Changes in Sunshine Duration in Humid Environments of Agartala (Tripura), India

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Abstract Study of changes in the global solar radiation is one of the key factors in sustainable agricultural production and management. Therefore, we investigated trends in the solar radiation using sunshine duration as a suitable alternative, based on the recommendation of the FAO Irrigation and Drainage—Paper No. 56, by using the Mann-Kendall (MK) test at different time scales in the humid environments of Northeast India. The average annual bright sunshine hours over Agartala is found to be 6.6 hours (h) with a standard deviation of 0.4 h and coefficient of variation of 6.4%. On annual (seasonal) time scale, statistically significant decreasing trends in bright sunshine duration through the MK test were observed at 5% level of significance at the rate of 0.245 h/decade (0.545 and 0.118 h/decade in winter and monsoon) over Agartala. Similarly, sunshine decreases were observed in the months of January, February, March, May, September, October, and December in the range of 0.237–0.688 h/decade. The observed decreases in sunshine duration

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modify the evapotranspiration process and affect the crop water requirements, which, in turn, will negatively influence the agricultural production in humid environments of Northeast India.

Keywords Trend · Mann-Kendall · Sunshine duration · Agartala

Introduction

The anthropogenic-induced climate change has increased greatly in last few decades. Magnus et al. (2011) reported that temperature increased by an estimated 0.73 °C during the 43 years period from 1959 to 2002 globally. The decreasing trends in solar radiation are reported from various parts of the world under different environments. The occurrence of a reduction in global irradiance may lead to the global dimming. Global dimming refers to the decrease in the flux of solar radiation reaching the earth's surface both in the direct solar beam and in the diffuse radiation scattered by the sky and clouds (Stanhill and Cohen 2001). If aerosols and solar radiation would have remained at the 1959 level, then the expected global average temperature would have been 1.09 °C higher (Magnus et al. 2011).

Global dimming created a cooling effect that partially masked the effect of greenhouse gasses on global warming. The sunshine hour is the most important influencing parameter of evapotranspiration process (Pandey et al. 2014, 2016). Also, the global dimming interfered with the hydrological cycle by reducing evaporation, and may have reduced rainfall in some areas. Therefore, solar radiation is one of the most important factors affecting climate. Studying trends in radiation are of much concern in climate change studies and agricultural sustainability assessment. Solar radiation is also responsible for the photosynthesis in plants, which is the main essence in agriculture, and therefore any change in radiation pattern must be analyzed.

The objective of this work is to identify whether there is any sign of solar dimming or brightening over the Northeast India as there is nonavailability of solar radiation measured data not only in this region but around the globe. Usually, the solar radiation is recorded with the help of pyranometers. However, the data of bright sunshine duration are available for a number of sites because of ease in measurements of sunshine duration using the Campbell–Stokes sunshine recorder. Sunshine duration having strong linear relation with global solar radiation could be utilized in place of the solar radiation (Allen et al. 1998). Stanhill (1965) have reported that sunshine duration measurements are the most highly and linearly correlated with the global radiation. In this paper, sunshine duration data were tested for trend identification using the Mann-Kendall (MK) method in monthly, seasonal, and annual time scales in the humid environments of Agartala, Northeast India.

Materials and Methods

Study Area and Meteorological Data

The main ecosystem in the northeastern region of India is a tropical wetland. The Northeast India is the most appropriate region for cultivation of world-class tea, paddy, various forest products, like bamboo, different types of fruit crops, and orchids. The bright sunshine duration data of Agartala needed for this study were obtained from India Meteorological Department (IMD), Pune on a monthly basis from 1969 to 2007. The IMD uses Campbell–Stokes sunshine recorder to measure the bright sunshine hours over different locations in India. The sunshine recorder provides major information on changes in solar irradiance as it automatically records the duration of direct solar beam irradiance above a threshold of 120 W m^{-2} (WMO 1997). The monthly data of 3 years (1993, 1995, and 1997) were missing and were filled with the average values of sunshine of the previous 5 years over Agartala. Figure 1 shows the location of the site in the Tripura state in the northeastern region of India.

Methods of Trend Analysis

Trends in the data can be identified by using parametric or nonparametric methods, and both the methods are widely used. The nonparametric Mann–Kendall (MK) method (Mann 1945; Kendall 1975) is used for identifying the trends in solar

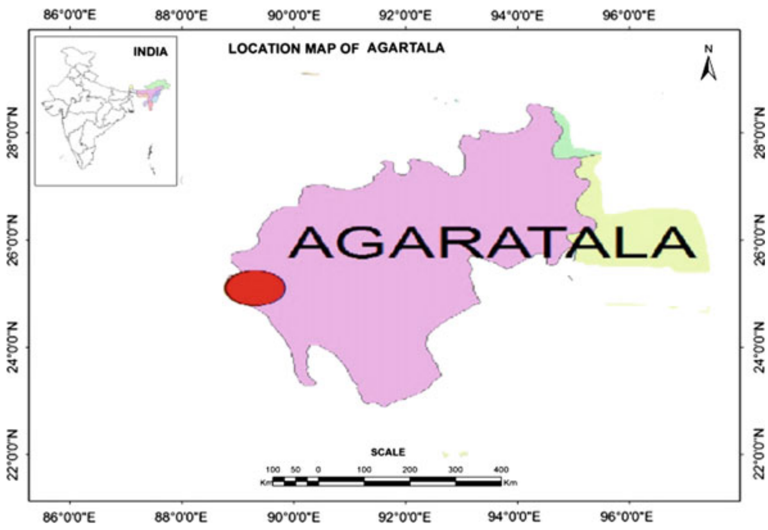

Fig. 1 Location of Agartala site (Tripura), Northeast India

radiation because it is distribution-free and has a higher power than many other commonly used tests (Hess et al. 2001). This method does not require normality of time series and is less sensitive to outliers and missing values. The MK testis based on the test statistic, S, defined as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k), \tag{1}$$

where n is the number of observations, and x_j is the jth observation and sgn($\cdot$) is the sign function. The mean of the S statistic is zero for the data set assumed to be independent and identically distributed. The variance of the S statistic, under the assumption that the data are independent and identically distributed, is given as:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18}, \tag{2}$$

where m is the number of groups of tied ranks, each with t_i tied observations.

The MK statistic, designated by Z, can be computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & S < 0 \end{cases} \tag{3}$$

The values of the Z statistic are calculated and if the value lies within (−) 1.96 and (+) 1.96, i.e., $-Z_{1-\alpha/2} \le Z \le Z_{1-\alpha/2}$, then the null hypothesis of no trend can be accepted at the 5% level of significance using a two-tailed test. Otherwise, the null hypothesis can be rejected, and the alternative hypothesis of trends in the data at the 5% significance be accepted.

The MK test requires that a series should not be serially dependent. The pattern-free prewhitening (TFPW) methodology was connected to remove of serial associations in the time series, on the off chance that they existed, to fit in with this necessity. This was carried out with the “R” software. In this technique, the slope was assessed. In the situation slope close to zero, it is not necessary to carry out pattern examination. In the case that the slope contrasts from zero, it is thought to be linear, then the series is detrended by the slope; the autoregressive model of order 1 is then processed for the detrended series. The residuals should be independent, and afterward, the trend and residuals are mixed. Last, the MK test is connected to the combined series to know the significance of the trend. Finally, MK test was applied to the data, if there existed a trend at the 95% significance level. The magnitude of trends identified in sunshine duration can be obtained by using the linear regression test. The total changes in bright sunshine duration are obtained by multiplying the value of slope with a total length of the sunshine data at Agartala.

Results and Discussion

The monthly data obtained from the IMD Pune were used to compute the seasonal and the annual time series of bright sunshine duration over Agartala, Tripura (NE India). The definition of four different seasons in the NE India given by Jhajharia et al. (2009, 2012), are as follows: winter (January–February), pre-monsoon (March–May); monsoon (June–September) and post-monsoon (October–December). Statistical parameters, such as, mean (in hours, h), standard deviation (h), coefficient of variation (%), and maximum (h) and minimum (h) values of sunshine duration are calculated to describe the characteristics of sunshine, and its variability over Agartala (see Table 1). The average annual bright sunshine duration for the considered period over Agartala is found to be 6.6 h with a standard deviation of 0.4 h and coefficient of variation of 6.4%.

The mean sunshine duration in winter and post-monsoon seasons are determined to be about 7.9 h. However, the bright sunshine hours fell drastically to 5.1 in the monsoon season over Agartala due to the presence of dark (rainy) clouds during the months of June to September. The bright sunshine duration in the winter, pre-monsoon and post-monsoon seasons are comparatively higher (mean the sunshine more than 7.3 h) due to the presence of clear skies at Agartala during these three seasons. The C_V of bright sunshine duration in monsoon (10.2%) is found to be the highest, which shows that the bright sunshine intensity has high variability

Table 1 Statistical properties of sunshine duration (h) over Agartala

Time scale	Mean (h)	Max (h)	Max (h)	S (h)	C_v (%)
January	7.69	9.20	6.10	0.83	10.81
February	8.05	9.10	6.40	0.71	8.82
March	7.70	8.80	6.50	0.70	9.09
April	7.49	9.00	5.90	0.68	9.06
May	6.77	9.30	3.10	1.40	20.67
June	4.26	5.90	2.40	1.06	24.81
July	4.02	5.70	2.00	0.71	17.56
August	5.17	6.80	3.00	0.88	16.93
September	5.19	7.80	3.40	1.12	21.50
October	7.04	8.50	5.10	1.03	14.64
November	7.83	9.00	6.90	0.57	7.33
December	8.00	9.10	6.10	0.74	9.25
Yearly	6.60	7.26	5.64	0.40	6.40
Winter	7.87	8.95	6.55	0.69	8.79
Pre-monsoon	7.32	8.77	6.03	0.63	8.60
Monsoon	5.14	6.34	3.98	0.52	10.19
Post-monsoon	7.91	8.65	6.80	0.47	5.95

Note Max, Min, S and C_v denote maximum, minimum, standard deviation, and coefficient of variation, respectively during the months of June to September over Agartala as compared to the C_V (5.95%) of sunshine in post-monsoon season. Similar characteristics of sunshine duration are observed on the monthly time scale at Agartala. The mean bright sunshine duration is found to be the highest (8.05 h) and second largest (8.0 h) during the months of February and December, respectively over Agartala. However, the months of July and June witnessed the lowest (4.02 h) and the second lowest (4.26 h) values of sunshine duration at Agartala, respectively because of intense rainfall activities and cloudy weather in these 2 months. The highest value of the C_V (24.81%) of sunshine duration is witnessed in the month of June that shows comparatively higher variability in bright sunshine in this month at Agartala.

Table 2 shows the trend results obtained through the MK test in different durations: all 12 months; the four seasons; and the yearly time scale in sunshine duration. The slope of the trend lines are computed using the linear regression test, and the magnitude of the trends (in h/decade) are given in Table 2. Dinpashoh et al. (2011) report that the value of the Z statistic lying within the confidence limits presents a value due to random fluctuations, meaning not much in the inferring existence of a trend from the statistical standpoint. On an annual time scale, the statistically significant trend at the 5% level of significance was witnessed as the absolute of Z statistics (3.81) was more than the tabulated value of 1.96. The decreasing trend in sunshine duration at the rate of 0.245 h/decade was witnessed over Agartala in annual time scale. Figure 2 shows the percent deviation of annual bright sunshine hours from the long-term average annual sunshine over Agartala

Table 2 Changes in sunshine duration at Agartala (Tripura)

Time scale	Test statistics (Z) value	Magnitude of trends (h/decade)
January	−3.720	−0.688
February	−3.504	−0.403
March	−2.289	−0.237
April	*−0.933*	*−0.083*
May	−2.421	−0.36
June	*−0.218*	*−0.003*
July	*0.545*	*0.041*
August	*0.182*	*0.069*
September	−1.683	−0.263
October	−3.196	−0.435
November	−1.214	**−0.206**
December	−2.640	−0.373
Yearly	−3.812	−0.245
Winter	−4.091	−0.545
Pre-monsoon	−3.123	−0.227
Monsoon	−1.986	−0.118
Post-monsoon	−2.809	−0.289

The bold number denote the statistically significant trends at 5% level of significance obtained through the *t*-test

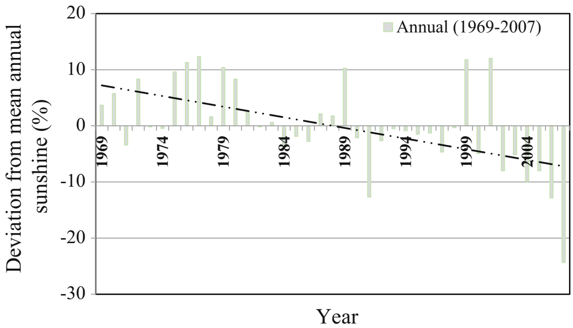

Fig. 2 Deviation of sunshine from average annual sunshine duration (1969–2007)

from 1969–2007. About 65% cases witnessed positive deviation from long-term average values of sunshine during 20 years from 1969 indicating to the phenomenon of brightening happening over the city of Agartala. However, 16 years witnessed negative deviation from long-term average values of sunshine since 1990 at Agartala, which was quite opposite from the recordings of possible sunshine hours before 1990 (see Fig. 2). The decreasing trends witnessed in the sunshine in humid environments of Agartala confirm global dimming since 1984 over the northeastern region of India.

On a seasonal time scale, Agartala witnessed statistically significant decreasing trends in sunshine duration in all the four seasons at 5% level of significance in the range of 0.545 (winter) and 0.118 (monsoon) h/decade. Figures 3a–d show the

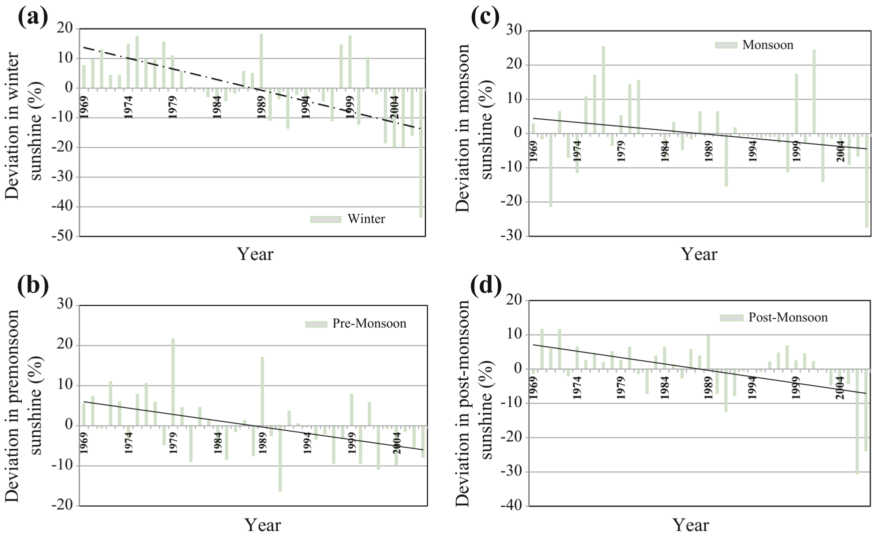

Fig. 3 **a** Deviation of sunshine from average sunshine duration in winter season. **b** Deviation of sunshine from average sunshine duration in pre-monsoon season. **c** Deviation of sunshine from average sunshine duration in monsoon season. **d** Deviation of sunshine from average sunshine duration in post-monsoon season

percent deviation of annual bright sunshine hours from the long-term average sunshine data in four different seasons over Agartala from 1969 to 2007. On a monthly time scale, 7 months (January to March, May, September, October, and December) witnessed statistically significant decreasing trends in the sunshine in the range of 0.69 (January) and 0.237 (March) h/decade. On the other hand, no trends were witnessed in bright sunshine hours in the remaining five months (April, June to August, and November) over Agartala.

Various studies are available in the literature, which reports changes in different meteorological parameters over Agartala in last 30 years or more. These studies confirm the anthropogenic-induced climate change is occurring over humid environments of Agartala. Decreasing trends in annual rainfall were reported at the rate of 2.4 mm/year at Agartala, Tripura (Jhajharia et al. 2007, 2009). The trends in annual rainfall at Agartala were in agreement with the decreasing trends observed in the total cloud amount over Agartala. Decreasing trends in pan evaporation and reference evapotranspiration over different sites of the NE India are also reported in last one decade (Jhajharia et al. 2009, 2012). Significant reduction in pan evaporation and reference evapotranspiration occurred mainly due to stilling (wind speed decreases) and dimming over different parts of Northeast India. Stilling is the process of significant reduction in wind speed at a place in last few years. McVicar et al. (2012) and Jhajharia et al. (2009) reported decreasing trends in wind speed on annual and seasonal time scales over different sites of NE India.

Figure 4a, b depict the relationship between rainfall and sunshine duration in annual time scale and monsoon season. Findings reveal that the total rainfall has increased on both annual and monsoon seasonal time scales at the rate of 30.3 and 63.2 mm/decade, respectively. It is worthwhile to mention that sunshine duration has decreased on both time scales over the site which may be due to the increase in intense cloud formation, i.e., more the cloud formation higher the rainfall amount, hence less sunshine availability over Agartala.

Conclusions

Availability of solar radiation is necessary for agricultural production, because sunlight is essential for photosynthesis and various solar appliances. Any study on changes in solar radiation is important for agriculture and energy sector. The trends in sunshine duration over Agartala are also investigated in annual, monthly, and seasonal (winter, pre-monsoon, monsoon, and post-monsoon) time scales by using the Mann-Kendall's nonparametric test. The average annual bright sunshine duration over Agartala is found to be 6.6 h with a standard deviation of 0.4 h and coefficient of variation of 6.4%. The mean sunshine duration in winter and post-monsoon seasons are about 7.9 h, and 5.1 h in monsoon season. The highest (lowest) mean bright sunshine duration is found to be 8.05 h (4.02 h) in the months of February (July) over Agartala.

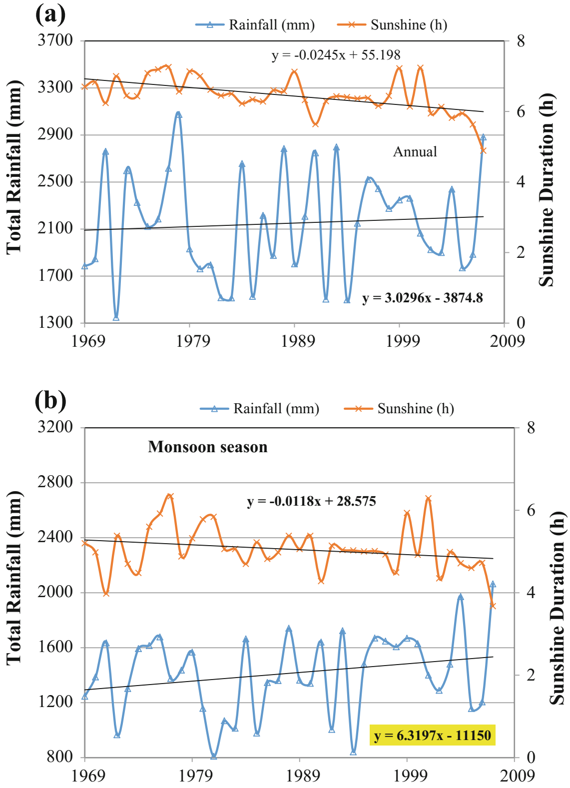

Fig. 4 **a** Annual time series of total rainfall and sunshine duration at Agartala. Note: *Straight line* denotes trend in respective meteorological parameter. **b** Time series of total rainfall and sunshine duration at Agartala in monsoon

Statistically, significant decreasing trends in bright sunshine duration were observed by using the MK test at 5% level of significance at the rate of 0.245 h/decade in annual duration (in the range of 0.545 and 0.118 h/decade in seasonal time scale) over Agartala. On a monthly time scale, Agartala observed sunshine decreases during 7 months in the range of 0.237–0.688 h/decade. Decreasing trends witnessed in sunshine over Agartala support the happening of global dimming over Northeast India in last two decades. Solar brightening phenomenon was observed from 1969 to 1982 over Agartala due to increased bright sunshine duration. However, a solar-dimming phenomenon occurred due to decreased sunshine duration for the remaining period of analysis. Crop water balance and evapotranspiration are closely coupled to solar radiation, and therefore, solar radiation decreases are likely to reduce water use and evapotranspiration.

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