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Climate variability and crop productivity in Himalayan ecosystem: A case study of Kullu district

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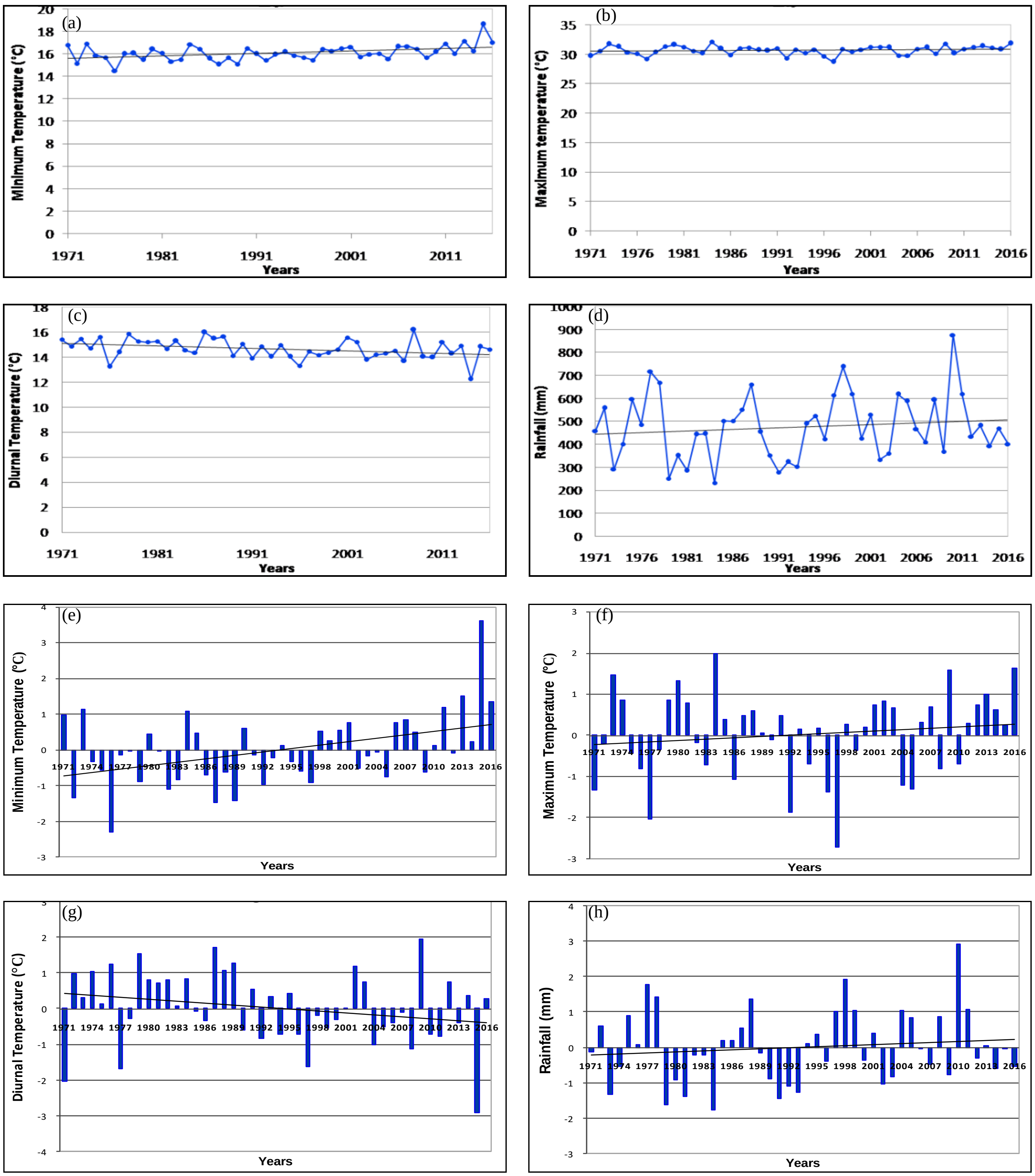
सार – हिमालय जलवायु परिवर्तन के लिए अतिसंवेदनशील प्राकृतिक पारिस्थितिक तंत्रो में से एक है। जलवायु परिवर्तनशीलता तापमान और वर्षा पैटर्न को प्रभावित कर रही है और अंततः यह इस क्षेत्र में फसल के उत्पादन को प्रभावित करती है। इसलिए इस वर्तमान अध्ययन का उद्देश्य 1971-2016 तक हिमाचल प्रदेश के कुल्लू जिले के वार्षिक औसत न्यूनतम, अधिकतम और दैनिक तापमान, वर्षा और प्रमुख कृषि फसलों की उत्पादकता पर पड़ने वाले इसके प्रभाव की अस्थाई प्रवृतियों की जाँच करना रहा। इसमें सेन की ढलान विधि का उपयोग मैन कैंडल टेस्ट के माध्यम से प्राप्त जलवायु चर में रूझानों को मापने के लिए किया गया। जलवायु पैरामीटर में परिवर्तनशीलता निर्धारित करने के लिए तापमान और वर्षा के लिए मानकीकृत विसंगति सूचकांक की गणना भी की गई। जलवायु चर और कृषि फसलों की उत्पादकता के बीच संबंध का निर्धारण सहसंबंध और समाश्रयण विश्लेषण के द्वारा किया गया। उपर्युक्त अवधि के परिणामों में रबी और खरीफ सीजन के दौरान औसत न्यूनतम तापमान में 0.02 डिग्री सेल्सियस की वृद्धि हुई है जबकि औसत अधिकतम तापमान और वर्षा में कोई महत्वपूर्ण बदलाव नहीं आया है। तापमान की मानकीकृत विसंगति सूचकांक में मामूली सी उष्णन (वार्मिंग) की प्रवृति दर्शाई गई है। उस समय में चावल, मक्का, आलू और गेहूँ की उत्पादकता में वृद्धि हुई है। अध्ययन से पता चला है कि जलवायु परिवर्तनशीलता जौ, मक्का, चावल, बाजरा, गेहूँ और आलू की उत्पादकता में क्रमशः 26%, 24%, 16.7%, 11.9%, 10.9%, और 6% की वृद्धि में योगदान दे रही है। शेष परिवर्तनशीलता को अन्य प्रभावशाली कारकों जैसे बेहतर बीज और बेहतर फसल प्रबंधन प्रथाओं द्वारा समझाया जा सकता है।

ABSTRACT. Himalayas are one of the most vulnerable natural ecosystems to climate change. Climate variability is affecting the temperature and rainfall patterns, ultimately influencing the crop production in the region. Therefore, present studies were aimed to investigate the temporal trends in annual mean minimum, maximum and diurnal temperature and rainfall in Kullu district of Himachal Pradesh, from 1971-2016 and its impact on productivity of major agricultural crops. Sen's slope method was used to quantify the trends in climatic variables obtained through Mann Kendall Test. Standardized anomaly index for temperature and rainfall was also calculated in order to determine the variability in the climatic parameters. Relationship between climatic variables and productivity of agriculture crops was determined by correlation and regression analysis. The results for the above period showed an increase of 0.02 °C in mean minimum temperature during rabi and kharif season whereas mean maximum temperature and rainfall did not show any significant change. Standardized anomaly index of temperature depicted slight warming trend. Productivity of rice, maize, potato and wheat has increased over the time. The study brought out that climate variability is contributing to the change in productivity of barley, maize, rice, millets, wheat and potato by 26%, 24%, 16.7%, 11.9%, 10.9% and 6%, respectively; remaining variability can be explained by other influential factors such as improved seeds and better crop management practices.

Key words – Climate change, Agriculture, Cropping season, Crop productivity, Himalayas.

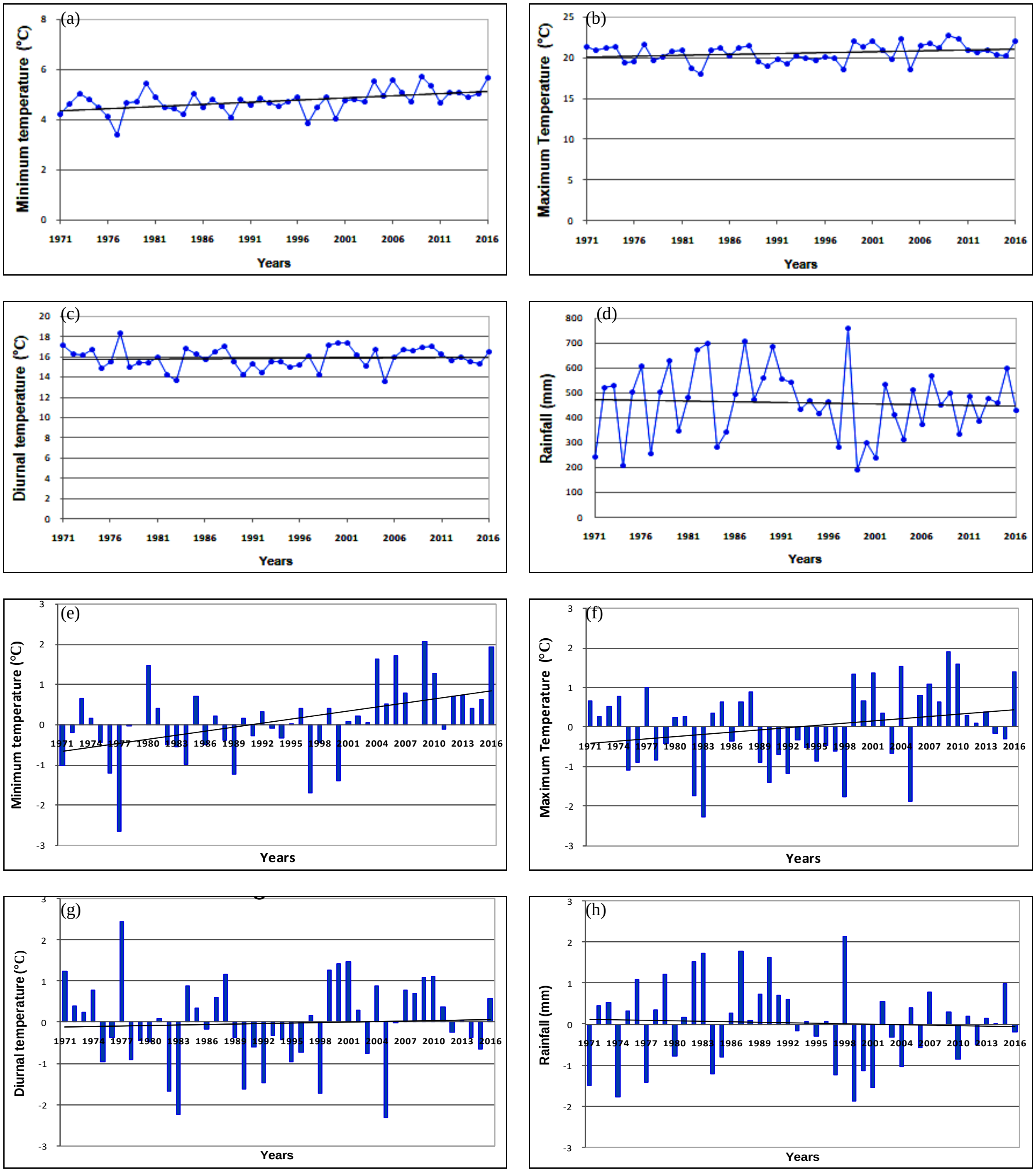
1. Introduction

Climate change is a global phenomenon with widespread impact on natural ecosystems. Increasing concentration of GHGs is contributing to rise in the temperature of earth surface which has already increased by 0.85 °C over the period 1880 to 2012 (IPCC, 2014). Indian subcontinent is expected to countenance possible climate change scenario by the middle of the next century. Lal *et al*. (1995) expected an increase in annual mean surface air temperature of 1 °C over Indian subcontinent in 2040s over 1980s. Unpredictable weather events such as floods, droughts, amplified rainfall intensity, frosting, temperature fluctuations etc. are some of the factors affecting the natural systems.



Figs. 1(a-h). (a-d) Trends of various climatic parameters and (e-h) SAI for climatic parameters, during kharif season (1971- 2016) in Kullu district of Himachal Pradesh

High mountain areas such as Himalayas are likely to get most disrupted from the climate change and thus present an ideal site to study the impact of climate change. North Western Himalayas have warmed at a rate higher than the global average during the last century (Eriksson *et al*., 2009). In high mountainous region, minimum temperature has increased at an elevated pace, whereas in North Western Himalayas the rise in air temperature is primarily due to rapid increase in both the maximum and minimum temperatures, with former increasing more rapidly (Bhutiyani *et al.*, 2007).



Figs. 2(a-h). (a-d) Trends of various climatic parameters (e-h) SAI for climatic parameters during rabi season (1971- 2016) in Kullu district of Himachal Pradesh

Many studies covering various regions and crops have weighed up high confidence negative impacts of climate change on crop yields than positive impacts (IPCC, 2014). Human managed ecosystems such as food production, livelihoods, health and economics are highly vulnerable to climate change in Asia. Saseendran *et al.* (2000) reported a reduction in crop duration due to increased temperature and predicted a possible increase in rice yields under rainfed conditions under changing climatic scenario in Kerala. Climatic variables which affect crop growth and development are temperature, precipitation, radiation and humidity. Climate change and variability can affect yield of rabi and kharif crops through their direct as well as indirect effects such as weather induced changes in incidence of insect pests and diseases (Singh *et al.*, 2015).

Himachal Pradesh is a hilly state of India situated in north-western part of Himalayas. Agriculture sector is the backbone of the state's economy with 76% of farming population. Among several crops grown in the state wheat, maize, paddy are some of the major cereal crops of the state. Apple and vegetable crops are major cash crops grown. Nearly 80% of agriculture area of the state is rainfed. Thus, change in climatic variables can directly affect the total crop production. In order to evaluate the effect of climatic trends of past years on the crops grown, the study was conceptualized to identify the long term change in climatic variables during rabi and kharif cropping seasons and their impact on productivity of cereal crops in Kullu district of Himachal Pradesh.

2. Data and methodology

2.1. *Study area*

Studies were conducted in Kullu district located in mid hill to high hill wet temperate zone (31.95° N, 77.10° E, 1729 m) of Himachal Pradesh which is known for its contribution in agriculture and horticulture sector. Wheat, maize, barley and paddy are the major cereal crops grown in the district.

2.2. *Data and method*

Temporal data on weather parameters and productivity from various government departments was collected in order to study the regional climate change trends. The study was further extended to appraise the effect of climate change on crop productivity.

2.3. *Climate datasets*

The mean minimum, maximum, diurnal temperature and rainfall data of Kullu district was collected from 1971 to 2016 from India Meteorological Department (IMD), Shimla. The datasets were further transformed into rabi and kharif seasons. Rabi season in the study area extends from November to April and kharif from May to October. Data sets of 45 years were analysed through Mann Kendall trend test to determine the climatic variability trends of average weather parameters against time.

2.4. *Agricultural datasets*

Agricultural crops data set on wheat, barley, rice, maize, potato and millets crops was collected from Department of Land Records, Shimla from 1971 to 2010. Wheat and barley are grown in rabi season while rest are the kharif crops of the study area.

2.5. *Trend analysis*

Seasonal trends were analyzed for climatic variables such as minimum, maximum, diurnal temperature and rainfall from 1971 to 2016. Yearly trends were worked out for productivity of wheat, barley, rice, maize and millets. Trend analysis was done by using Mann-Kendall test using XLSTAT 2017. Mann Kendall test was conducted to reject the null hypothesis stating that there is no trend in the dataset with the alternate hypothesis assuming that population follows a particular trend in the given period of time. Sen's slope method was used to quantify the trend (Sen, 1968).

2.6. *Standardized Anomaly Index (SAI)*

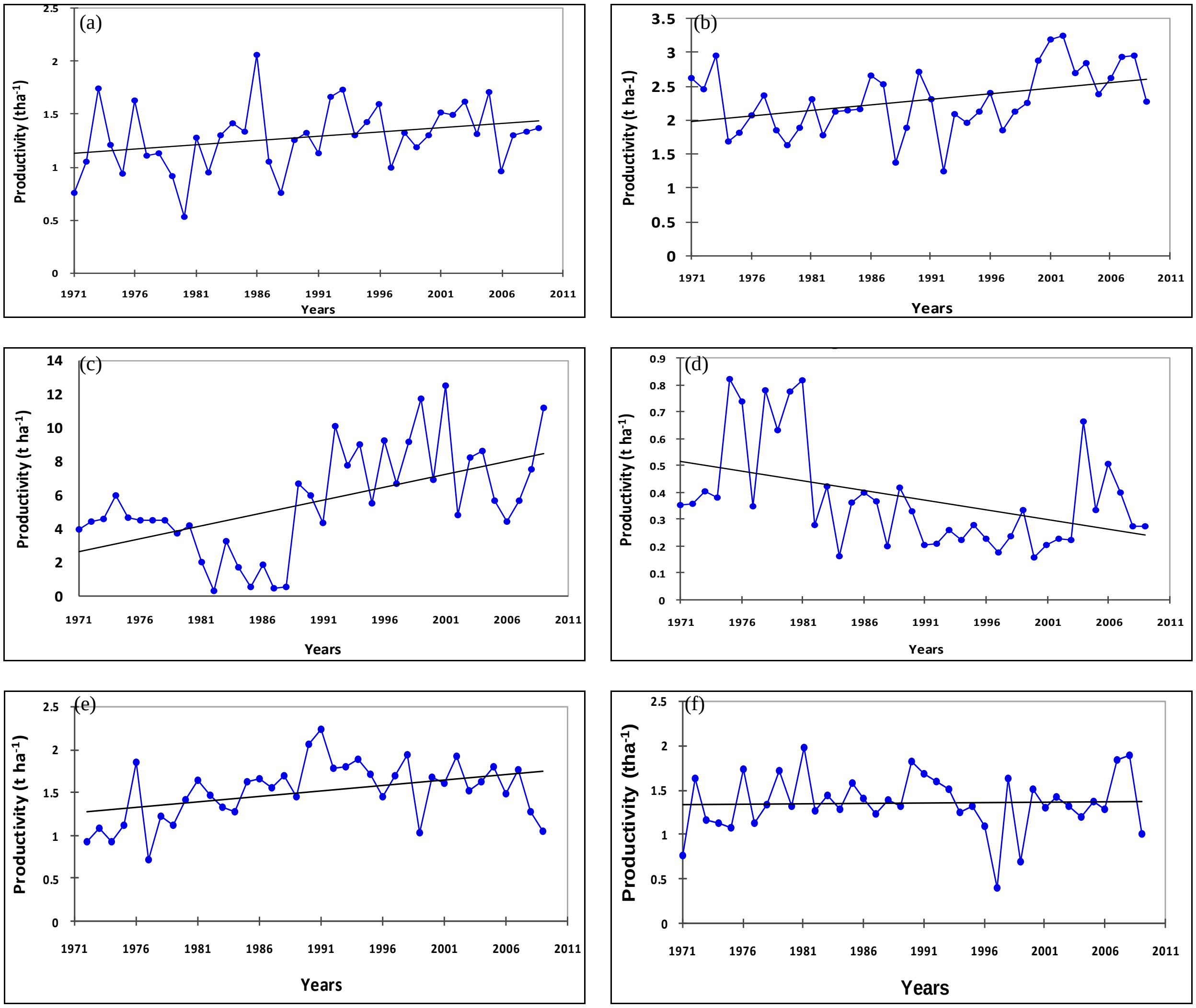
SAI is a commonly used index for regional climate change studies which can be premeditated by subtracting the long term mean value of temperature and rainfall data set from individual value and dividing by their standard deviation (Koudahe *et al.*, 2017). In this manner standardized temperature indices for mean minimum, maximum and diurnal temperature of rabi and kharif seasons were computed for the study area. Similarly standardized precipitation indices were also calculated for the cropping seasons.

2.7. *Climate-crop yield relationship*

Climate crop relationship was analysed by using correlation coefficient and multivariate regression analysis using SPSS-20. Pearson's correlation coefficient was used to measure the strength of association between climatic variables and crop productivity. Multivariate regression analysis was performed to confirm the contribution of anomalies of studied climatic parameters on crop productivity which can be explained by following linear model:

$$\Delta P = \text{constant} + (\alpha \times \Delta T_{min}) + (\beta \times \Delta T_{max}) + (\gamma \times \Delta T_{dt}) + (\delta \times \Delta R)$$

where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature and rainfall in the respective cropping season of the crop and α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt} and ΔR are the observed changes in minimum, maximum, diurnal temperature and rainfall respectively of the cropping seasons during the study period.



Figs. 3(a-f). Productivity trends of various (a-d) kharif and (e&f) rabi, season crops (1971- 2010) in Kullu district of Himachal Pradesh

3. Results and discussion

Temporal changes in climatic variables of kharif season in Kullu district from 1971 to 2016 have been illustrated in Figs. 1(a-d). Standardized Anomaly Index for minimum, maximum, diurnal temperature and rainfall has been depicted in Figs. 1(e-h). Using Mann Kendall test, it has been observed that minimum and diurnal temperature has undergone a significant change in Kullu district during kharif season over past 45 years (Table 1). The analysis brought out that minimum temperature is increasing at the rate of 0.02 °C/year. After 2005 minimum temperature remained above the long term average except for the years 2009 and 2012, indicating a warming trend [Fig. 1(e)]. If the same trend continues, the minimum temperature is expected to increase by 1.58 °C by 2050. Whereas, the diurnal temperature range is following a decreasing trend of 0.02 °C/year. The decrease in diurnal temperature range has been intensified after the year 1997 except 2001, 2002, 2008, 2011, 2013 and 2016 [Fig. 1(g)]. Steady maximum temperature and rising minimum temperature resulted in narrowing down the diurnal range during kharif season. However, rainfall did not show any significant change during kharif season over the last 45 years.

The analysis of climatic data during rabi season substantiate that minimum temperature has changed significantly during rabi season whereas no significant trend was observed in maximum, diurnal temperature and rainfall over the past 45 years [Figs. 2(a-h)]. Minimum temperature is increasing at the rate of 0.02 °C per year in Kullu district. However, SAI for minimum and maximum temperature depicts a warming trend since 1998 except the years 2000, 2011 for minimum temperature and 2003, 2005, 2014 and 2015 for the maximum temperature [Figs. 2(e&f)]. SAI of minimum temperature denotes an intense warming trend over the mean value since 2001, as

TABLE 1

Climatic trends during rabi and kharif seasons with Sen's slope value

Climate variables	Mean	Sen's slope	p-value	Confidence interval
Kharif				
Max T	30.7	0.01	0.25	0.00, 0.01
Min T	16.1	0.02	0.003	0.02,0.02
Diurnal T	14.7	-0.02	0.04	-0.02, -0.01
Rainfall	475.0	1.24	0.45	0.58, 1.07
Rabi				
Max T	20.6	0.02	1.11	0.02, 0.03
MinT	4.7	0.02	0.002	0.01, 0.02
Diurnal T	15.9	0.005	0.68	-0.001, 0.01
Rainfall	457.1	-1.00	0.51	-1.80, -0.31

TABLE 2

Crop yield trends with Sen's slope value

Crops	Sen's slope	p-value	Confidence interval
Wheat	0.01	0.04	0.01, 0.02
Barley	0.02	0.78	-0.001, 0.004
Rice	0.01	0.02	0.01,0.01
Maize	0.02	0.01	0.02, 0.02
Potato	0.13	0.002	0.11, 0.15
Millets	-0.005	0.01	-0.01, -0.004

TABLE 3

Multivariate regression analysis of detrended crop yields

Crops	Coefficient/ p-value	Minimum temperature	Maximum temperature	Diurnal temperature	Rainfall	R^2	Climate dependent variation
Wheat	Coefficient	-0.02	-0.31	-0.31	0.22	0.109	10.9%
	p-value	0.46	0.03	0.02	0.09		
Barley	Coefficient	0.00	-0.30	-0.29	0.49	0.260	26.0%
	p-value	0.50	0.03	0.03	0.004		
Rice	Coefficient	-0.10	0.05	0.20	-0.34	0.167	16.7%
	p-value	0.53	0.74	0.47	0.04		
Maize	Coefficient	0.37	0.11	-0.19	-0.21	0.240	24.0%
	p-value	0.02	0.53	0.25	0.20		
Potato	Coefficient	-0.01	-0.17	-0.15	0.09	0.060	6.0%
	p-value	0.97	0.31	0.34	0.60		
Millets	Coefficient	-0.01	-0.01	-0.01	0.10	0.119	11.9%
	p-value	0.47	0.48	0.47	0.27		

only the year 2011 was observed with temperature slightly below average, rest all the years were observed with temperature substantially higher than normal in Kullu district. Higher rate of increase in minimum annual temperature as compared to maximum temperature was also reported in Nepal Himalayan region, where Pudel and Shaw (2016) observed an increase in minimum temperature by 0.07 °C as compare to 0.02 °C in maximum temperature from 1980 to 2010. Similar findings of higher rate of increase in minimum temperature were also obtained by Beniston (2003) and Schaer *et al.* (2004) in Europe. However, contrasting results were observed by Borgaonkar and Pant (2001) for Asian continent. A non-uniform rate of increase in temperature was observed by Bhutiyani *et al.* (2007), while studying across the different stations of north-western Himalayas. In compliance to this study no change in rainfall pattern in Himalayan region was also observed by Joshi *et al.* (2011).

3.1. *Crop productivity*

Analysis of productivity trends of rice, maize, potato, millets, wheat and barley crops showed that the productivity of all crops has changed significantly over time except barley [Figs. 3(a-f)]. An increase in productivity was recorded in rice, maize, potato, wheat whereas millets displayed a decreasing trend in productivity from 1971 to 2010 (Table 2). Potato crop showed the highest correlation coefficient value. Productivity of potato crop has increased by 0.13 t $ha^{-1}year^{-1}$ during 40 years. Potato yields showed a jump since 1987, probably due to change in variety cultivated. Maize also exhibited an increase in productivity over the time at the rate of 0.02 t $ha^{-1}year^{-1}$. Productivity of rice and wheat crops was also registered an increase over the study period at the rate of 0.01 t ha^{-1} $year^{-1}$. Although the productivity of wheat has increased over time, it is relatively below than the national average of 3.07 t ha^{-1}.

However, in case of millets the productivity has decreased over the years by 0.005 t ha^{-1} $year^{-1}$. Use of high yielding varieties, advanced farm practices and high input might be the reason for the increase in productivity of all crops other than millets. Millets were the routine food item in the past time, but with the increased availability of easy processing cereals, millets were towed to less productive areas, being the most neglected crops of the state. Millet cultivation is now restricted to some remote patches of the state. Unavailability of quality seed and lack of adoption of appropriate package and practices are few reasons leading to reduction in productivity of these nutritionally rich future crops.

Contribution of changing climate to yield fluctuation of the crop cannot be overlooked. Climate change in addition to other factor can be an emerging aspect affecting the crop yield over the time. Therefore, we tried to determine the relationship between change in crop productivity due to climate change in the following section through correlation and multivariate regression analysis.

3.2. *Climate crop productivity relationship*

In order to determine the relationship between climatic variability and crop productivity, a correlation analysis was performed. The results revealed a comparatively good relationship between climate variability and productivity of rabi crops such as wheat and barley, whereas, negligible relationship was observed in case of the kharif crops (rice, maize, potato and millets) in Kullu district (Table 3). While testing the effect of minimum temperature a significant and positive trend (0.37) was observed in the productivity of maize.

In case of maximum temperature, a negative correlation coefficient of -0.31 and -0.30 was observed with wheat and barley depicting that increase in maximum temperature is likely to decrease the productivity of wheat and barley, as can be seen during the period after 1991 [Fig. 3(e)]. Similar results for wheat, barley, maize and paddy were obtained by Singh *et al.* (2015), Mishra *et al.* (2015) and Gammans and Merel Ortiz-Bobea (2017). However, contrasting results of increase in wheat yield due to increase in minimum temperature was observed in Australia (Nicholls, 1997) and in maize were observed in Africa where the researchers predicted a decrease in future maize yield by a factor of -0.73% to -14.33% by mid-century and by -13.19% to -31.86% by the end of the century (Msowoya *et al.*, 2016). In case of rainfall, diverging effects were observed for barley and rice. The coefficients for barley and rice were 0.49 and -0.39 respectively.

3.3. *Change in yield due to climatic variables*

To test whether there is any direct relation between climatic variables and crop productivity in Kullu district, a multivariate regression analysis between detrended climatic variables of minimum, maximum, diurnal temperature and rainfall and productivity of rice, maize, potato, millet, wheat and barley was performed. Climatic and productivity data was de-trended by computing the difference in values from one year to the next. A multivariate regression model was used to confirm and quantify the relationship between climate change and crop productivity and results are depicted in Table 3. Results advocate a variation of 6.0 to 26.0% in the food crop productivity which can be explained by the model based on climatic variables. Climate variables accounts for 26.0% yield variation in barley crop, whereas 74.0% of variation in productivity in barley can be explained by other influential factors such as better seeds and crop management practices. Similarly the regression analysis indicate that in case of maize, climate variables accounts for 24.0% of yield changes with the R-squared value of 0.240, while 76% of the variation can explained by other factors. Change in productivity with a value of 16.7% was observed in case of rice and 10.9% in case of wheat are due to climatic variables, while 83.3% and 89.1%, respectively, are due to improved seed varieties, intense fertilizer application and better farm management practices. In case of millets and potato climatic variables account for 11.9% and 6.0% change in productivity, respectively. The results are in line with the findings of Poudal and Shaw (2016) who have observed similar results for Nepal. Climatic variables contributed 30-50% of observed increase in wheat yield in Australia (Nicholls, 1997).

4. Conclusions

An evaluation of change in climatic variables such as minimum, maximum and diurnal temperature and rainfall during rabi and kharif cropping season from 1971 to 2016 was done and its impact on crop productivity in Kullu district of Himachal Pradesh was analyzed. The results confirmed that mean minimum temperature has increased by 0.02 °C during rabi and kharif seasons in the study area. Diurnal temperature was also found to decrease by 0.02 °C during kharif season. Standardized Anomaly Index of temperature depicted that the warming trend has intensified after 1998. Climate variability is contributing to the change in productivity of barley, maize, rice, millets, wheat and potato by 26%, 24%, 16.7%, 11.9%, 10.9% and 6%, respectively. Results further revealed a strong relationship between climatic variability and productivity of rabi crops in comparison to kharif crops.

Disclaimer **:** The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of their organizations.

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