

LONG TERM TREND ANALYSIS OF SURFACE INSOLATION AND EVAPORATION OVER SELECTED CLIMATE TYPES IN INDIA

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ABSTRACT:

The atmospheric radiative forcing is a central theme of climate change impact studies. The presence of Atmospheric Brown Clouds due to increased aerosol concentrations and green house gases such as water vapour, CO₂ alter solar radiation and atmospheric thermal regimes. Both have strong feedbacks on open water evaporation. The measured daily global (direct + diffuse) insolation for a period of more than fifty years (1960-2003) and diffuse insolation for the period of 30 yrs (1973-2003) were analyzed over four stations in India representing different climate types. Weekly pan evaporation of Lysimetric stations was analyzed for the period 1975-1994 to explain inter-relations of insolation and evaporation trends. The annual, pentad (five years' average) and decadal (ten years' average) insolation at all stations showed average solar dimming rate varying between 1.15 to 3.35 % per decade. During 1975 to 1994, a significant increase in annual diffuse insolation was observed at arid station, Jodhpur which could be due to increase in concentration of dust aerosols leading to atmospheric cooling. Both solar dimming and atmospheric cooling triggered a substantial reduction in pan evaporation. But in some stations such as New Delhi, pan evaporation did not decrease in spite of decrease in global radiation. This indicated least role of aerosol but trade-off between increase in air temperature and solar insolation cut by green house gases and clouds, respectively. The study emphasizes the strong need to have detailed investigation about the impact of air quality on surface physical (e.g. lake evaporation) and biophysical (e.g. evapotranspiration) processes at different microclimates of India.

1. INTRODUCTION

Solar radiation is essential to drive directly or indirectly all biological and physical processes on the Earth. Measurements of solar radiation at the surface are important for assessment of climate change and global warming because they can indicate anthropogenic disturbances (Ramanathan et al., 2001). Solar radiation reaching at the earth surface (called surface insolation) depends on atmospheric constituents such as aerosols, water vapour, ozone content and cloudiness (Yamasoe et al., 2006).

A decrease in global (direct + diffuse components) insolation (Liepert, 2002, Stanhill and Cohen, 2001, Wild et al., 2005), has been observed at the Earth surface over the period between 1950-1990, called solar dimming. Such dimming gradually started to transform into brightening in some regions of the world since late 1980s (Wild et al., 2005). The effect of these changes in global insolation and associated changes in diffuse insolation affect photosynthesis. Recent studies have shown that photosynthesis is more efficient under diffuse light conditions (Gu et al., 2003, Baldocchi, 2002, Niyogi et al., 2004, Oliveira et al., 2007, Roderick et al., 2001).

Due to this global dimming other factors were also affected, one of the important parameter is pan evaporation. It also decreased in last 50 yrs (Roderick and Farquhar, 2002). In this paper, we have presented the findings of study of long term trend of global insolation over four selected stations of India representing different

climate types. The effect of radiation trend on pan evaporation was also analyzed using collocated datasets from Lysimetric stations.

2. STUDY REGION AND DATA SETS

Time series of daily measured data on global radiation (GR) and diffuse radiation (DR) at four selected IMD (India Meteorological Department) stations were used to conduct a long-term trend analysis of incident solar radiation at surface. The GR and DR were measured using pyranometer and shaded ring pyranometer, respectively. All data were calibrated to world radiometric references (WRR). The four stations are Jodhpur (26°23'N, 73°08'E), New Delhi (28°37'N, 77°13'E), Nagpur (21°08'N, 79°10'E) and Kolkata (22°36'N, 88°24'E). The climate of Jodhpur is generally hot and arid. Nagpur has tropical wet and dry conditions prevailing for most of the year. New Delhi represents semiarid climate with high variation between summer and winter temperature. Kolkata represents monsoon maritime climate. The data periods for GR were more than fifty years from 1960 to 2003 for Jodhpur and Nagpur, and from 1957 to 2003 for New Delhi and Kolkata. The data period for DR is thirty years 1973-2003. The data from 37 lysimetric stations in India between 1975 to 1994 were also obtained.

These data consist of weekly pan evaporation, bright sunshine hours (BSS), maximum air temperatures (T_{max}), and minimum air temperatures (T_{min}), maximum relative humidity (RH_{max}) and minimum relative humidity (RH_{min}), cumulative rainfall, wind

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speed, and cumulative crop evapotranspiration measured through weighing lysimeters.

The data were recorded in two seasons (*Kharif*: July – October; *Rabi*: November – April) corresponding to crop growth cycles. Out of all these, the collocated radiation and evaporation measurement stations are at Jodhpur (arid continental) and New Delhi (semi-arid continental). Moreover, these two stations gave the maximum length of period of data recording of weekly surface meteorological variables at Lysimetric set-ups. This period of data record overlaps with that of pyranometer based radiation measurements. Therefore, the radiation, evaporation and other supporting data from these two stations were analyzed to correlate trend in solar radiation and evaporation.

3. METHODOLOGY

3.1 Gap Filling of Discrete Time Series Radiation Data

There were irregular gaps in radiation data. In every station, data on number of days were missing. The missing data on a given day are substituted with the long term average on a given day at a given station.

3.2 Statistical Test for Trend Significance

Mann Kendall test was used to test the trend significance. It is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987).

Let x_1, x_2, x_3 represent n data points where x_j represents the data point at time j . Then the Mann-Kendall statistic (S) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad (1)$$

where:

$$\begin{aligned} \text{sign}(x_j - x_k) &= 1 \text{ if } x_j - x_k > 0 \\ &= 0 \text{ if } x_j - x_k = 0 \\ &= -1 \text{ if } x_j - x_k < 0 \end{aligned}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. Then calculated the variance of S , $\text{VAR}(S)$, by the following equation

$$\text{VAR}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum t_p(t_p-1) (2t_p+5)] \quad (2)$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the p th group. Then a Z -statistic was computed as follows:

$$\begin{aligned} Z &= S-1/ [\text{VAR}(S)]^{1/2} \quad \text{if } S > 0 \\ &= 0 \quad \text{if } S=0 \end{aligned}$$

$$= S+1/ [\text{VAR}(S)]^{1/2} \quad \text{if } S < 0$$

The tabulated and calculated Z -statistics were compared at 95% and 90 % ($p=0.05, p=0.1$) level of significance. The trend is said to be decreasing if sample Z is negative and absolute Z is greater than the tabulated value at a given level of significance. The trend is said to be increasing if the sample Z is positive and greater than the level of significance. If the computed Z is less than the level of significance, the trend is not significant.

4. RESULTS AND DISCUSSIONS

4.1 Trend in Global (GR) and Diffuse Radiation (DR)

The annual global and diffuse insulations during two terminal years in the time series showed, in general, decline in GR from 7477 to 5808 MJm^{-2} in Jodhpur, 6673 to 5884 MJm^{-2} in New Delhi, 6851 to 5803 MJm^{-2} in Nagpur and 8034 to 7534 MJm^{-2} in Kolkata. There was an overall increase in DR in all the stations such as: 2675 to 2766 MJm^{-2} in Jodhpur, 2884 to 3027 MJm^{-2} in New Delhi, 2583 to 2835 MJm^{-2} in Nagpur and 2996 to 3030 MJm^{-2} in Kolkata. The decrease in GR was observed to be highest in Jodhpur but the increase in DR was highest in Nagpur. An overall declining trend in GR and increasing trend in DR at all the four climate types were noticed from the time series data of annual insolation. Though the evenness of distribution of annual radiation is less, the five-year averages (called pentad insolation) showed more distinct trends in declining GR and increasing DR. Similar trends become more distinct for decadal averages (Figure 1).

4.2 Assessment of Solar Dimming

Rate of solar dimming per decade was computed as percent deviation of GR and DR in a given decade from mean over 50 years (1960 – 2000) and presented in Table 1. The mean rates of decadal solar dimming were -2.9%, -3.2%, -3.4% and -1.5% in GR and 1.2%, 1.3%, 3.6% and 0.8% in DR at Jodhpur, New Delhi, Nagpur and Kolkata, respectively.

It was noticed that dimming in terms of GR occurred during decades 1960-70 and 1980-90 in arid, semi-arid and wet-dry continental climates. In monsoon-maritime climate GR dimming has occurred in all the three decades except 1970-80. A systematic increase in DR was noticed over all the decades in arid and wet-dry continental climates. But the increase in DR for semi-arid continental climates occurred during 1970-80, 1990-2000 and the increase in DR in monsoon-maritime climate was during 1970-80 and 1980-90. Based on Mann Kendall test results (Table 2), statistically significant ($p=0.05$) declining trend was observed in Nagpur, New Delhi, and Kolkata; however Jodhpur exhibited significant ($p=0.1$) decreasing trend in GR. Further the DR experienced significant increasing trend only at arid (Jodhpur) and wet-dry tropical (Nagpur) climate at $p=0.1$ and $p=0.05$ level of significance, respectively.

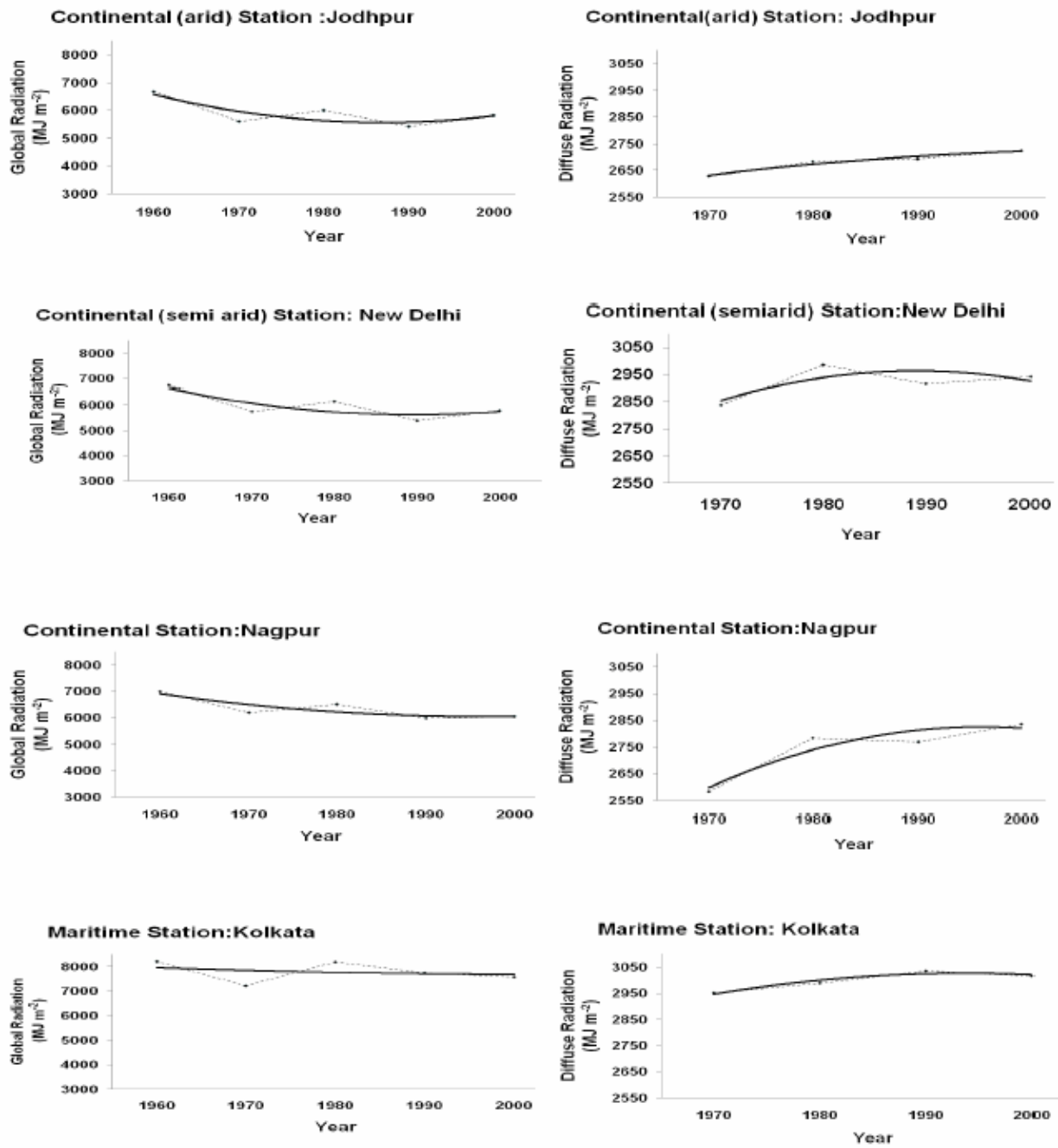


Figure 1. Decadal Trend in Global and Diffuse Radiation

Decadal period	Jodhpur		New Delhi		Nagpur		Kolkata	
	GR	DR	GR	DR	GR	DR	GR	DR
1960-1970	-15.975	--	-14.82	--	-11.47	--	-11.92	--
1970-1980	6.859	2.025	6.741	5.21	4.94	7.786	13.42	1.31
1980-1990	-9.79	0.40	-12.148	-2.284	-8.14	0.584	-5.3	1.53
1990-2000	7.368	1.14	7.312	0.85	1.25	2.44	-2.26	-0.58
Mean	-2.9	1.2	-3.2	1.3	-3.4	3.6	-1.5	0.8

Table 1: Rate of Decadal Solar Dimming as Percent Deviation from Long-Term Averages (1960, 70, 80..... Represents Years from 1960-69, 1970-79, 1980-89.....)

Sl. no.	Stations	Z Calculated		Trend	
		GR	DR	GR	DR
1.	Jodhpur	-1.75	1.69	**Dec.	**Inc.
2.	New Delhi	-4.73	0.74	Dec.	No trend*
3.	Nagpur	-4.78	2.78	Dec.	Inc.
4.	Kolkata	-2.95	1.25	Dec.	No trend*

Table 2: Results of Mann Kendall Test for Insolation Trend

Trend in GR and DR ($p=0.05$, at 5% level of significance) Dec.: Decrease; Inc.: Increase

*Not Significant ($p=0.1$, $p=0.05$), ** Significant ($p=0.1$)

4.3 Effect of Radiation Trend on Pan Evaporation

During 1976 to 1994, there was a significant increase in annual DR (Table 3) from 348 to 433 MJm⁻² at Jodhpur, which could be due to increase in concentration of dust aerosols that could lead to atmospheric cooling as evidenced through decline in mean of maximum and minimum air temperatures from 26.7 °C to 25.0°C and from 11.30°C to 10.20°C, respectively. At New Delhi, annual global insolation decreased (1628 to 1433 MJm⁻²) substantially from 1976 to 1993 with little change in DR. This indicated less role of aerosol but prominent influence of clouds on global insolation as observed from significant decrease in annual total sunshine hours from 130.6 to 102.1 hours. The annual means of maximum and minimum air temperatures were also found to increase from 23.6 to 24.4°C and from 8.3 to 9.4°C, respectively. These could be due to increase in green house gases (GHG). Two important atmospheric radiative forcing variables, cloudiness and aerosols have bearing on GR and DR. But the later alters atmospheric thermal regime through cooling. Therefore, increase in aerosols has double added effects: (1) lowering the GR and (2) cooling the ambient air

Sl. No	Stations	GR (MJm ⁻²)		DR (MJm ⁻²)		BSS (hrs)		Tmax (°C)		Tmin (°C)	
		1976-77	1992-93	1976-77	1993-94	1975-76	1992-93	1975-76	1993-94	1975-76	1993-94
1.	*Jodhpur	1336	1253	348	433	129.2	109.2	26.7	25	11.3	10.2
		1976-77	1992-93	1975-76	1992-93	1976-77	1992-93	1975-76	1990-91	1977-78	1992-93
2.	**New Delhi	1628	1433	635	673	130.6	102.1	23.6	24.4	8.3	9.4

Table 3. Global and diffuse insolation, BSS, T_{max} and T_{min} at New Delhi and Jodhpur (*Standard weeks 48 to 9, ** Standard weeks 51 to 13)

CONCLUSION

The extent of solar dimming over representative climate types in India has been brought out through this study. The increasing trend in diffuse component is not significant at all the stations except arid and wet-dry tropical climates. The increase in diffuse insolation indicated presence of dust aerosols in arid station (Jodhpur) and cooled down ambient air over the years. Simultaneous reduction in global insolation and atmospheric thermal regime led to substantial reduction in pan evaporation. The trend in DR and air temperatures alongwith GR, plays an important role to identify aerosol trend and thereby evaporation. The future work should investigate the effect of these on crop evapotranspiration measured through collocated lysimeter. This will set the goal for future research on air quality and crop productivity.

temperatures; both the phenomena lead substantial reduction in evaporation as is noticed in Jodhpur (484 to 334.6 mm). But the increase in cloudiness only reduces evaporation through radiation cut. However, it can be compensated due to increase in air temperature (due to enhanced CO₂) as could be the case of New Delhi. Pan evaporation trends at Jodhpur and New Delhi are shown in Figure 2.

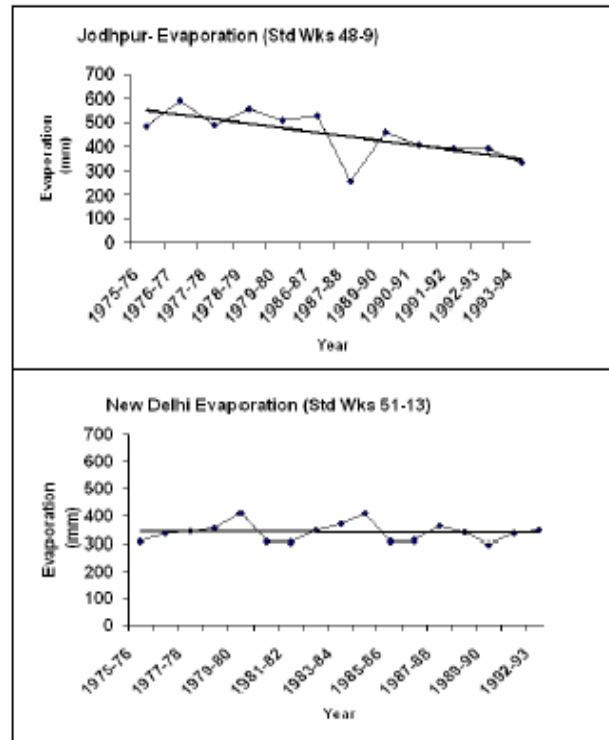


Figure 2. Trend of Annual Cumulative Pan Evaporation at Jodhpur and New Delhi between 1975 to 1994

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