed that rice yield was strongly positive correlated with total rainfall, they father reported that if the total rainfall was less that 610 mm, yield averaged 1.4t/h, where as if rainfall was greater than 690 mm yield averaged 2.5t/h. Chi-Chung *et al*. (2004) submitted that more rainfall can cause maize yield levels to rise. Akintunde *et al*. (2013) in their study of the effects of agro climatic factors on some selected food crops such as rice and maize by using correlation and regression analysis found that rainfall, and rainy days have positive effects on the yield. Another important parameter which showed positive effect with crop yield is sunshine hours. This is because radiation has an important role in photosynthesis and crop productivity.

4.0 Conclusions:

Variability and regression analysis did not show any significant trend of the selected weather parameters over time during the period under study as perceived that temperature has increasing trend and rainfall has decreasing trend. The cubic function which does not show any increasing or decreasing trend was found to be best fit. However, Sen's estimate showed the increasing trend for maximum and minimum temperature while rainfall, sunshine hours and relative humidity showed decreasing trend over the period of time. Individual weather parameters did not show any significant impact on crops yields, however, combined weather parameters showed significant effect on selected crops which indicates that crop yields are influenced by combinations of weather parameters. The yield of selected crops showed increasing trend over period of time through Sen's estimate. Overall, the study suggests the changes in weather parameters, which are influencing the crop yields. This is also the general perception about the climate changes in the study area.

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