

On the Link of Global Warming and Cloudiness in Mid Hills of Himachal Himalayas, India

Mohan Singh Jangra^{1,*}, Priyanka Jattan², S.K. Bhardwaj³, Purnima Mehta⁴

Abstract

The present study investigated the monthly, seasonal, and annual cloud cover variability over two stations in the mid hills sub-temperate subhumid zone of Himachal Pradesh, by using Pearson's correlation coefficient, Mann-Kendall (MK), and Sen's slope estimator test. Daily data on cloud cover, sunshine hours, maximum and minimum temperature, morning and evening relative humidity, evaporation and rainfall for the period of 22 years (2001–2022) were used in the investigation. In the study, we have tried to analyze the trends in cloud cover and their relationship with bright sunshine, temperature, and other climatic variables under changing climatic scenarios. Both the stations showed an increasing trend in cloudiness, which was increasing at a non-significant rate of 0.01 Okta/year at Solan and 0.30 Okta/year at Kullu. From -0.64 to -0.87 , a significant inverse correlation was observed between cloud cover and sunshine hours. It was negatively correlated with maximum temperature and ranged from -0.03 to -0.42 and evaporation with an r value that ranged from -0.08 to -0.44 . The minimum temperature showed a significant positive correlation with cloud cover at Kullu but a non-significant positive correlation at Solan. Rainfall showed a negative correlation at Solan whereas a positive correlation was found at Kullu as the total cloudiness and its increasing rate were higher at Kullu. The overall trend in cloud cover in the study area was significantly increasing ($Z = 1.66$) with an upward magnitude ($Q = 0.03$). We tried a case study to work out a local trend in cloud cover, which may be extended over time and space to reach some conclusions.

Keywords: Cloudiness; weather variables, correlation; trend analysis; Himachal Himalayas

*Author for Correspondence

Mohan Singh Jangra
E-mail: jangra.2u@gmail.com

¹Principal Scientist, Department of Environmental Science, Dr. YS Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh, India

²Research Scholar, Department of Environmental Science, Dr. YS Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh, India

³Professor & Head, Department of Environmental Science, Dr. YS Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh, India

⁴Research Associate, Department of Environmental Science, Dr. YS Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh, India

Received Date: March 28, 2026

Acceptance Date: April 03, 2026

Published Date: April 07, 2026

Citation: Mohan Singh Jangra, Priyanka Jattan, S.K. Bhardwaj, Purnima Mehta. On the Link of Global Warming and Cloudiness in Mid Hills of Himachal Himalayas, India. International Journal of Climate Conditions. 2025; 2(2): 39–49p.

INTRODUCTION

The cloud is one of the most obvious, influential features also the most variable components of Earth's climate system. Clouds cover more than two-thirds of Earth at any given moment and play a crucial role in the warming and cooling of the planet [1–13]. They substantially affect Earth's energy budget by affecting both radiation fluxes and latent heat fluxes (Randall *et al.* [14]1984; Pokrovsky,[13] 2019). How clouds will perform in a warmed world has some modelers saying they will help cool the planet, while the majority say clouds will further warm it. As the planet warms, clouds have a cooling effect if there are more low-level clouds or fewer high-level clouds, but more warming if the opposite is true. The presence of clouds sometimes results in an enhancement of global irradiance (Duchon and Malley, [4]1999). In some specific cases, the scattering of radiation from the sides of the cloud may enhance global

irradiance to levels higher than those in a clear sky (Mims and Frederick,[10] 1994; Feister *et al.*, [6]2015). Mims and Frederick[10] (1994) determined that the scattering from the sides of clouds can enhance the total UV-B solar irradiance by 20% or more. Similarly, Feister et al.[6] (2015) concluded that the scattering of solar radiation by clouds can enhance UV irradiance at the surface [15, 16].

There is a large amount of evidence that net feedback is positive and will amplify global warming. Norris [12] (2000) recommended studying surface-observed clouds in terms of interannual variations or on small scales rather than looking for multidecadal trends on zonal or global scales. A similar analysis was performed using data from weather stations on land (Warren *et al.*[17] 2007). The present study investigated the monthly, seasonal, and annual cloud cover variability trends over two stations in the mid hills of the Himachal Himalayas using simple Pearson's correlation coefficient, Mann-Kendall (MK), and Sen's slope estimator tests and their relations with other climatic parameters using the surface manually observed daily cloud cover data.

MATERIALS AND METHODS

Study Area Data Sources

The study area covers the sub-montane sub-humid mid-hills sub-tropical zone (Solan) and the high-hills wet temperate zone (Kullu) of the state of Himachal Pradesh, which lies on the southern slope of the Himalayan Range. The mid-hill zone ranges from 651 m to 1800 m above sea level and has a mild temperate climate with an annual rainfall of 1156.3 mm and temperatures ranging from -2 to 37°C, whereas the high hills wet temperate zone ranges from 1801 to 2200 m above sea level and has a humid temperate climate and alpine pastures with an annual rainfall of 1016.5 mm and temperatures ranging from -4 to 36°C.

Cloud cover (also known as cloudiness, cloudage, cloud amount, or cloud coverage) refers to the fraction of the sky obscured by clouds on average when observed from a specific location. Okta is the usual unit for measuring cloud cover, but the %age method is also common). Cloud feedback is the effect of changes in the surface air temperature on clouds and vice versa. Daily data on cloud cover, sunshine hours, maximum and minimum temperature, morning and evening relative humidity, evaporation, and rainfall were collected for 21 years (2001–2021) from the agrometeorological observatory situated at each station (Table 1).

Data Analysis

Basic statistics related to cloud cover, such as mean, standard deviation (σ), coefficient of variation, slope, deterministic coefficient (R^2), and correlations, were computed for months and seasons viz., viz., pre-monsoon (March–May), Monsoon (June–September), Post monsoon (October–November), and winter (December–February), and on an annual basis. A linear regression model and Pearson's correlation coefficient (r) between cloud cover and other climatic parameters were also determined. Non parametric Mann-Kendall (MK) test was also performed with Sen's slope estimation method.

Mann-Kendall Trend Test

non-parametric statistics are usually much less affected by the presence of outliers and other forms of non-normality since they depend on the positive or negative sign (Asfawet *al.*, [1]2017) and represent a measure of monotonic linear dependence. The most frequently used non-parametric test for identifying trends in climatic variables is the Mann-Kendall (MK) test (Buffoniet *al.*,[2] 1999; Jain and Kumar, [7]2012; Mondal *et al.*,[11] 2012). The World Meteorological Organization recommended this test to detect trends in climatic data.

Table 1. Agrometeorological station information.

Station	Data period	Altitude	Latitude	Longitude	Area (km ²)	Rainfall (mm)	Temp (°C)
Solan	2001–2021	1275	30.8°N	77.1°E	1936	1156.3	-2 to 37
Kullu	2001–2021	1350	31.9°N	77.1°E	5503	1016.5	-4 to 36

The statistics S is calculated as:

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i)$$

where x_j and x_i are annual values in years j and i , $j > i$, respectively; n is the number of data points; and $\text{sign}(x_j - x_i)$ is calculated as

$$\text{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases}$$

If the number of data values is 10 or more, the S-statistics approximately behave as normally distributed, and the test is performed with normal distribution with the mean and variation as follows:

$$E(s) = 0$$

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^n t_i(t_i-1)(2t_i+5)}{18}$$

where n is the number of tied (zero difference between compared values) groups and t_i is the number of data points in the i^{th} tied group. The standard normal distribution (Z-statistics) is computed using the following equation:

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

A positive value of Z shows an upward (increasing) trend, while a negative value indicates a downward (decreasing) trend.

Sen's Slope Estimator Test

The statistical significance trend detected by the MK test can be complemented with Sen's slope estimation to determine the magnitude of the trend (Duhan and Pandey [5]2013; Jhajharia *et al.* [9] 2012). The slope T_i is calculated as

$$T_i = \frac{x_j - x_k}{j - k} \text{ For } i=1, 2, 3 \dots n$$

Where, x_j and x_k are data values at time j and k ($j > k$) separately. The median of these n values of T_i represented by Sen's slope estimation which is estimated by using the following equation

$$Q_i = \begin{cases} T \frac{n+1}{2} & \text{for } n \text{ is odd} \\ \frac{1}{2} \left(T \frac{n}{2} + T \frac{n+2}{2} \right) & \text{for } n \text{ is even} \end{cases}$$

A positive value of Q_i indicates an 'upward trend, whereas a negative value of Q_i indicates a downward trend (Xu *et al.*, [18] 2010).

RESULTS AND DISCUSSION

Monthly Cloud Cover Analysis

The cloud cover in the morning (6.04 Okta) and evening (6.14 Okta) was highest in July at Solan, whereas the cloud cover in the morning (5.38 Okta) and evening (4.79 Okta) was highest in August at station Kullu. In October, they were at their lowest in both locations, ranging from 1.35–1.58 Okta in Solan and 1.41–2.43 Okta in Kullu. The mean monthly cloud cover was observed to be somewhat higher at Kullu (3.34 Okta) than at Solan (3.31 Okta).

Table 2. Descriptive statistics of monthly morning and evening cloud cover at Solan and Kullu.

Months	Morning (0830 hrs)					Evening (1430 hrs)				
	Mean (Okta)	Sd (σ)	CV (%)	Slope (rate)	R ²	Mean (Okta)	Sd (σ)	CV (%)	Slope (rate)	R ²
<i>Nauni (Solan)</i>										
Jan	3.17	1.44	45.3	-0.031	0.020	3.41	1.19	34.80	-0.017	0.008
Feb	3.22	1.22	37.8	-0.024	0.016	3.52	1.08	30.66	-0.032	0.039
Mar	2.27	0.79	34.8	0.004	0.001	3.29	0.92	28.02	-0.006	0.002
Apl	2.07	0.68	33.0	0.030	0.084	3.01	0.90	29.79	0.023	0.029
May	2.11	0.72	33.9	0.041	0.140	3.23	0.72	22.20	0.021	0.039
Jun	3.56	1.17	33.0	-0.026	0.021	4.42	0.80	18.15	0.019	0.025
Jul	6.04	0.62	10.3	-0.015	0.027	6.14	0.88	14.33	-0.027	0.041
Aug	5.83	0.75	12.9	0.021	0.033	6.04	0.66	10.96	0.037	0.132
Sep	3.70	1.09	29.5	0.032	0.036	4.37	1.17	26.81	0.063	0.122
Oct	1.35	1.02	75.8	0.021	0.017	1.77	1.01	56.79	0.039	0.065
Nov	1.45	0.82	56.2	-0.009	0.005	1.68	0.93	55.25	0.006	0.002
Dec	1.80	0.68	37.6	0.000	0.000	1.86	0.58	31.29	-0.0001	0.0001
Annual	3.05	0.22	7.35	0.003	0.011	3.56	0.27	7.52	0.01	0.066
<i>Seobag (Kullu)</i>										
Jan	2.97	1.17	39.3	0.023	0.015	3.64	1.16	31.8	0.035	0.036
Feb	3.33	1.11	33.4	0.025	0.020	4.07	1.21	29.6	0.009	0.002
Mar	2.71	0.85	31.3	0.055	0.163	4.06	1.02	25.1	0.063	0.148
Apl	2.84	1.50	52.8	0.052	0.047	4.08	0.78	19.2	0.016	0.016
May	2.01	0.76	37.9	0.071	0.339	4.11	0.96	23.3	0.009	0.003
Jun	2.97	1.07	36.1	0.022	0.016	4.27	0.61	14.3	0.029	0.087
Jul	4.95	0.66	13.4	0.018	0.029	4.69	0.64	13.7	0.008	0.006
Aug	5.38	0.89	16.5	-0.033	0.054	4.79	0.67	14.0	-0.024	0.051
Sep	3.30	0.82	24.9	0.026	0.040	3.77	0.66	17.5	-0.018	0.029
Oct	1.39	0.93	67.0	0.072	0.235	2.43	0.69	28.5	0.009	0.007
Nov	1.51	0.91	60.1	0.071	0.239	2.08	1.05	50.5	0.072	0.184
Dec	2.21	0.71	32.3	0.005	0.002	2.53	0.87	34.3	-0.022	0.025
Annual	2.96	0.39	13.1	0.034	0.300	3.71	0.37	9.9	0.015	0.070

The morning cloud cover at Nauni (Solan) deviated the most in January (= 1.44), February (= 1.22), and June (= 1.17), and the least in July (= 0.62), April, and December (= 0.68). They were most variable in October (CV = 75.8 %), followed by November (CV = 56.2 %) and January (CV = 45.3 %), and the least variable in July (CV = 10.3 %), followed by August (CV = 12.9%) and September (CV = 29.5%). Of the twelve months, six months, that is, March, April, May, August, September, and October, observed a positive slope, whereas the rest of the five months observed a negative slope, and no trend was observed in December. The deterministic coefficient (R²) was not significant for any of the months (Table 2). The descriptive statistics of evening cloud cover at Nauni showed the highest SD again for January (1.19), followed by September (1.17), and February (1.08). The CV was at par with morning trends. The slope was positive for seven months (April, May, June, August, September, October, and November) and negative for the remainder of the year. Again, the deterministic coefficient (R²) was non-significant for all months (Table 2).

Morning cloud cover at Seobag (Kullu) was most deviated in April (=1.50), January (=1.17), and February (=1.11), and most variable in October (CV =67%), followed by November (CV =60.1%). The slope was calculated as positive for all the months except August, which showed a decreasing trend. The R² was non-significant for all the months (Table 2). For the evening cloud cover at Seobag,

the SD was found to be highest for the month of February (1.21), followed by January (1.16) and November (1.05). The CV was highest in November (50.5%), followed by December (34.3%) and January (31.8%). The slope was negative for August, September and December and positive for all the remaining months with non-significant R^2 values (Table 2). The amount of clouds in the morning and evening was found to be highest in the month of July at Solan, and highest in the month of August at Kullu. The lowest amount of morning and evening cloud cover was found in November at both the stations. Rokonzaman and Rahman [15] (2017) also observed maximum cloud coverage in the month of July for all the weather stations in Bangladesh. They also stated that cloud coverage statistically differs from month to month and station to station.

Seasonal Cloud Cover Analysis

The analysis of morning and evening cloud cover was carried out for four seasons (Summer/Pre monsoon, Monsoon, Post monsoon, and Winter) at both stations for the period of 22 years (2000–2021). For morning cloud cover at Solan, the SD was observed to be highest during the winter season (0.73), followed by the post-monsoon (0.55) and the lowest during the summer season (0.46). The CV was highest in the post monsoon (39.3%) and the lowest in the SWM (11.0%). All the seasons observed positive slopes except the winter season, during which it was negative. The deterministic coefficient (R^2) was non-significant for all the four seasons (Table 3). The SD for evening cloud cover was found to be highest during the post-monsoon season (0.65), followed by summer (0.56), and winter (0.54). The CV was highest during the post monsoon season (36.9%), followed by winter (18.3%), summer (18.0%) and SWM (9.0%). The slope was positive for all the seasons except winter, in which it was negative, showing a decreasing trend. The deterministic coefficient (R^2) was non-significant for all the four seasons (Table 3).

At Seobag (Kullu), the analysis of cloud cover in the morning showed the highest SD for the post monsoon season (0.81), followed by summer (0.70), winter (0.59), and SWM (0.57). They were highly variable during the post monsoon season (CV = 55.6%), followed by summer (27.9%), winter (20.9%), and SWM (13.6%). All seasons observed a non-significant increasing trend, with a higher rate during the post-monsoon season. For the evening time cloud cover, the standard deviation was highest during the post monsoon season (0.69), followed by summer (0.61), winter (0.60), and SWM (0.43). They were most variable during the post monsoon season, with a CV of 30.7%, followed by winter, summer, and the SWM seasons. All seasons observed a positive slope, except the SWM season, in which it was negative, but the entire trend was non-significant (Table 3).

Table 3. Seasonal morning and evening cloud cover statistics at Nauni and Kullu

Seasons	Morning (0830 hrs)					Evening (1430 hrs)				
	Mean (Okta)	Sd (σ)	CV (%)	Slope (rate)	R^2	Mean (Okta)	Sd (σ)	CV (%)	Slope (rate)	R^2
<i>Nauni (Solan)</i>										
Summer	2.14	0.46	21.7	0.027	0.147	3.13	0.56	18.0	0.019	0.051
SWM	4.78	0.52	11.0	0.003	0.001	5.25	0.47	9.0	0.022	0.093
Post-M	1.40	0.55	39.3	0.005	0.004	1.73	0.64	36.9	0.023	0.055
Winter	2.74	0.73	26.7	-0.019	0.031	2.94	0.54	18.3	-0.018	0.049
Annual	2.77	0.22	7.4	0.003	0.011	3.26	0.27	7.5	0.010	0.066
<i>Seobag (Kullu)</i>										
SWM	2.52	0.70	27.9	0.059	0.277	4.08	0.61	14.8	0.029	0.092
Summer	4.15	0.57	13.6	0.008	0.008	4.38	0.43	9.8	-0.001	0.000
Winter	1.45	0.81	55.6	0.072	0.308	2.26	0.69	30.7	0.041	0.136
Post-M	2.83	0.59	20.9	0.018	0.036	3.41	0.60	17.6	0.007	0.006
Annual	2.74	0.39	13.1	0.034	0.300	3.53	0.37	9.9	0.015	0.070

Annual Cloud Cover Analysis

On an annual basis at Nauni (Solan), morning cloud cover showed more consistency than evening cloud cover, as indicated by the lower values of SD and CV. Unlike Solan, the evening cloud cover at Kullu was more consistent than in the morning, as indicated by the higher SD and CV values. A higher positive slope was observed in the morning (0.034) than in the evening (0.015), with a higher deterministic coefficient (Table 3).

The annual average of cloud cover for the period (2000-2021) at Solan was 3.31 Okta, with the highest of 3.78 Okta in 2019, followed by 3.68 Okta in 2005, and the lowest in 2010 (2.89 Okta), followed by 2018 (2.99 Okta), with SD and CV values of 0.223 and 6.75%, respectively (Figure 1). Similarly, the annual average at Kullu was 3.37 Okta, with the highest during 2019 (4.17 Okta), followed by 2017 (4.15 Okta), and the lowest during 2010 (2.92 Okta), followed by 2018 (2.99 Okta), with standard deviation and coefficient of variation of 0.357 and 10.7%, respectively. Both stations observed a positive increasing trend, which was increasing at a non-significant rate of 0.007 Okta/year at Solan and 0.025 Okta/year at Kullu (Figure 1).

Monthly Trends in Cloud Cover

The variation in cloud cover on a monthly basis was calculated individually for each month using the Mann-Kendall test method, and the magnitude of the slope was calculated using Sen’s slope estimator. There was a significant change in the monthly cloud cover data at both stations; some months showed an increasing (upward) trend, while others showed decreasing (downward) trends (Figure 2 and 3).

At Solan, six months (January, February, March, June, July, and November) showed a decreasing trend (-Z), and the remaining months showed an increasing trend (+ Z). In Kullu, all months showed an increasing trend (+Z), except August. At Solan, the highest magnitude (Q) of a decreasing trend (-0.042 Okta/year) was found in July, and the highest increasing magnitude (0.069 Okta/year) was found in September (Figure 4). At Kullu, the highest magnitude of a decreasing trend (-0.037 Okta/year) was found in August and the highest magnitude of an increasing trend (0.070 Okta/year) in November for the study period. It was lower for Solan than for the Kullu trend line (Figure 3).

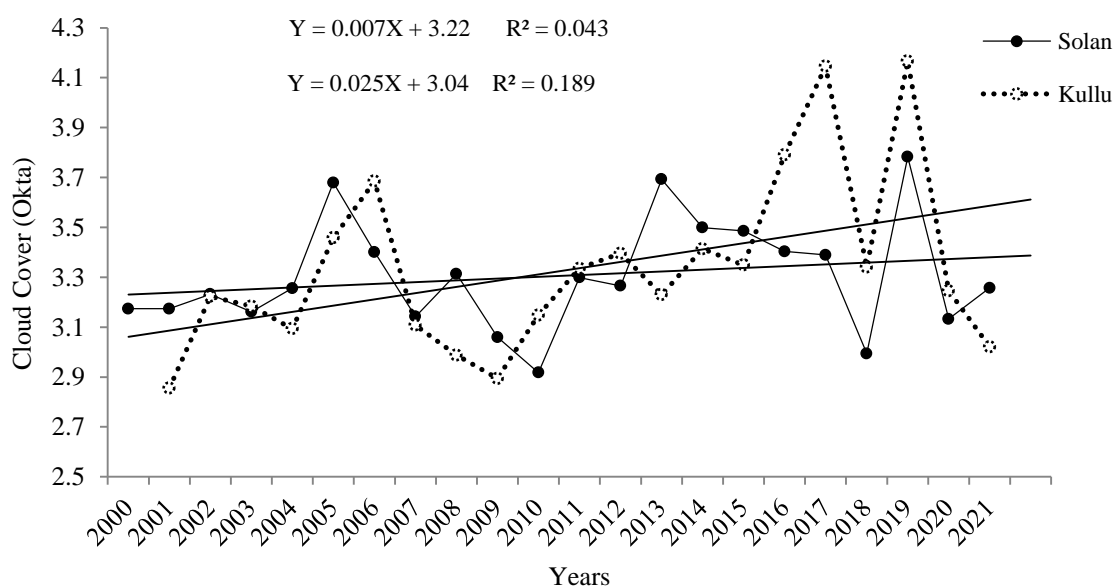


Figure 1. Variation of annual cloud covers at Solan and Kullu.

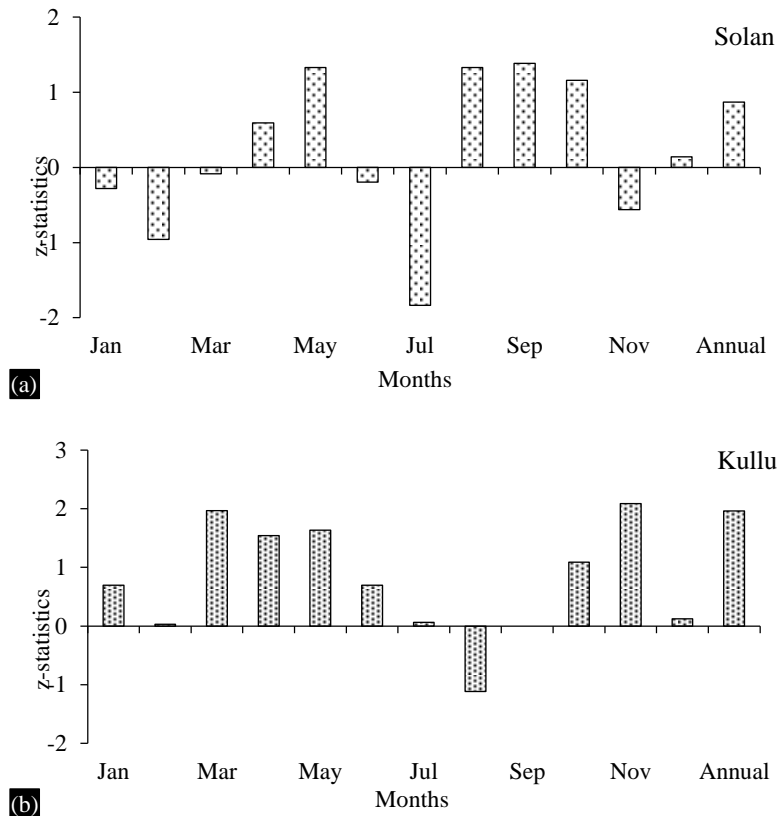


Figure 2. (a, b) The Mann-Kendall Z- statistics for monthly trends for Solan and Kullu.

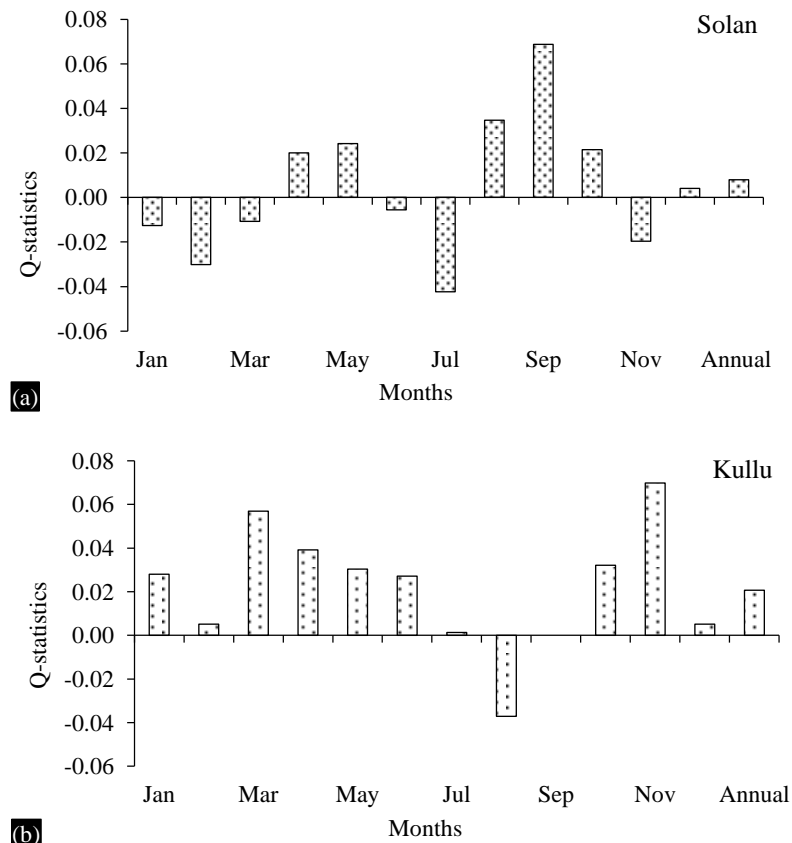


Figure 3. (a, b) The magnitude of trend using Q- statistics for both the stations.

Table 4. Descriptive statistics of seasonal pooled cloud cover.

Seasons	Mean (Okta)	Sd (σ)	CV (%)	Z (Value)	Q (value)
<i>Nauni (Solan)</i>					
Summer	2.66	0.46	17.2	1.44 ⁺	0.01
SWM	5.01	0.46	9.1	1.10 ⁺	0.02
Post-M	1.57	0.58	36.9	0.42	0.01
Winter	2.83	0.62	21.8	-0.59	-0.02
Annual	2.83	0.62	21.8	0.59	0.01
<i>Seobag (Kullu)</i>					
Summer	2.52	0.70	27.9	0.059	0.28
SWM	4.15	0.57	13.6	0.008	0.01
Post-M	1.45	0.81	55.6	0.072	0.31
Winter	2.83	0.59	20.9	0.018	0.04
Annual	2.74	0.39	13.1	0.034	0.30
<i>Pooled (Solan+Kullu)</i>					
Summer	2.99	0.45	14.9	1.78 ⁺	0.03
SWM	4.64	0.44	9.5	0.33	0.01
Post-M	1.71	0.57	33.1	1.42 ⁺	0.03
Winter	2.97	0.56	18.8	-0.03	-0.01
Annual	3.08	0.28	9.2	1.66 ⁺	0.03

Seasonal and Annual Trends in Cloud Cover

For Solan, the highest cloudiness was observed during the SWM season (5.01 Okta), followed by winter (2.83 Okta), summer (2.66 Okta) and post monsoon (1.57 Okta). The SD was highest during winter (0.62) and at par in the remaining three seasons. The CV was highest in the post monsoon season (36.69%) and lowest in SWM (9.1%). For Kullu, the highest was during SWM (4.26 Okta), followed by summer (3.30 Okta), winter (3.12 okta) and post monsoon (1.85 okta), with a somewhat higher amount in Solan in each season. Here the highest SD was observed during the post monsoon (0.71) with a CV of 38.4%. All the remaining seasons showed par values (Table 4). The pooled data also showed the same trend with the highest during SWM (4.64 Okta), followed by summer (2.99 Okta), winter (2.97 Okta) and post monsoon (1.71 Okta). The annual cloud cover was found higher at Kullu (3.12 okta) with lower SD (0.58) and CV (18.6%) compared to Solan (2.83 okta) with somewhat higher SD (0.62) and CV (21.8%) values (Table 4).

The MK curve of cloud cover at Solan revealed a significant increasing trend in summer ($Z = 1.44$) and SWM ($Z = 1.10$), a non-significant increasing trend in post monsoon ($Z = 0.42$), and a decreasing trend in winter ($Z = -0.59$), with a negative magnitude. the overall trend in cloudiness was increasing ($Z = 0.59$). At Kullu, the trend was significantly increasing during summer ($Z = 1.3$) and post monsoon season ($Z = 1.6$) and had a non-significant decreasing trend during SWM ($Z = -0.63$) and winter season ($Z = -0.15$). Here, the overall trend was significantly increasing ($Z = 1.3$). The magnitude of the trend was positive for all the seasons except SWM ($Q = -0.01$). The trend in pooled data from both stations was significant increasing during summer ($Z = 1.78$) and post-monsoon ($Z = 1.42$), non-significant increasing during SWM ($Z = 0.33$), and non-significant decreasing during winter season ($Z = -0.03$), but the overall trend in cloudiness over the study area was significant increasing ($Z = 1.66$) with an upward ($Q = 0.015$) magnitude (Table 4). The effect of the clouds on the "earth's radiative budget" and temperature depends upon their types. Among the three types of clouds low-level clouds have a cooling effect due to higher albedo, whereas high-level clouds trap outgoing long-wave radiation, contributing to the warming of the earth's surface, as concluded by Zelinka and Hartmann [19] (2010). Norris [12] (2000) concluded that cloudiness since 1952 has had a net cooling effect on the earth. The results were similar to the finding of Jaswal [8] (2017), who

analyzed the seasonal variability in total cloud cover in India for the period of 1951–2010 and concluded that total cloud cover for the winter season showed a decreasing trend over the western Himalayas, whereas a significant increasing trend was found in the range of +4% to +6% per decade in the monsoon season. Tan *et al.* [16] (2015) also found that trends in tropical precipitation can be linked to changes in the frequency of cloud systems.

Cloud Cover Versus Sunshine Hours

A direct inverse relationship was observed between cloud cover and sunshine hours at both stations. The bright sunshine decreased at the rate of 2.82 h per increase of 0.2 Okta at Solan and at a lower rate of 1.05 h per 0.2 Okta increase in cloudiness in Kullu. A total of 74% and 77% of the variation in sunshine hours was explained by cloud cover at Solan and Kullu, respectively (Figure 4).

This relationship was stronger with evening cloudiness ($r = -0.80$) than with morning cloudiness ($r = -0.77$) at Solan, but the reverse was observed at Kullu, where the morning relationship was stronger ($r = -0.64$) than the evening one ($r = -0.59$). Sunshine showed a negative correlation with daily cloud cover at Solan ($r = -0.87$) and Kullu ($r = -0.65$), as shown in Table 5. Rokonuzzaman and Rahman [15] (2017) also concluded that cloud coverage negatively affects bright sunshine.

Cloud Cover Versus Other Weather Parameters

The Pearson correlation coefficient was analyzed between cloud coverage and different weather variables, as depicted in Table 5. The morning, evening, and mean maximum temperatures at Solan and the evening and mean maximum temperatures at Kullu showed a negative significant correlation with cloud cover but a positive non-significant correlation with the morning maximum temperature. (Table 5)

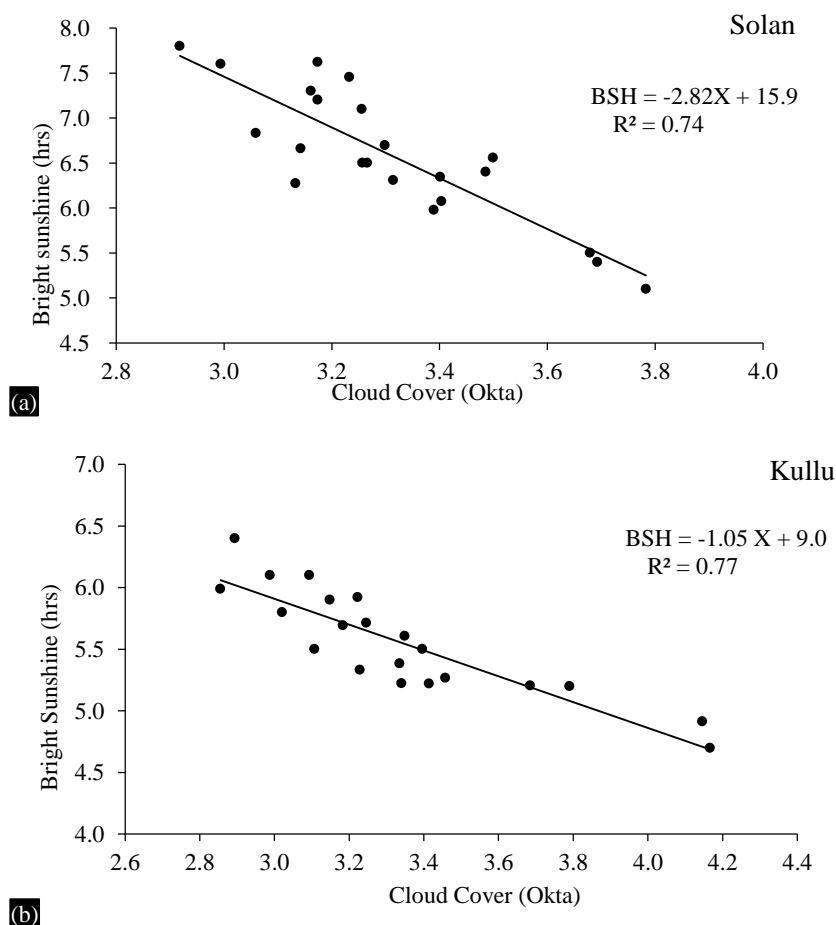


Figure 4. (a, b) Variation of bright sunshine hours with cloud cover

Table 5. Pearson correlation coefficient (r) between cloud cover and weather parameters.

Parameters	Solan			Kullu		
	Morning (Okta)	Evening (Okta)	Mean (Okta)	Morning (Okta)	Evening (Okta)	Mean (Okta)
Bright Sunshine (hrs)	-0.77*	-0.80*	-0.87*	-0.64*	-0.59*	-.65*
Maximum temperature (°C)	-0.34*	-0.41*	-0.42*	0.01	-0.07	-0.03
Minimum temperature (°C)	0.08	-0.06	0.01	0.42*	0.39	0.43*
Mean temperature (°C)	-0.22	-0.34*	-0.32	0.24	0.18	0.22
Morning relative humidity (%)	0.18	-0.03	0.07	0.63*	0.37*	0.54*
Evening relative humidity (%)	0.49*	0.07	0.29	0.58*	0.35*	0.49*
Mean relative humidity (%)	0.37*	0.01	0.19	0.64*	0.39*	0.54*
Evaporation (mm)	-0.14	-0.38	-0.29	-0.44*	-0.08	-0.28
Rainfall (mm)	-0.24	-0.29	-0.30	0.19	0.01	0.11

(* Significant at 5% level of significance)

The morning, evening, and mean minimum temperatures showed a positive correlation with cloud coverage at both stations, except for the evening minimum temperature of Solan, which showed a negative correlation. The mean temperature correlated negatively with the amount of clouds at Solan and positively with the amount of clouds at Kullu for all three periods. The results are similar to the findings of Jaswal [8] (2017), who concluded that cloud cover has a strong negative correlation with maximum and diurnal temperature range. Dia *et al.* [3] (1997) also explained the strong correlation between the observed decreases in India's average total cloud cover and an increase in the diurnal temperature range.

All the three periods (morning, evening, and mean) of relative humidity showed a positive correlation with morning, evening, and mean cloud cover at both the stations, except for the morning relative humidity with evening cloudiness, which showed a non-significant negative correlation at Solan. Evaporation was showing a negative correlation with morning, evening and mean cloud cover at both the stations as the Pearson correlation coefficient (r) varied from -0.08 to -0.44. This correlation was significant at the 5% level of significance with evening time cloud cover at Solan and morning time at Kullu. The negative correlation at Solan indicated that non-rainfall-bearing clouds were increasing in the lower altitude of the study area, as shown in Table 5. The rainfall displays a positive correlation with cloud coverage at Kullu and is insignificant. Rokonzaman and Rahman [15] (2017) also analyze the effect of cloud coverage on different weather variables with a random effect model. They found that humidity and rainfall have a significant positive impact on cloud coverage, but sunshine and temperature have a negative impact on the amount of cloud cover.

CONCLUSION

The study was done to analyze the monthly, seasonal, and annual trends of clouds and the relationship of different variables with cloud coverage at both the stations. The amount of clouds in the morning and evening was found to be highest in the month of July at Solan, and highest in the month of August at Kullu. The lowest amount of morning and evening cloud cover was found in November at both the stations. The percentage of clouds was statistically different from month to month and station to station. The level of clouds was observed to be somewhat higher at Kullu. On an annual basis, the cloud coverage showed an increasing trend in both the stations. On a monthly basis, six months (January, February, March, June, July, and November) were showing a decreasing trend and the remaining months an increasing trend at Solan. In Kullu, all the months showed an increasing trend except August. All the seasons observed an increasing trend except winter in Solan and monsoon season in Kullu, which showed a decreasing trend. Overall, on a seasonal basis, only the winter season showed a decreasing trend. Different weather variables have a strong relationship with cloud coverage. Relative humidity and minimum temperature were positively correlated with cloud

coverage, whereas evaporation, bright sunshine hours and maximum temperature were negatively correlated with cloud cover.

REFERENCES

1. Asfaw A, Simane B, Hassen A, Bantider A. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and climate extremes*. 2018 Mar 1;19:29-41. <https://doi.org/10.1016/j.wace.2017.12.002>
2. Buffoni L, Maugeri M, Nanni T. Precipitation in Italy from 1833 to 1996. *Theoretical and Applied Climatology*. 1999 Jun;63(1):33-40.
3. Dai, A., Genio, A. D., and Fung, I. Y., Clouds, precipitation and temperature range. *Nature.*, 1997, 386: 665–666.
4. Duchon CE, O'Malley MS. Estimating cloud type from pyranometer observations. *Journal of Applied Meteorology*. 1999 Jan;38(1):132-41.
5. Duhan D, Pandey A. Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. *Atmospheric Research*. 2013 Mar 1;122(1):136-49.
6. Feister U, Cabrol N, Häder D. UV irradiance enhancements by scattering of solar radiation from clouds. *Atmosphere*. 2015 Aug 18;6(8):1211-1228.
7. Jain SK, Kumar V. Trend analysis of rainfall and temperature data for India. *Current science*. 2012 Jan 10;102(1):37-49.
8. Jaswal AK. Variability and changes in cloud cover over India during 1951–2010. In *Observed Climate Variability and Change over the Indian Region 2016* Nov 4 (pp. 107-127). Singapore: Springer Singapore. DOI 10.1007/978-981-10-2531-0_7.
9. Jhajharia D, Dinpashoh Y, Kahya E, Singh VP, Fakheri-Fard A. Trends in reference evapotranspiration in the humid region of northeast India. *Hydrological Processes*. 2012 Jan 30;26(3):421-435.
10. Mims III FM. Cumulus clouds and UV-B. *Nature*. 1994 Sep;371(6495):291-291
11. Mondal A, Kundu S, Mukhopadhyay A. Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. *International Journal of Geology, Earth and Environmental Sciences*. 2012 Jan;2(1):70-78.
12. Norris JR. What can cloud observations tell us about climate variability?. *Space Science Reviews*. 2000 Nov;94(1):375-80.
13. Pokrovsky OM. Cloud changes in the period of global warming: The results of the international satellite project. *Izvestiya, Atmospheric and Oceanic Physics*. 2019 Dec;55(9):1189-97.
14. Randall DA, Coakley JA, Fairall CW, Kropfli RA, Lenschow DH. Outlook for research on subtropical marine stratiform clouds. *Bulletin of the American Meteorological Society*. 1984 Dec 1;65(12):1290-301.
15. Rokonzaman MD, Rahman MM. Effect of Cloud Coverage on Sunshine, Humidity, Rainfall and Temperature for Different Weather Stations in Bangladesh: A Panel Analysis. *IOSR Journal of Environmental Science, Toxicology and Food Technology*. 2017;11(03):01-6.
16. Tan J, Jakob C, Rossow WB, Tselioudis G. Increases in tropical rainfall driven by changes in frequency of organized deep convection. *Nature*. 2015 Mar 26;519(7544):451-4.
17. Warren SG, Eastman RM, Hahn CJ. A survey of changes in cloud cover and cloud types over land from surface observations, 1971–96. *Journal of climate*. 2007 Feb 15;20(4):717-38.
18. Xu Z, Liu Z, Fu G, Chen Y. Trends of major hydroclimatic variables in the Tarim River basin during the past 50 years. *Journal of arid Environments*. 2010 Feb 1;74(2):256-67.
19. Zelinka MD, Hartmann DL. Why is longwave cloud feedback positive?. *Journal of Geophysical Research: Atmospheres*. 2010 Aug 27;115(D16):1-46 DOI:10.1029/2010JD013817