A STUDY ON EFFECT OF LATITUDE ON SOLAR RADIATION DURING DIFFERENT SEASONS IN INDIA

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Abstract : Solar energy is available at any part of the globe, but the amount made available differs with respect to geographical location, time and season. An accurate knowledge of solar radiation data at a particular geographical location has vital importance to harvest the maximum utilization of solar energy. The present study was conducted on average solar radiation received at 4 cities (Madurai, Okha, Delhi, and Srinagar) of India with different latitudes in a year for different seasons. Results confirm that the latitudes 22°N to 30°N receives maximum solar radiation. Delhi (28.7041°N) and Okha (22.4649°N) have the highest radiant energy than Madurai (9.9414°N) and Srinagar(34.0837°N). Moreover Okha, since on coastal area, experiences higher radiation in post monsoon period.

Key words: *Radiation, Solar Energy, Monsoon.*

I. INTRODUCTION

Continuous growth of world population, expected to increase with 1.7 billion people over the next 25 years (1), and the rising living standards, especially in the underdeveloped areas, have major implications in the rise of the energy demand in all sectors of activity. The fossil fuels are unfortunately depleting fast to a point where it is unlikely to be able to sustain the great rate of the world energy consumption within the next 200 years (2).Information on the amount of global solar radiation at the earth's surface is essential for designing any solar energy related systems. Since the earth is inclined at an angle of 23.5° with its vertical axis and revolves in an elliptical orbit around the sun, the amount of solar energy received at all points will not be equal at all times and experiences seasonal changes. Also seasonal and atmospheric conditions have their impact on the amount of solar radiation. So location based analysis of the energy received will help in commissioning and establishing the solar energy systems to gather and use the utmost of the solar energy reaching the earth. Many countries alongside equator experience excessive solar radiation. The solar radiation intensity is higher in the locations in subtropical zone (3).

India lies between 68°7′ to 97°25′ east longitude and 8°4′ to 37°6′ north latitude, i.e., between equator and Tropic of Cancer thus have a significant diversified climatic condition (4).It is blessed with abundant natural resources and renewable energy potential, but millions of people still lack access to energy, electricity and clean fuels(5). India is one of the best recipients of solar energy due to its favorable location in the solar belt (40˚S to 40˚N). India has a vast potential for solar power generation since about 58% of the total land area (1.89 million km^2) receives annual average Global insolation above 5 $kWh/m^2/day$(6)

In India, the annual global radiation is 5.0 to5.5 $kWh/m^2/day$ (7), whereas direct radiation is around 4.5 to5.0 $kWh/m^2/day$,which is adequate to generate 6,081,709 TWh/year of eco-friendly energy (8). In 2005, the contribution of renewable energy was merely 2% (9), which has increased to 10.5% as of March 31st, 2013(10). In 2010, the Ministry of New and Renewable Energy (Government of India) had started a solar mission to produce 175 GW of clean energy till 2020 (11). Punjab, Uttar Pradesh, Haryana, Rajasthan and some areas of Gujarat and coastal Maharashtra receive the highest solar insolation between 5.7 and 7.5 $kWh/m^2/day$ during summer. During the monsoon i.e., June, July and August, Jammu & Kashmir, Haryana, Punjab, Rajasthan Uttar Pradesh, Madhya Pradesh, Gujarat and Uttaranchal receive the highest amount of solar insolation, in the range of 5.3 - 7.1 $kWh/m^2/day$ (12). During these months, the southern half of the country receives moderate to low solar energy insolation in the range of 3.5 - 5.5 kWh/m2/day.

The key drivers for renewable energy requirement are the following (13)

- The demand-supply gap, especially as population increases
- A large untapped potential
- Concern for the environment

- The need to strengthen India's energy security

Several studies indicate that the solar radiation data for India is not normally distributed (14).

The major objective of this paper was to measure and analyze the global radiation recorded at four cities (Madurai, Okha, Delhi, and Srinagar) of India in different latitudes during the three pre classified periods of seasons.

II. DATA AND SOURCES OF DATA

The sites were selected with the prime point that they should have different latitudes covering north to south of India. Moreover, the global radiation data along with other meteorological data wind speed, sunshine hour, humidity for the analysis were measured at Madurai and for the remaining stations it was procured from the IMD, Pune for a period of 1 year from1st January 2016 to 31st December 2016.

The period of study has been divided into three parts as given.

Pre monsoon - (Jan - May)
Monsoon - (Jun - Sep)
Post Monsoon - (Oct - Dec)

III. RESULT AND ANALYSIS

Table 3.1: The geographical details of the selected four cities of India with its latitude and longitude

Location	Latitude (°N)	Longitude (°E)
Madurai	9.9414	78.0088
Okha	22.4649	69.0702
Delhi	28.7041	77.1025
Srinagar	34.0837	74.7973

Table 3.2: Measured values of monthly average solar radiation and meteorological data for Madurai

Season	Month	Global Solar Radiation (kWh/m^2/day)	Sunshine Duration(hrs/day)	Relative humidity (%)	Wind speed (m/s)
Pre-monsoon	January	5.2	8	70	2.3
	February	5.9	8	72	2.1
	March	6.6	7.5	70	1.8
	April	6.6	7	71	1.8
	May	5.6	6.5	68	1.6
Monsoon	June	4.8	5	68	2.3
	July	4.9	5.5	67	1.9
	August	5.6	6	64	1.8
	September	5.7	6.5	73	1.7
Post-Monsoon	October	5.3	5.5	69	1.2
	November	4.8	5.5	74	1.7
	December	4.7	7	77	2.1

Table 3.3: Measured values of monthly average solar radiation and meteorological data for Okha

Season	Month	Global Solar Radiation (kWh/m^2/day)	Sunshine Duration(hrs/day)	Relative humidity %	Wind speed (m/s)
Pre-Monsoon	January	4.9	9	54	4
	February	5.7	9.5	45	4.8
	March	6.6	9	47	5
	April	7.2	9.5	58	5.8
	May	7.1	8.5	64	7.1
Monsoon	June	6	8	67	7.2
	July	4.5	5	75	7.9
	August	4.1	4	81	7.3
	September	5.4	7.5	74	6.2
Post-Monsoon	October	5.2	9.5	69	4.5
	November	5.1	9	56	3.5
	December	4.6	9	49	4.1

Table 3.4: Measured values of monthly average solar radiation and meteorological data for Delhi

Season	Month	Global Solar Radiation (kWh/m^2/day)	Sunshine Duration(hrs/day)	Relative humidity (%)	Wind speed (m/s)
Pre-Monsoon	January	4	7	83	2
	February	4.9	7.5	68	2.4
	March	5.9	7.5	61	2.6
	April	6.9	8.5	37	2.7
	May	7.1	8.5	47	2.8
Monsoon	June	6.4	7	59	2.8
	July	4.3	5	80	2.1
	August	4.4	5.5	78	2.4
	September	5.4	7.5	69	2.4
Post-Monsoon	October	5.1	9	68	2.1
	November	4.4	8	67	2.5
	December	3.9	7	79	2.2

Table 3.5: Measured values of monthly average solar radiation and meteorological data for Srinagar

Season	Month	Global Solar Radiation (kWh/m^2/day)	Sunshine Duration(hrs/day)	Relative humidity (%)	Wind speed (m/s)
Pre-Monsoon	January	3.4	5	73	1
	February	4.8	5	61	0.9
	March	4.5	5	68	0.8
	April	5.5	6.5	69	0.7
	May	6.7	8.5	63	0.7

Monsoon	June	6.9	9	57	0.7
	July	5.8	8.5	65	0.7
	August	5.4	7.5	71	0.6
	September	5.5	7.5	63	0.6
Post-Monsoon	October	4.8	7.5	59	0.5
	November	3.5	7	68	0.6
	December	3.3	5	76	0.8

Table 3.6: Monthly Average Global radiation profile for all selected four stations in India

(Kwh/m²/day)

	Delhi	Okha	Srinagar	Madurai
Jan	4	4.9	3.4	5.2
Feb	4.9	5.7	4.8	5.9
Mar	5.9	6.6	4.5	6.6
Apr	6.9	7.2	5.5	6.6
may	7.1	7.1	6.7	5.6
Jun	6.4	6	6.9	4.8
Jul	4.3	4.5	5.8	4.9
Aug	4.4	4.1	5.4	5.6
Sep	5.4	5.4	5.5	5.7
Oct	5.1	5.2	4.8	5.3
Nov	4.4	5.1	3.5	4.8
Dec	3.9	4.6	3.3	4.7

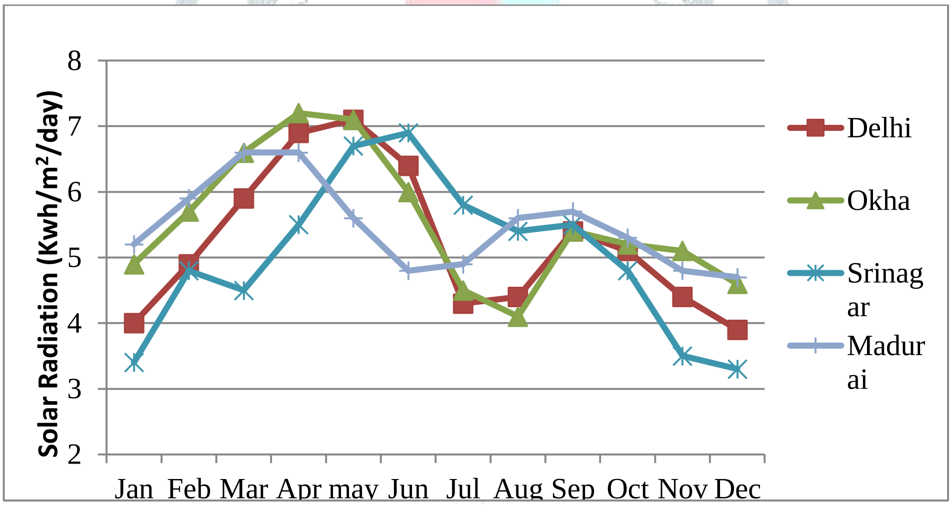

Figure 3.1: Monthly Average Global radiation for all selected four stations in India

Solar radiation reaches their maximum for all the stations during the transition period from pre monsoon to monsoon between April to June. In the beginning of pre monsoon Madurai with least latitude has the highest solar radiation received and Srinagar with highest latitude recorded the least.. All the four stations records minimum during the monsoon period between June and August. Okha has reached maximum 7.2 Kwh/m^2/day in April and Srinagar was the least 3,3 Kwh/m^2/day in December. All the statins show a decrease in the post monsoon period after a slight rise during the transition period. Srinagar attained its highest amount 6.9 Kwh/m^2/day in June.

Table 3.7: Monthly Average Sunshine *Duration profile for all selected four stations in India*

(hrs/day)

	Delhi	Okha	Srinagar	Madurai
Jan	7	9	5	8
Feb	7.5	9.5	5	8
Mar	7.5	9	5	7.5
Apr	8.5	9.5	6.5	7
may	8.5	8.5	8.5	6.5
Jun	7	8	9	5
Jul	5	5	8.5	5.5
Aug	5.5	4	7.5	6
Sep	7.5	7.5	7.5	6.5
Oct	9	9.5	7.5	5.5
Nov	8	9	7	5.5
Dec	7	9	5	7

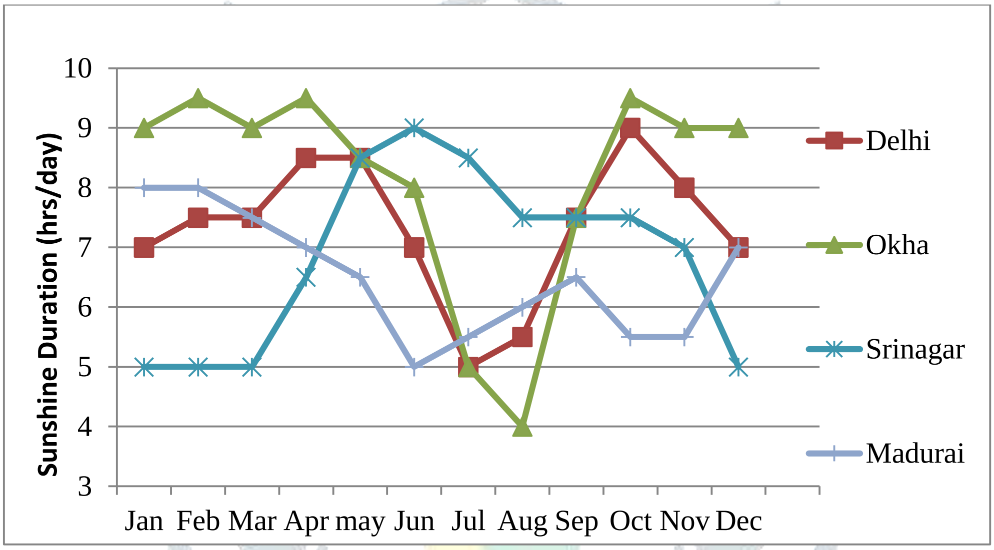

Figure 3.2: Monthly Average Sunshine Duration for all selected four stations in India

Srinagar with highest latitude had the least sunshine hour and Madurai with least latitude had the higher sunshine hours during the pre-monsoon period and this clearly reflected in the amount of solar radiation received. Srinagar had gradual increase in sunshine till the beginning of monsoon and exhibited fall after that. Most of the stations in other regions of latitude shown decrease in sunshine hours in monsoon period and increase in post monsoon. Less radiation received indicates the influence of other weather parameters.

Table 3.8: Monthly Average Relative humidity for all selected four stations in India

(%)

	Delhi	Okha	Srinagar	Madurai
Jan	83	54	73	70
Feb	68	45	61	72
Mar	61	47	68	70
Apr	37	58	69	71
may	47	64	63	68
Jun	59	67	57	68
Jul	80	75	65	67
Aug	78	81	71	64
Sep	69	74	63	73
Oct	68	69	59	69
Nov	67	56	68	74
Dec	79	49	76	77

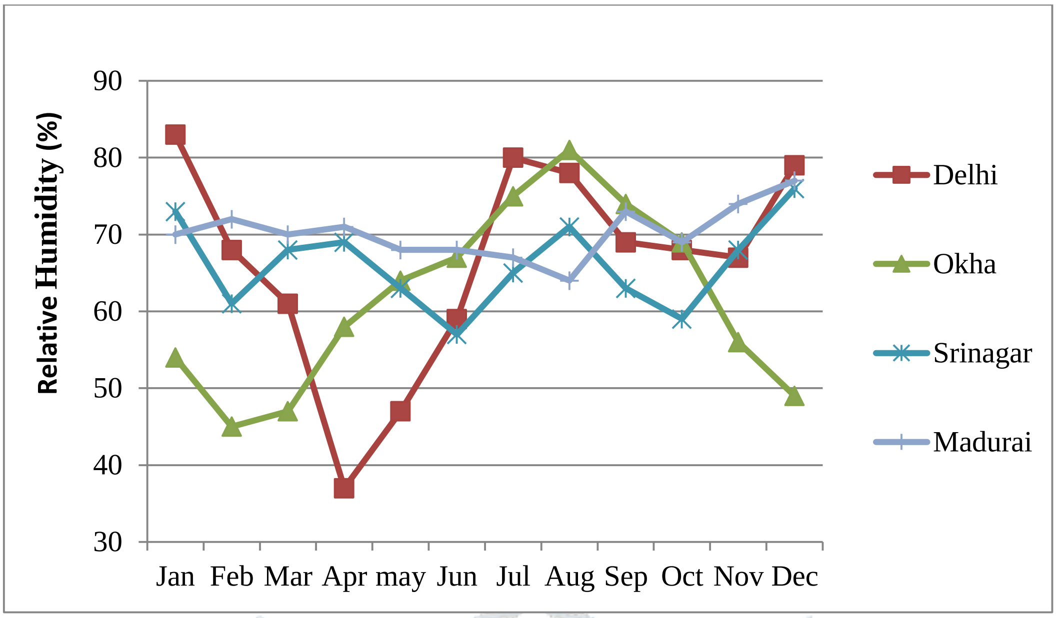

Figure 3.3: Monthly Average Relative humidity for all selected four stations in India

In all the four sites the relative humidity was above 50% in pre monsoon. Only for Delhi it falls sharply to 37% in April then starts to increase till 80% in July. All sites in various latitude points had their maximum relative humidity in the monsoon period bringing down the amount of solar energy received. Post monsoon has decreased relative humidity in Okha due to its geographical location.

Table 3.9: Monthly Average Wind speed for all selected four stations in India

(m/s)

	Delhi	Okha	Srinagar	Madurai
Jan	2	4	1	2.3
Feb	2.4	4.8	0.9	2.1
Mar	2.6	5	0.8	1.8
Apr	2.7	5.8	0.7	1.8
may	2.8	7.1	0.7	1.6
Jun	2.8	7.2	0.7	2.3
Jul	2.1	7.9	0.7	1.9
Aug	2.4	7.3	0.6	1.8
Sep	2.4	6.2	0.6	1.7
Oct	2.1	4.5	0.5	1.2
Nov	2.5	3.5	0.6	1.7
Dec	2.2	4.1	0.8	2.1

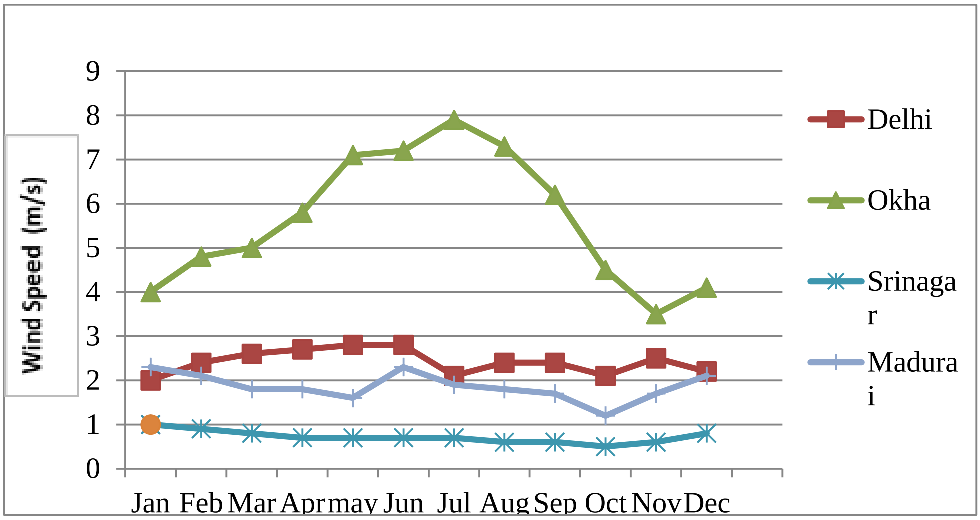

Figure 3.4: Monthly Average Wind speed for all selected four stations in India

Except Okha, sites in all latitudes have very moderate wind speed throughout the year. Since Okha has is on the seashore experiences more wind speed. Generally wind speed is not much affecting the amount of radiation received. Global radiation is weakly anticorrelated with wind speed

IV. CONCLUSION

On the basis of the different types of analysis, the results for 4 Indian locations at different latitudes during three weather classification period of a year , it is concluded that there is a correlation with latitude and average solar radiation received. Cities in latitude area 22.4649°N and 28.7041°N (Okha and Delhi) have maximum solar radiation during the end of pre monsoon period (May and June). Okha has higher relative humidity comparing with other area makes it to have higher radiation even during the monsoon period. Madurai with lower latitude (9.9414N) had moderate variations in meteorological parameters and thus the solar radiation. Post monsoon period generally, results in lower radiation energy received for all the four stations.

V. RECOMMENDATIONS

On the basis of the findings of the study the following recommendations had been made:
1. Similar study can be undertaken with large no of cities to generalize the findings.
2. More dependent factors of solar radiations can be included.
3. Duration of the data collection can be for longer period.
4. Seasonal study can be done as elaborately to get better findings.

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