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Climate and its variability over the *Tarai* region of Uttarakhand

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सार – यह अध्ययन 1981-2020 की अवधि में वार्षिक आधार पर मौसम प्राचलों अर्थात् अधिकतम तापमान, न्यूनतम तापमान, वर्षा, धूप के घंटे और वाष्पीकरण की प्रवृत्ति के विश्लेषण के संबंध में उत्तराखंड के तराई क्षेत्र के लिए आयोजित किया गया है। दशकीय विविधताओं के लिए उपरोक्त बताए गए प्राचलों के लिए 5-वर्ष, 10-वर्ष और पचास वर्ष के अंतराल, के क्रमागत औसत का अध्ययन किया गया है। परिणामों से पता चला कि अधिकतम और न्यूनतम तापमान में क्रमशः 0.0004 °C/वर्ष और 0.0180 °C/वर्ष की वृद्धि की प्रवृत्ति है। वर्षा, धूप के घंटों और वाष्पीकरण में क्रमशः 1.461 मिमी/वर्ष, 0.042 घंटे/वर्ष और 0.028 मिमी/वर्ष की घटती प्रवृत्ति देखी गई है।

ABSTRACT. The study is conducted for the Tarai region of Uttarakhand regarding the trend analysis of the weather parameters, namely maximum temperature, minimum temperature, rainfall, sunshine hours and evaporation on an annual basis over the periods from 1981-2020. The moving average for 5-year, 10-year intervals and the pentadal, decadal variations has been studied for the above stated parameters. The results revealed that there is an increasing trend in the maximum and minimum temperature of about 0.0004°C/year and 0.0180°C/year respectively. The decreasing trend in the rainfall, sunshine hours and evaporation is observed of about 1.461 mm/year, 0.042 hr/year and 0.028 mm/year respectively.

Key words – Moving average, Pentadal, Decadal, Trend, Weather parameters.

1. Introduction

The climate change has led to variations in food and fiber feeds, which will alter socio-economic growth and regional competitiveness. Therefore, analysis of climate change scenario in terms of temperature, rainfall, reference evapotranspiration (loss of water from a grass surface that is well-watered), relative humidity, sunshine hour, evaporation and wind speed becomes an important task for better understanding of dynamics in the climate (Djaman *et al*., 2017). Uttarakhand, one of the 12 Himalayan territories of India, is known for its common excellence and profoundly changed geography. Its snow-clad pinnacles, lovely slope stations, expanded dunes and rich organic progression makes it a most loved objective for sightseers.

Around 83% of places, state that lies under slopes while a large portion of the number of inhabitants in the state lives in the southern tight belt, of the *Tarai* fields. Uttarakhand is viewed as profoundly delicate for environmental related changes because of its fluctuating geography and rich glacial mass (Aryal *et al*., 2020). The strengthening human exercises like deforestation, urbanization, mining and so forth, may influence the territorial climo-balance, unfortunately and along these lines, may change the speed and destiny of continuous geomorphic processes, *i.e.*, the changes in the configuration of the Earth's surface, due to physical stresses and chemical actions present on the earth.

The precipitation is mainly associated with the sequence of synoptic systems known as 'western disturbances'. The precipitation has considerable spatial and temporal variability, with maximum precipitation occurring particularly over northern hilly regions, with decreasing influence southwards (Yadav *et al*., 2012). The inter-annual variability of seasonal precipitation over India strongly depends upon the El Nino-Southern Oscillation (ENSO) phenomenon. The ENSO is anti-correlated with Indian summer monsoon (ISM). While, the Indian north-east monsoon, and the north and central India winter precipitation (NCIWP) are correlated with ENSO (Yadav *et al.*, 2013).

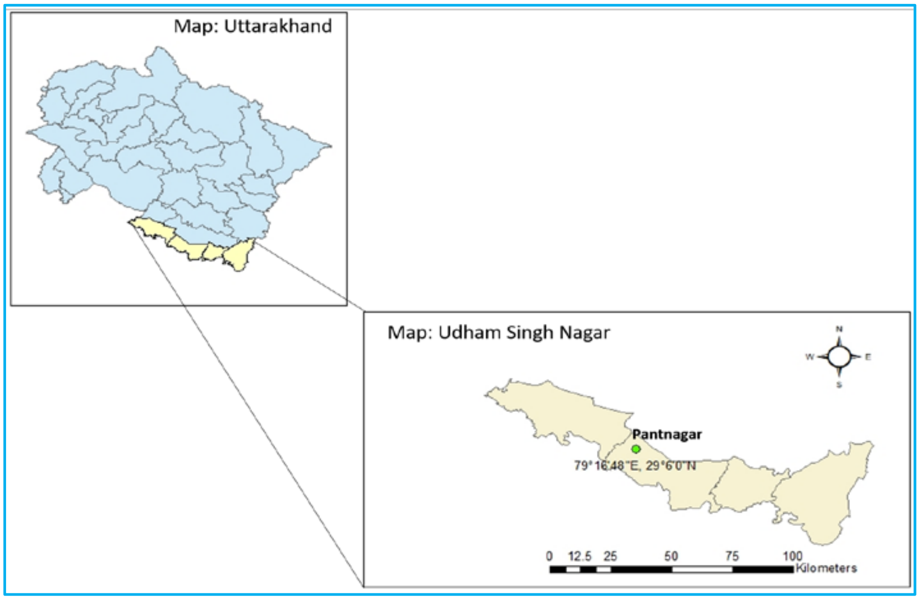

Fig. 1. Map of Udham Singh Nagar indicating Pantnagar station

TABLE 1

Descriptive statistical analysis of different parameters, on an annual basis for the Tarai region of Uttarakhand from 1981-2020

Statistical parameters	*T*max (°C)	*T*min (°C)	Rainfall (mm)	Sunshine hours (hr)	Evaporation (mm)
Mean	29.70	17.02	1555.36	7.23	4.77
SD	0.60	0.68	528.09	0.65	0.57
CV%	2.02	4.00	33.95	8.95	11.97

Pantnagar is the town and a university campus that lie in Udham Singh Nagar district, Uttarakhand. Nainital, Kashipur, Rudrapur and Kiccha, Haldwani are the major cities surrounding Pantnagar. The area falls under the sub-humid subtropical climate of the *Tarai* belt, located in the foothills of the Himalayas at 29.02° N latitude, 79.48° E longitude and at an altitude of 244.0 m above the mean sea level as shown in Fig. 1. In Udham Singh Nagar, Haridwar, the Gangetic plain, Pauri Garhwal and some parts of Nainital were called the *Tarai* region. Its width is from 20 to 30 km. The geographical area of the town is 3055 km^2 and it ranks 9^{th} in Uttarakhand state. The *Tarai* belt is 8-25 kms wide, with a general slope of 1% to the south.

There is a need to study the climate change scenario, to tackle the challenges faced by the farmers regarding the reduced crop yields and nutritional quality, may be due to drought, heat waves and excess rainfall leads flooding as well as increase in the pests and plant diseases. The main objective of this study is to sustainably increase the agricultural productivity by the shift on the date of sowing, selection of tolerant varieties and different agronomic management practices based on the temperature and rainfall trend. These two weather parameters mainly affect the crop growth and development, thus it is important to have knowledge about the trend of these weather parameters, in order to build our agricultural sector more climate change resilient.

2. Materials and methodology

The weather data are collected from the agrometeorological observatory located at N. E. Borlaug Crop Research Centre, G B Pant Univ of Ag & Tech, Pantnagar (29.02° N & 79.48° E and altitude of 244 m) from 1981-2020 of the following parameters namely- Maximum Temperature (°C), Minimum temperature (°C), Relative Humidity (morning and evening hours in %), Sunshine Hours (hrs), Rainfall (mm/day), Rainy days, Wind speed (km/hr), Evaporation (mm) and the statistical analysis was carried out with the following parameters using MS EXCEL application software:

(*i*) *Mean* : The mean is the average or the most common value in a collection of numbers.

$$\text{Mean} = \sum_{i=1}^{n} X\,i/n \qquad (1)$$

where, Xi is the data for i^{th} term and n is the total number of data.

(*ii*) *Standard Deviation* : It is defined as the positive square root of the arithmetic mean of the squares of the deviations of the given values from the arithmetic mean. The standard deviation is a measure of the amount of variation or dispersion of a set of values.

$$\text{SD} = \frac{\sqrt{\sum Xi - X\text{mean}}}{n-1} \qquad (2)$$

(*iii*) *Coefficient of Variation* :The coefficient of variation (CV) is a statistical measure of how individual data points vary about the mean values.

$$\text{CV} = \text{SD/Mean} * 100 \qquad (3)$$

The statistical parameters like mean, maximum, minimum, standard deviation, coefficient of variation for the different weather parameters, like, maximum temperature, minimum temperature, rainfall, sunshine hours and evaporation is computed for studying the above stated climatic parameters, variability in the *Tarai* region of Uttarakhand.

For calculation, the average of annual Minimum Temperature, Maximum temperature, Rainfall, Sunshine Hours and Evaporation is done by taking daily data from 1981-2020 (sum of the min or max temperatures of 52 weeks / no. of observation of a particular year, *i.e.*, 52 weeks).

(*i*) Pentads (*i.e.*, 1981-85, 1986-90……….2016-20).

(*ii*) Decades (*i.e.*, 1981-90, 1991-00……….2011-20).

(*iii*) Moving average of 5 years (1981-85, 1982-86, 1983-87…………2016-20).

(*iv*) Moving average of 10 years (1981-90, 1982-91, 1983-92……….2011-20).

TABLE 2

Descriptive daily heat waves based on maximum temperature for the *Tarai* region of Uttarakhand from 1988-89, 1996-97

Date	Actual Temp. (°C)	Normal Temp. (°C)	Wave
1/13/1988	24.1	19.1	Heat Wave
4/11/1988	40.2	35.1	Heat Wave
4/12/1988	40.1	35.2	Heat Wave
5/10/1988	41.3	37.1	Heat Wave
5/11/1988	42.6	36.8	Heat Wave
5/12/1988	43.3	37.2	Heat Wave
5/13/1988	41.1	37.0	Heat Wave
5/22/1988	40.5	37.6	Heat Wave
5/23/1988	41.8	37.3	Heat Wave
5/24/1988	42.6	37.2	Heat Wave
5/25/1988	44.2	37.4	Heat Wave
5/26/1988	44.3	37.7	Heat Wave
5/27/1988	42.4	37.8	Heat Wave
5/28/1988	44.0	38.3	Heat Wave
5/29/1988	44.5	38.0	Heat Wave
5/30/1988	41.0	37.4	Heat Wave
6/11/1988	40.2	35.7	Heat Wave
6/12/1988	40.1	34.8	Heat Wave
6/28/1988	38.7	33.5	Heat Wave
6/30/1988	38.6	33.1	Heat Wave
12/19/1988	25.5	20.4	Heat Wave
12/31/1988	23.9	18.2	Heat Wave
5/2/1989	40.2	36.8	Heat Wave
5/5/1989	40.1	36.8	Heat Wave
5/11/1989	40.2	36.8	Heat Wave
5/12/1989	41.0	37.2	Heat Wave
5/20/1989	40.8	37.7	Heat Wave
5/22/1989	40.8	37.6	Heat Wave
1/1/1996	23.7	18.4	Heat Wave
1/2/1996	24.1	18.3	Heat Wave
1/3/1996	23.2	17.9	Heat Wave
1/4/1996	23.7	18.3	Heat Wave
1/5/1996	23	17.7	Heat Wave
4/28/1996	40.3	36.2	Heat Wave
4/29/1996	41	36.4	Heat Wave
4/30/1996	41.6	37.0	Heat Wave
5/1/1996	40	36.6	Heat Wave
5/2/1996	41.2	36.8	Heat Wave
5/3/1996	40.5	36.9	Heat Wave
5/4/1996	41.5	37.1	Heat Wave
5/17/1996	40.2	37.4	Heat Wave
5/18/1996	41.9	37.7	Heat Wave
5/19/1996	40.1	37.4	Heat Wave
5/21/1996	40.5	37.5	Heat Wave
5/22/1996	42.5	37.6	Heat Wave
5/23/1996	42.2	37.3	Heat Wave
5/24/1996	42.5	37.2	Heat Wave
5/26/1996	40.4	37.7	Heat Wave
6/5/1996	40.4	37.0	Heat Wave
12/14/1996	26.9	21.2	Heat Wave
1/3/1997	22.9	17.9	Heat Wave
5/9/1997	40.5	37.3	Heat Wave
5/12/1997	40.1	37.2	Heat Wave
5/13/1997	40.2	37.0	Heat Wave
5/15/1997	40.1	37.3	Heat Wave
5/16/1997	40.7	37.4	Heat Wave
6/2/1997	40.0	37.3	Heat Wave
6/3/1997	40.7	37.5	Heat Wave
6/9/1997	41.0	36.5	Heat Wave
6/10/1997	42.5	35.4	Heat Wave
6/11/1997	40.0	35.7	Heat Wave

TABLE 3(a)

Pentadal variation of the different weather elements and computation of the statistical parameter

Pentads	Tmax (°C)	Tmin(°C)	Rainfall (mm)	Sunshine hours (hr.)	Evaporation (mm)
1981-85 (P1)	29.52	16.42	1657.46	7.57	7.57
1986-90 (P2)	29.85	17.54	1582.04	7.96	7.96
1991-95 (P3)	30.15	16.49	1009.36	7.69	7.69
1996-20 (P4)	29.31	16.83	2040.36	7.37	7.37
2000-05 (P5)	29.49	17.07	1817.46	7.03	7.03
2006-10 (P6)	29.81	17.25	1603.96	7.24	7.24
2010-15 (P7)	29.71	17.28	1460.08	6.34	6.34
2016-20 (P8)	29.69	16.99	1586.24	7.13	7.13
Mean	29.69	16.98	1594.62	7.29	4.82
SD	0.24	0.37	276.87	0.46	0.36
CV (%)	0.82	2.15	17.36	6.32	7.46

TABLE 3(b)

A decadal variation of different parameters and its statistical computation

Decads	*T*max (°C)	*T*min (°C)	Rainfall (mm)	Sunshine hours (hr)	Evaporation (mm)
1981-1990 (D1)	29.68	16.98	1619.75	7.77	5.16
1991-2000 (D2)	29.73	16.66	1524.86	7.53	5.10
2001-2010 (D3)	29.60	17.11	1676.10	7.26	4.51
2011-2020 (D4)	29.77	17.34	1400.74	6.37	4.32
Mean	29.70	17.02	1555.36	7.23	4.77
SD	0.06	0.25	104.36	0.53	0.37
CV (%)	0.20	1.45	6.71	7.32	7.67

Then the graph is plotted and a regression equation is computed on the graph and a positive or negative slope depicts the increasing or decreasing trends of the different parameters, stated above on an annual basis. The graphical analysis is the simplest method to find the trend of all the weather variables (Basistha, 2009). The graph was drawn between rainfall *vs* time/year and temperature *vs* time/year, to analyze the rising or falling pattern and a trend line was drawn. The graph was plotted for the historical period (1981-2020) of rainfall and temperature. The trend analysis of rainfall, temperature, sunshine hours and evaporation data by the graphical method, tells us only whether, there is an increasing or decreasing trend.

3. Result and discussion

The present study was undertaken to estimate the trends, their magnitude and changes in the pattern of rainfall, maximum temperature, minimum temperature, sunshine hours and evaporation in the *Tarai* region of Uttarakhand. To carry out the analysis, the long-term climatic data of 40 year is taken from 1981 to 2020. The climatic variability in the weather pattern for the short and long term influenced the water requirement **(**Banashree *et al*., 2019). The rainfall, temperature, sunshine hours and evaporation are the major components of agricultural water management, irrigation scheduling as well as water resource planning. In the present study, statistical analysis was carried out for studying the variability in rainfall, temperature, sunshine hours and evaporation of the *Tarai* region.

The annual statistical parameters, of the different weather elements like maximum temperature, minimum temperature, rainfall, sunshine hours, evaporation over the periods from 1981 to 2020 is presented in the Table 1 and

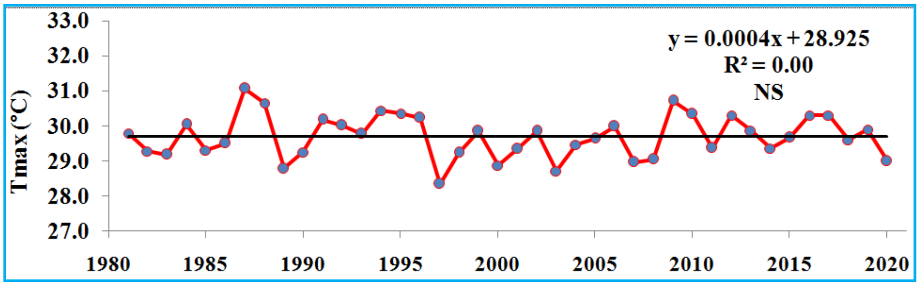

Fig. 2. Trend analysis of Annual *T*max variation for Tarai region of Uttarakhand from 1981-20

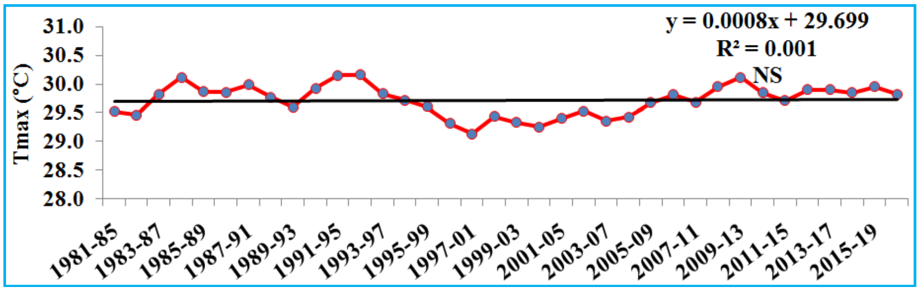

Fig. 3. Trend analysis for 5 years moving average of *T*max variation

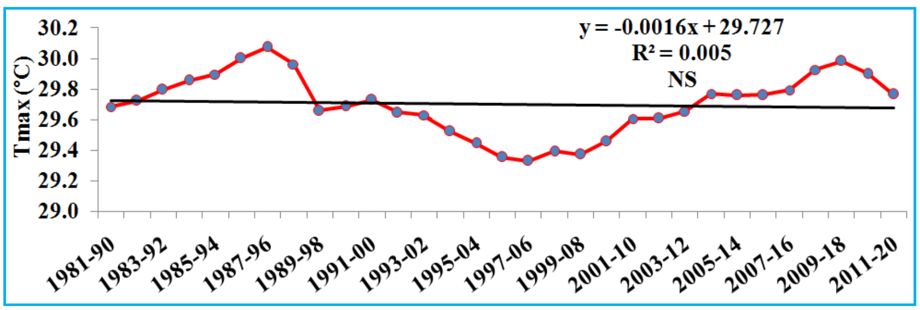

Fig. 4. Trend analysis for 10 years moving average of *T*max variation

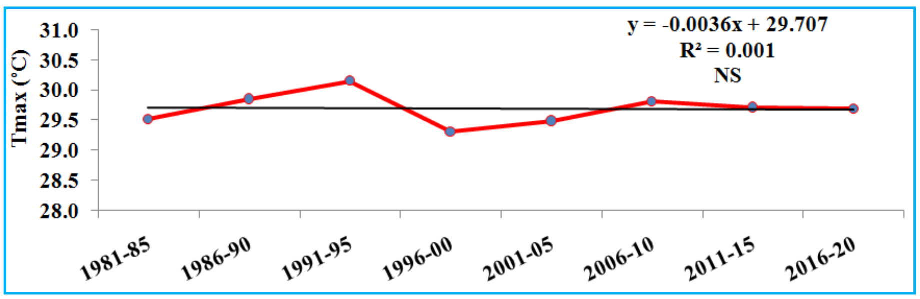

Fig. 5. Trend analysis for Pentadal *T*max variation

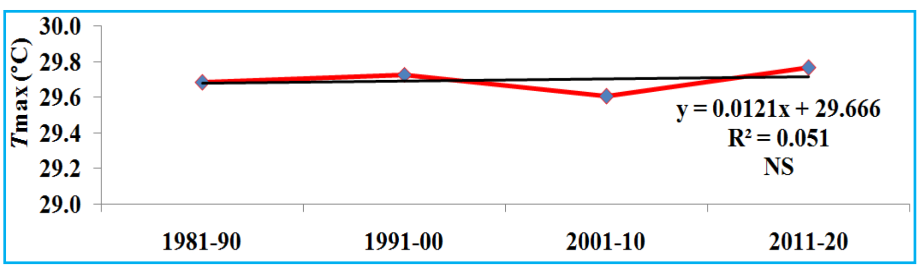

Fig. 6. Trend analysis for Decadal *T*max variation

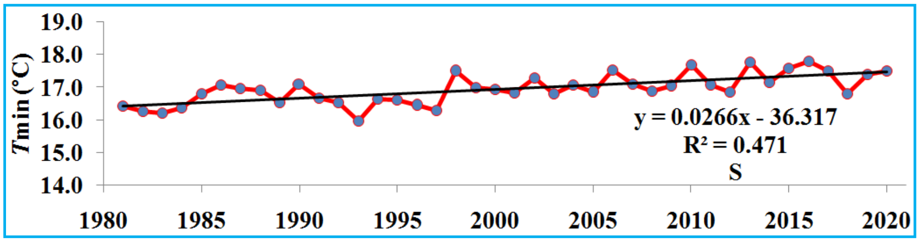

Fig. 7. Trend analysis for Annual *T*min variation for *Tarai* region of Uttarakhand from 1981-20

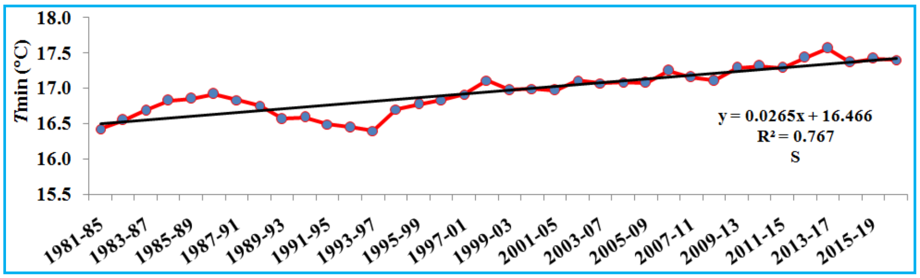

Fig. 8. Trend analysis for 5 years moving average of *T*min variation

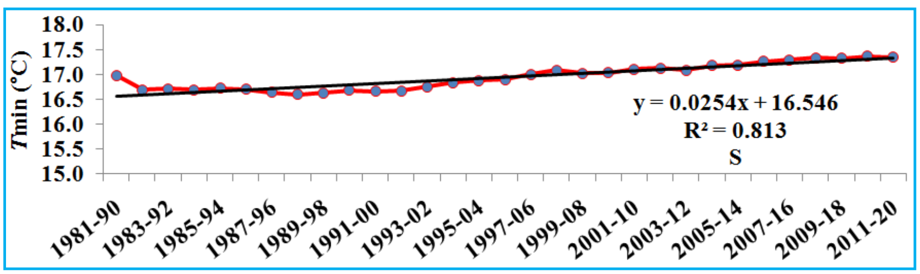

Fig. 9. Trend analysis for 10 years moving average of *T*min variation

it has been revealed that, of all the weather parameters, a significant variation of the total rainfall can be seen in the *Tarai* region of Uttarakhand. As CV% is about 34% in the total rainfall, which is the maximum and the least variation can be seen in the maximum temperature as CV% is found to be 2% and CV% for evaporation, sunshine hours and minimum temperature is found to be 12%, 9%, 4% respectively. The average total rainfall in the *Tarai* region is about 1555.4 mm, which shows good rainfall over this region.

In the Table 3(a), the pentadal variation of the different weather parameters were depicted along with the statistical parameters over the periods from 1981 to 2020. After the analysis, it has been found that the highest average maximum temperature, minimum temperature, total rainfall, sunshine hours and evaporation is observed during P3, P2, P4, P2, P2 respectively. The smallest average maximum temperature, minimum temperature, total rainfall, sunshine hours and evaporation were found during P4, P1, P3, P7, P7 respectively. The pentads were plotted to depict the accuracy of the data, as in the case of maximum and minimum temperature, there is a slight variation of 0.01 °C and 0.04 °C respectively, when compared with an annual data. In the same way as per Table 3(b), the decadal variation of the above stated parameters and statistical analysis has been done, it has been concluded that a decadal variation is closer to the average annual variation.

3.1. *Trend analysis of maximum temperature*

In the Fig. 2, *i.e.*, for the graphical trend analysis of maximum temperature over the periods of 1981-2020 and it has been concluded that there is a slight increasing trend in the maximum temperature as presented below, the slope is found to be 0.003 °C which indicates that maximum temperature has a positive trend over the period from 1981-2020. The steep slope could be observed in the year 1989 & 1997 as compared to the previous year as per the Fig. 1 because more heat waves was observed in the summer months as compared to the previous year as depicted below in the Table 2. Similarly, in the Fig. 3, *i.e.*, for the five years moving average of the maximum

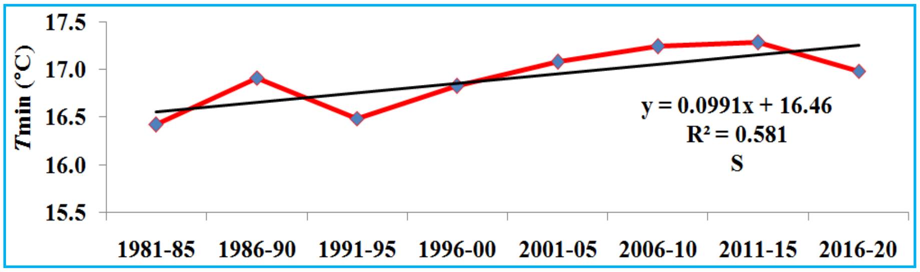

Fig. 10. Trend analysis for Pentadal *T*min variation

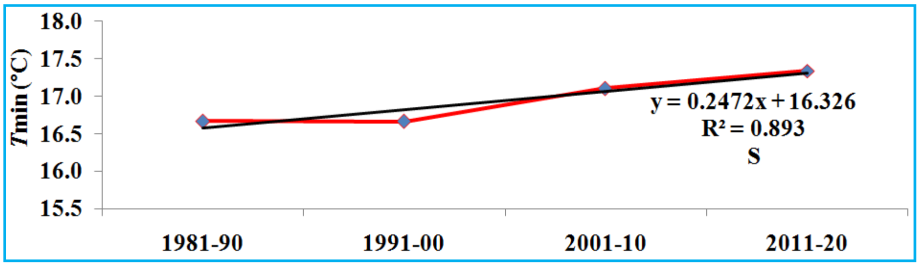

Fig. 11. Trend analysis for Decadal *T*min variation

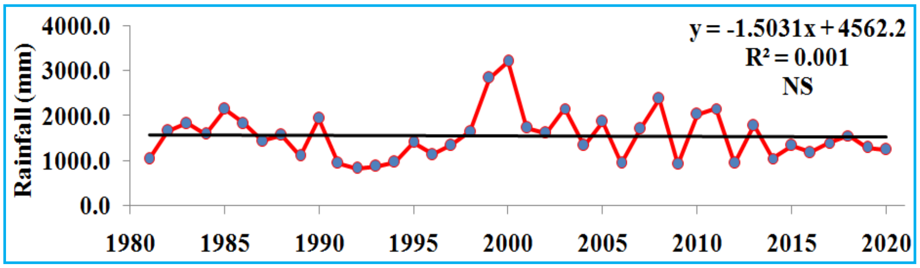

Fig. 12. Trend analysis for Annual Rainfall variation for Tarai region of Uttarakhand from 1981-2020

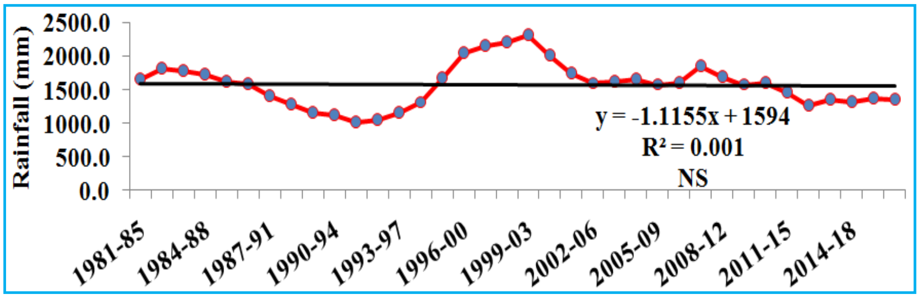

Fig. 13. Trend analysis for 5 years moving average of Rainfall variation

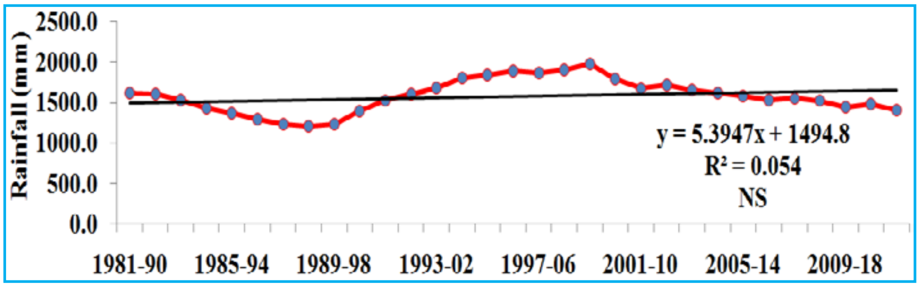

Fig. 14. Trend analysis for 10 years moving average of Rainfall variation

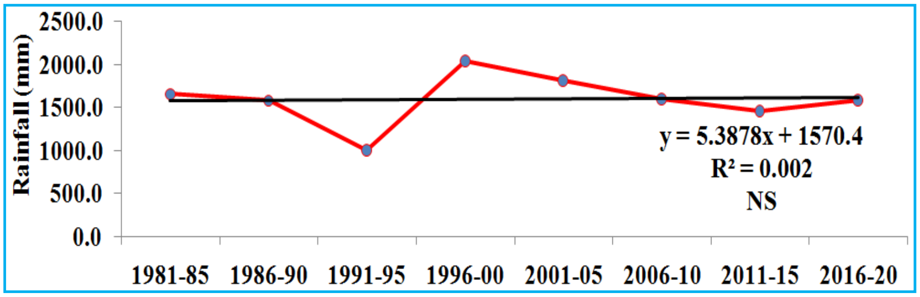

Fig. 15. Trend analysis for Pentadal Rainfall variation

TABLE 4

Variation in the maximum temperature at the different time scales

Time Scale	Total change over the periods (°C)	Change/year (°C)/year
An annual	0.016	0.0004
Five year moving average	0.028	0.0007
Ten year moving average	-0.004	-0.0001
Pentads	-0.025	-0.0006
Decads	0.036	0.0009

TABLE 5

Variation in the minimum temperature at the different time scales

Time Scale	Total change over the periods (°C)	Change/year (°C/year)
An annual	0.702	0.018
Five year moving average	0.518	0.013
Ten year moving average	0.534	0.017
Pentads	0.431	0.011
Decads	0.458	0.011

temperature, revealed that there is a positive trend in the maximum temperature as the slope is found to be 0.001 °C which is almost equals to zero. In the Fig. 4 & 5, *i.e*., for the ten years moving average of *T*max and the pentadal variation depicts a slight negative trend in the maximum temperature, slope is found to be as -0.001 °C & -0.003 °C respectively.

Similar results were reported by Murthy (2004), in the case of minimum temperature for Hill Campus, Ranichauri in mid Himalayan region of Uttarakhand. He observed that there is a positive trend in the *T*min over the period from 1982-2002 on an annual basis, but he found a slight negative trend in the 3, 5 & 10 years moving average. The Fig. 6 which depicts the decadal variation of *T*max, a positive trend could be observed, as slope is found to be 0.0121 °C. An actual increase in the maximum temperature of about 0.016 °C over the period from 1981-2020 and a rate of an increase in maximum temperature of about 0.004 °C is found as per the results presented in the Table 4. These variations in the *T*max, which is observed during a moving average of 10 years and the pentadal variation, may be because as we move towards larger scale, deviations in the temperature were expressed in the40-year data, so negative trend in the graph could be observed. While for the 5 years moving average and the decadal time scale shows the positive trend as per the Fig. 3 & 6 respectively. In the Table 5, absolute increase or decrease and a rate of change of maximum temperature, at the different time scales had been depicted.

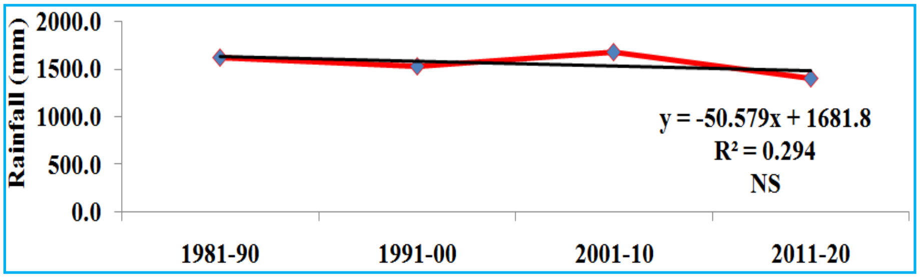

Fig. 16. Trend analysis for Decadal Rainfall variation

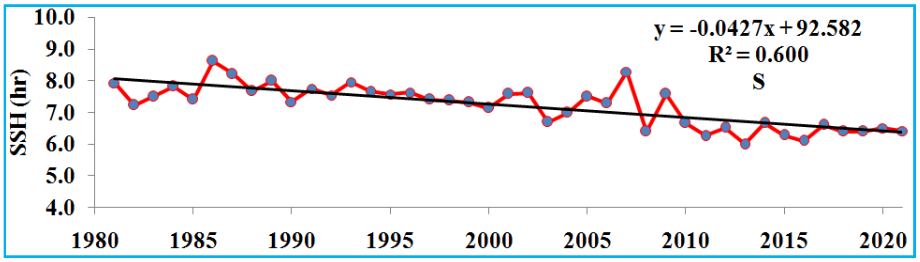

Fig. 17. Trend analysis for Annual Sunshine hours variation for Tarai region of Uttarakhand from 1981-20

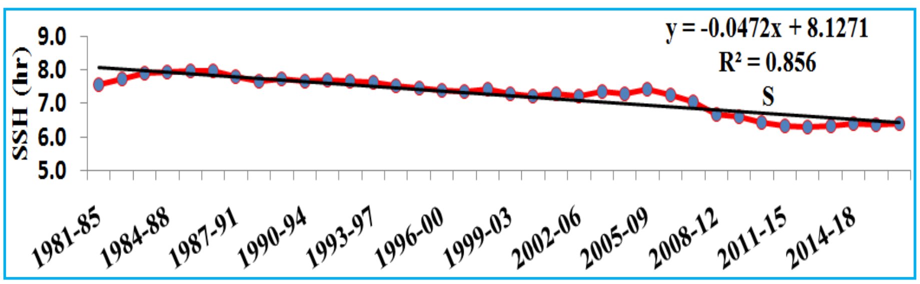

Fig. 18. Trend analysis for 5 years moving average of sunshine hours variation

TABLE 6

Variation in the rainfall at the different time scales by the graphical method

Time Scale	Total change over the periods (mm)	Change/year (mm/year)
An annual	-58.621	-1.461
Five year moving average	-39.043	-0.976
Ten year moving average	161.841	4.046
Pentads	37.175	0.943
Decads	-151.737	-3.793

3.2. *Trend analysis of minimum temperature*

In the Fig. 7 to 9, *i.e.*, for an annual minimum temperature variation in the 5 & 10 years moving average over the period from 1981-2020 respectively, shows a slight positive trend in *T*min and slope is found to be 0.0175 °C, 0.0148 °C, 0.0178 °C respectively. Whereas, in the Fig. 10 & 11, *i.e.*, for the pentadal and decadal

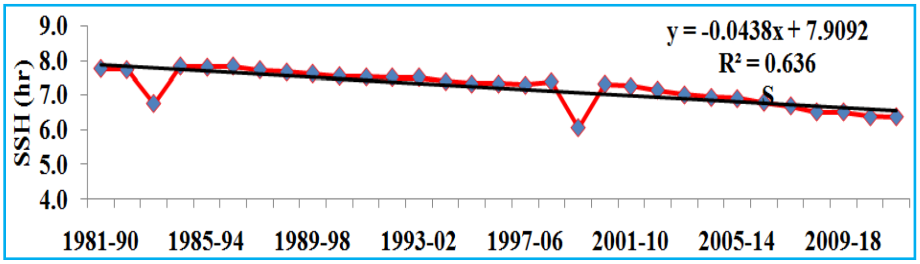

Fig. 19. Trend analysis for 10 years moving average of sunshine hours variation

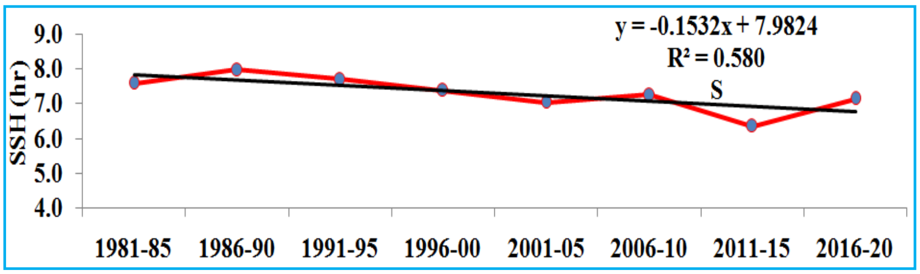

Fig. 20. Trend analysis for Pentadal Sunshine hours variation

TABLE 7

Variation in the sunshine hours at the different time scales by the graphical method

Time scale	Total change over the periods (hr)	Change/year (hr/year)
An annual	-1.673	-0.042
Five year moving average	-1.652	-0.041
Ten year moving average	-1.314	-0.033
Pentads	-1.072	-0.027
Decads	-1.440	-0.034

variation of minimum temperature shows a positive trend for *T*min and slope is found to be 0.061 °C & 0.152 °C and an annual increase in the *T*min is about 0.706 °C and 0.018 °C/year. At larger scales *i.e.*, at 5 and 10 years moving average there is an increase in temperature of 0.514 °C & 0.534 °C and the rate of an increase in the minimum temperature is found to be 0.013 °C & 0.017 °C respectively. There is significant rise in the minimum temperature as per the Fig. 7, while there is non-significant changes in the maximum temperature that indicates the range of temperature is decreasing. It will cause forced maturity of the grains, thus yield of the crop would be adversely affected (significance and non-significance based on the R squared value).

3.3. *Trend analysis of rainfall distribution*

In the Fig. 12 & 13, *i.e.*, for an annual and 5 years moving average of total rainfall in the *Tarai* region of Uttarakhand, shows a slight negative trend in the total rainfall and slope is found to be -0.396 mm & -1.115 mm respectively which is minimal as well as there is a slight absolute decrease in the annual rainfall of about 1.461 mm/year as presented in the Table 6. After 2000, a significant drying trend was experienced as per the Fig. 12 due to occurrence of El Nino event. It is a climate pattern that describes the unusual warming of surface waters in the eastern tropical Pacific Ocean which results in the decreased rainfall over Asian countries, which was

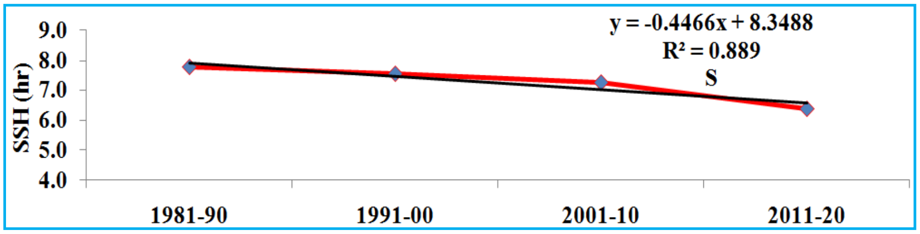

Fig. 21. Trend analysis for Decadal sunshine hours variation

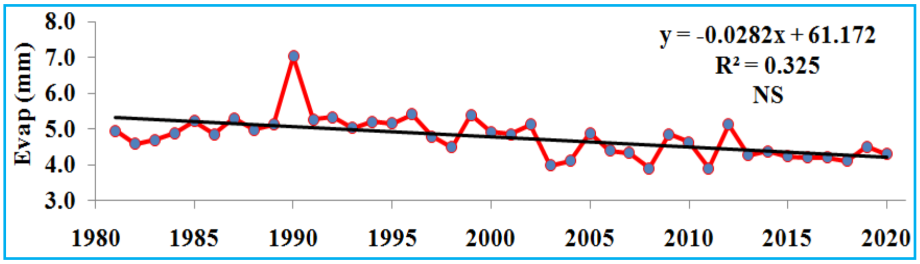

Fig. 22. Trend analysis for annual evaporation variation for Tarai region over the periods 1981-2020

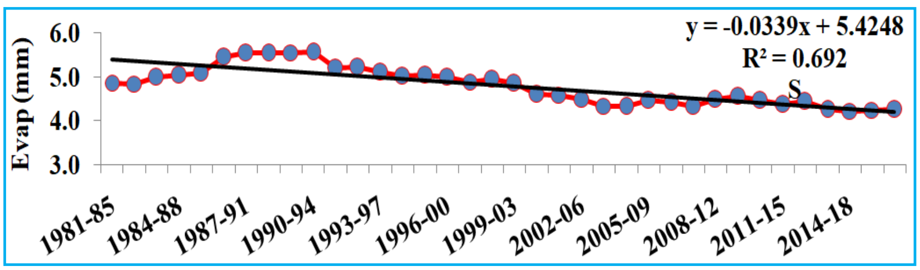

Fig. 23. Trend analysis for 5 years moving average of evaporation variation

TABLE 8

Variation in the evaporation at the different time scales by the graphical method

Time scale	Total change over the periods (mm)	Change/year (mm/year)
An annual	-1.100	-0.028
Five year moving average	-1.187	-0.030
Ten year moving average	-1.227	-0.031
Pentads	-0.78	-0.019
Decads	-0.938	-0.023

experienced in the year 2002, 2004, 2006, 2009, 2015-16 in India (Pandey *et al.*, 2019). If we observe the Fig. 14 & 15, *i.e.*, in the ten years moving average and the pentadal variation of total rainfall respectively, depicts the positive trend in the total rainfall and slopes are found to be nearly equal *i.e.*, 5.394 mm & 5.387 mm. Similar results has been found by **(**Singh, 2007) in the case of minimum temperature and he observed that for most of the year *T*min departure was near normal, followed by a decrease in minimum temperature at Hisar.

In the Fig. 16, *i.e.*, for the decadal variation of the rainfall shows a sharp negative trend in the total rainfall, as slope is found to be -50.579 mm over the period from 1981-2020. The annual decrease in the total rainfall is

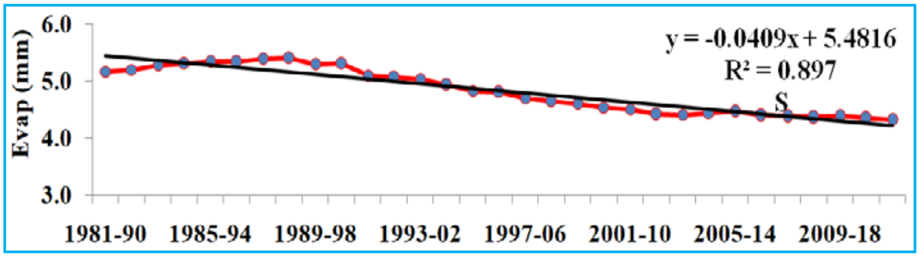

Fig. 24. Trend analysis for 10 years moving average of evaporation variation

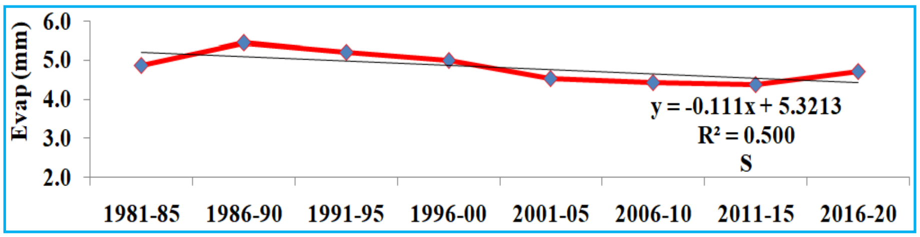

Fig. 25. Trend analysis for Pentadal evaporation variation

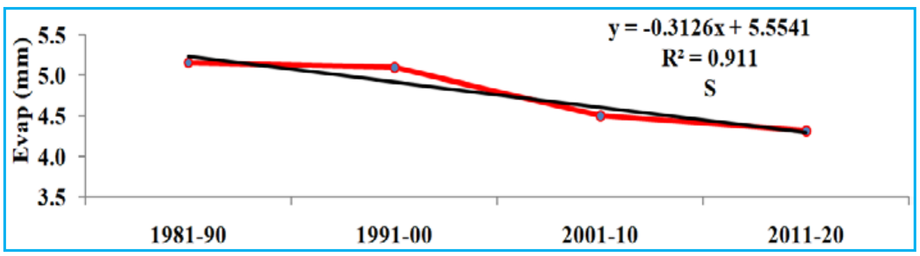

Fig. 26. Trend analysis for decadal evaporation variation

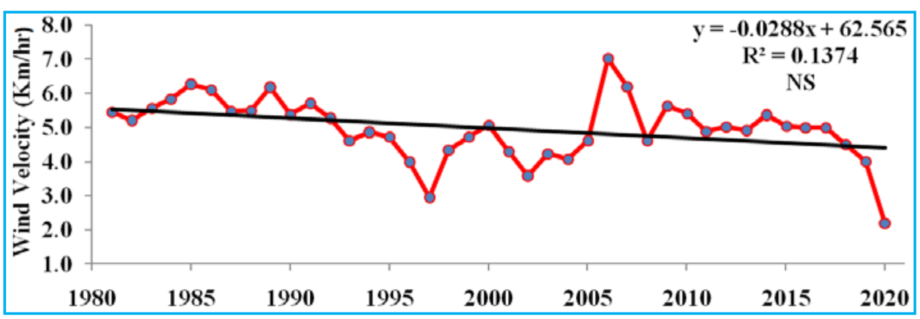

Fig. 27. Trend analysis of wind velocity and its variability over the periods from 1981-2020 for the *Tarai* region of Uttarakhand

about 58.621 mm and 1.461 mm/year. In the 5 & 10 years moving average decrease in the rainfall is about 39.043 mm & 0.976 mm/year and 151.737 mm & 3.793 mm/year respectively. The ten years moving average and pentads graph shows a positive trend, as we know moving towards a larger scale causes deviation due to the errors, are expressed as in the Fig. 14 & 15. It can be concluded that there is an erratic distribution in this region and most of the rainfall is experienced during the monsoon season as per the results.

3.4. *Trend analysis of sunshine hours*

In the Fig. 17 to 21, *i.e.*, for the average annual variation, 5 & 10 years moving average, the pentadal and decadal variation of sunshine hours in the *Tarai* region over the period from 1981-2020 respectively, depicts a negative trend. The slope of the best fit line of the graphs shows the negative trend of -0.043 hr, -0.047 hr, -0.043 hr, -0.153 hr, -0.447 hr. The actual decrease in sunshine hours annually is about 1.673 hr and 0.042 hr/year as depicted in the Table 7. The reason behind the decreasing trend in the sunshine hours is due to increase in the no. of cloudy days as well as increase in the pollutants and dust particles which absorb the short wave incoming radiation of the sun. As sunshine hours is decreasing and rate of evaporation is also declining which eventually decreases the condensation process, thus affecting the rainfall adversely.

3.5. *Trend analysis of evaporation*

In the Fig. 22 to 26, *i.e.*, for the annual, the 5 & 10 years moving average, the pentadal and decadal variation of the evaporation in the *Tarai* region of Uttarakhand over the period from 1981-2020 respectively, shows the declining trends and the slope of the best fit line is found to be -0.028 mm, -0.034 mm, -0.041 mm, -0.111 mm & -0.313 mm respectively, but an actual annual decrease in the evaporation is about 1.100 mm and 0.028 mm/year as depicted in the Table 8. The reason behind the decreasing trend in the evaporation is due to the decreasing trend in the sunshine hours as well as due to the decrease in the wind velocity over the period from 1981-2020 in the *Tarai* region of Uttarakhand as shown below in the Fig. 27. Wind is partly a result of a contrast in temperature such as across a strong cold front or between low and high latitudes (Pryor *et al.*, 2009) as this contrast in the temperature is decreasing as explained above (range of temperature is decreasing) so wind velocity is decreasing.

4. Conclusion

It has been concluded from the study that there is an increase in the rate of maximum temperature and minimum temperature by 0.002 °C & 0.003 °C and the decrease in the rate of rainfall, sunshine hours and evaporation by 0.043 mm, 0.004 hr. & 0.024 mm respectively, on an annual basis over the period from 1981-2020 in the *Tarai* region of Uttarakhand. If we talk about the overall increase in the maximum and minimum temperature, is about 0.016 °C and 0.702 °C which means that increase in *T*max has been not as much as *T*min, so it can be concluded that the range of temperature is decreasing for this region, which would adversely affect the photosynthetic rate of the crops. Similarly, if we observe the actual decrease in the rainfall, sunshine hours and evaporation for 40 years in the *Tarai* region of Uttarakhand then it is about 58.621 mm, 1.673 hr, 1.1 mm. A decrease in rainfall has been observed due to a population explosion, urbanization & global warming (Liu *et al.*, 2019) and the decrease in sunshine hours & evaporation can be seen in this region because of the increase in the pollution due to which dimming effect could be observed and thus prevents the incoming solar radiation and evaporation as well.

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Declaration

Herein I/We, Shubhika Goel consciously assure that for the manuscript entitled, "Climate and it's variability over the Tarai region of Uttarakhand" the following is fulfilled: This material is the authors' own original work, which has not been previously published elsewhere. The manuscript/part of, is not currently being considered for publication elsewhere. The manuscript reflects the authors' own research and analysis in a truthful and complete manner. The manuscript properly credits the significant contributions of coauthors and co-researchers. The results are properly placed in the context of earlier and existing research. All sources used in the manuscript are properly disclosed with correct citation. All authors have been personally and actively involved in significant work leading to the manuscript and will take public responsibility for its content. The manuscript has been prepared strictly as per permissible similarity limit and the guidelines available online for the purpose.

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