Study of Clearness and Cloudiness Index at Tropical Locations

R. K. Aruna, B. Janarthanan

Abstract – An attempt has been made to evaluate the daily average clearness index (H_g/H_0) and cloudiness index (H_d/H_g) and to find the relation between them for three tropical locations in South India (Chennai, Trivandrum and Visakapatnam). Long range 15 years (1993 – 2007) measured data of daily average global and diffuse solar radiation have been utilized for this study. Two simple mathematical models have been proposed for each location for estimating H_d/H_g in terms of H_g/H_0 and found its validity for the prediction of diffuse radiation.

Keywords: clearness index, cloudiness index, global solar radiation, diffuse solar radiation

1 INTRODUCTION

The availability of solar radiation is indispensable to harness solar energy for different applications. Design of any solar energy system is influenced by the daily average global and diffuse solar radiation on a horizontal surface. Extensive solar radiation measuring devices are installed only in selected locations due to cost**,** maintenance and calibration requirements of the devices. Researchers have made sincere efforts to develop empirical models by using measured radiation to calculate global and diffuse solar radiation by incorporating various climatic parameters where measured data are not available. Angstrom [1] and Prescott [2] have proposed a correlation to estimate the monthly average daily global solar radiation on a horizontal surface using sunshine duration as

$$\frac{\overline{H}}{\overline{H_0}} = a + b\frac{\overline{S}}{\overline{S_0}}$$

Followed by them, empirical correlations have been developed by the researchers by incorporating different meteorological parameters viz., latitude, ambient temperature, humidity, the elevation, water vapor pressure etc.

Babatunde and Aro [3] have studied the characteristics of clearness and cloudiness index by expressing the cloudiness index in terms of clearness index. It has been found that they are opposite in characteristics and higher the clearness index more the transparency of the atmosphere and higher the cloudiness index more the turbidity or cloudiness of the atmosphere. Correlations have been developed for the estimation of monthly average daily diffuse solar radiation as a function of sunshine hours and clearness index at Karachi, Pakistan by Firoz Ahmad *et al*., [4]. It has been found that the established relations, Iqbal and Stanhill overestimate and Liu and Jordan underestimate the radiation value. Empirical correlations for beam and diffuse fraction of the global radiation to clearness index have been developed by Lanetz and Kudish [5] for semi-arid southern region of Israel. It has been concluded that the approach is intended to correct the multiplicity of possible cloud conditions that can give the same value for the cloudiness index. Coppolino [6] has developed a new correlation between clearness index and relative sunshine for computing the monthly mean daily global radiation at Italian locations and found that it is suitable to predict monthly mean global solar radiation with a high degree of accuracy.

Elagib *et al*., [7] have expressed the clearness index of 16 meteorological stations in Sudan in terms of the fraction of bright sunshine duration. The established relationships are statistically significant at 99.9% accuracy level. Udo [8] has characterized the sky conditions at Illorin, Nigeria by

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incorporating clearness index and relative sunshine duration and revealed that results were comparable with frequency distribution of global solar radiation at Ibdan and Kumasi. Paliatsos *et al*., [9] have correlated experimental values with modeled values of global and diffuse clearness index in Athens, Greece. The modeled linear regression has shown better fit with the experimental data. Further an attempt has been made by Saima Munawwar and Tariq Muneer [10] to explore the prospects of using sunshine duration and cloud cover in the estimation of daily diffuse irradiation besides the conventional use of global irradiation. It has been shown that estimation of daily diffuse irradiation by incorporating effective variables along with global radiation for local and independent sites. Koray Ulgan and Arif Hepbasli [11] have developed empirical correlation to establish relationship between cloudiness index, clearness index and sunshine fraction for three big cities in Turkey. The new model for cloudiness index and diffuse coefficient as a function of clearness index and sunshine fraction has shown better result than other available models.

Moreover Marco Bortolini *et al*., [12] have proposed a multi-locations model to estimate the horizontal diffuse component of solar radiation by using European geographical area comprising of 44 weather stations in all countries. It has proved the effectiveness of multi-location approach to estimate solar radiation components instead of several single location models.

In the present study, long range 15 years measured data of daily average global and diffuse solar radiation of three tropical locations in South India (Chennai, Trivandrum and Visakapatnam) have been used to find the relationship between clearness and cloudiness index. Moreover two sets of equation for each location i.e., cloudiness index in terms of clearness index (linear and polynomial) have been developed. The equations have been validated with measured data of global and diffuse solar radiation to predict the best fit with least error (linear or polynomial).

2 DATA

Measured data of daily average global and diffuse solar radiation of three South Indian locations viz., Chennai, Trivandrum and Visakapatnam for the period of 15 years are collected from Indian meteorological Department, Pune. These data are used to find daily average clearness and cloudiness index for the corresponding location. The daily amount of extra- terrestrial radiation for the locations have been found by using the expression

$$H_0 = \frac{24\times3600}{\pi} I_{sc}\left[1 + 0.033\, Cos\left(\frac{360\, n}{365}\right)\right] \times \left(Cos\,\phi\, Cos\,\delta\, Sin\,\omega_s + \frac{2\pi\omega_s}{360}\, Sin\,\phi\, Sin\,\delta\right) \quad (1)$$

Where, I_{sc} - solar constant
n - day of the year
ϕ - latitude of the location
δ - solar declination
ω_s - hour angle

The latitude and longitude of the locations have been presented in Table . 1.

Location	Latitude	Longitude
Chennai	13°N	80°E
Trivandrum	8°28'N	76°57'E
Visakapatnam	17°N	83°E

3 METHODOLOGY

For the three locations, 15 year data of daily average global and diffuse radiation has been averaged to find the daily average global and diffuse radiation for all the days in the year. Daily extra-terrestrial radiation for the three locations (Chennai, Visakapatnam and Trivandrum) has been evaluated by using the Eq. (1) and it has been used to find the daily average clearness index for all the days in the year. The daily average cloudiness index is evaluated by utilizing the average global and diffuse radiation.

4 RESULTS AND DISCUSSION

4.1 Comparison of Clearness and Cloudiness index

The daily average clearness and cloudiness index for the three locations have been plotted with respect to the day of the year and depicted in Figs. 1-12.

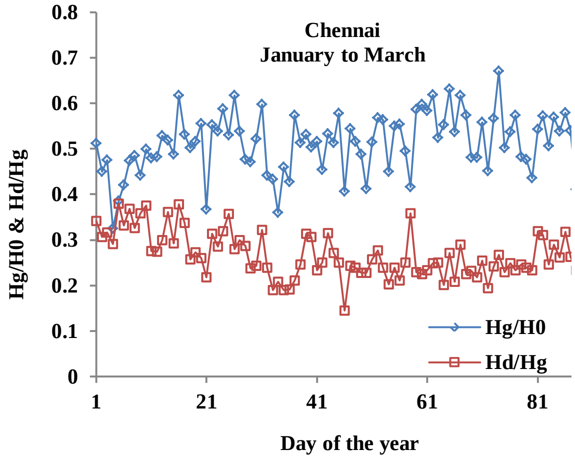

Fig. 1 Variation of Clearness and Cloudiness index with respect to day of the year

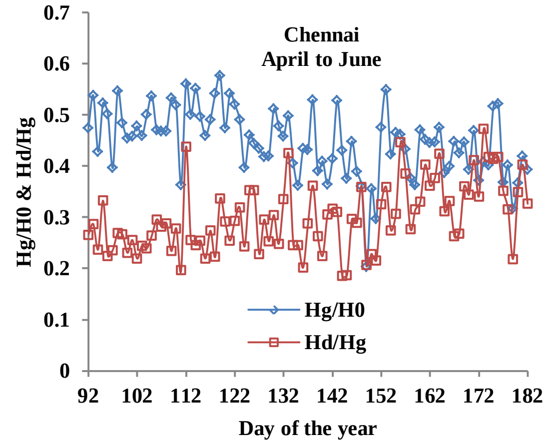

Fig. 4 Variation of Clearness and Cloudiness index with respect to day of the year

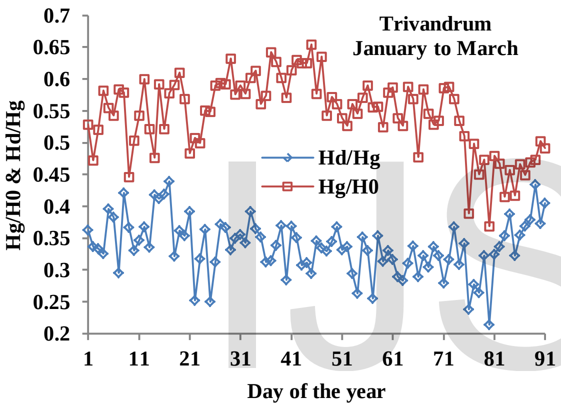

Fig. 2 Variation of Clearness and Cloudiness index with respect to day of the year

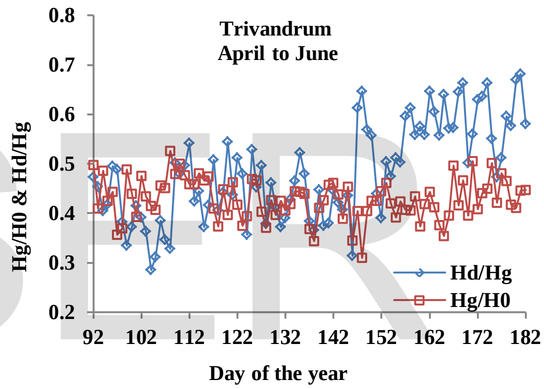

Fig. 5 Variation of Clearness and Cloudiness index with respect to day of the year

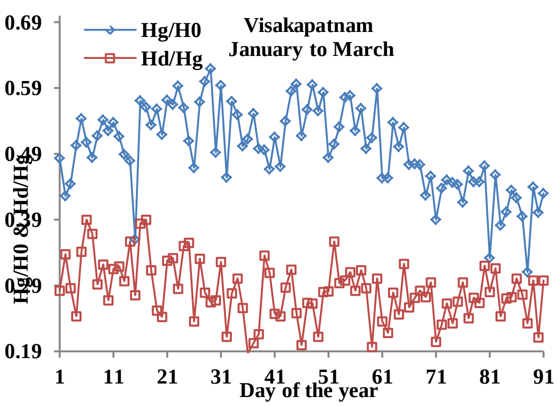

Fig. 3 Variation of Clearness and Cloudiness index with respect to day of the year

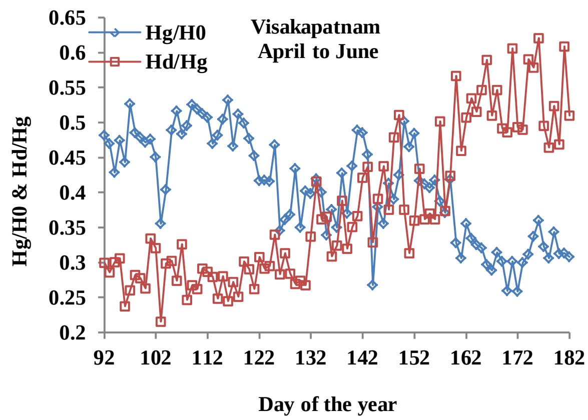

Fig. 6 Variation of Clearness and Cloudiness index with respect to day of the year

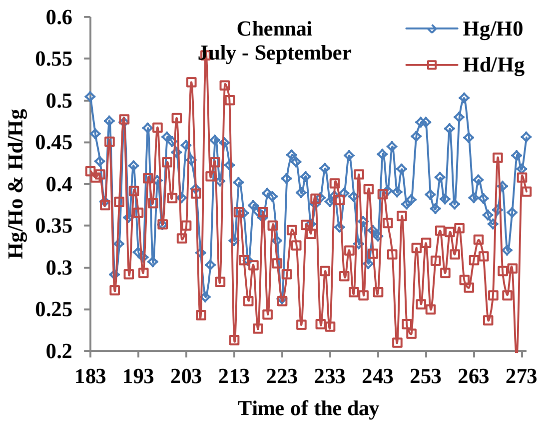

Fig. 7 Variation of Clearness and Cloudiness index with respect to day of the year

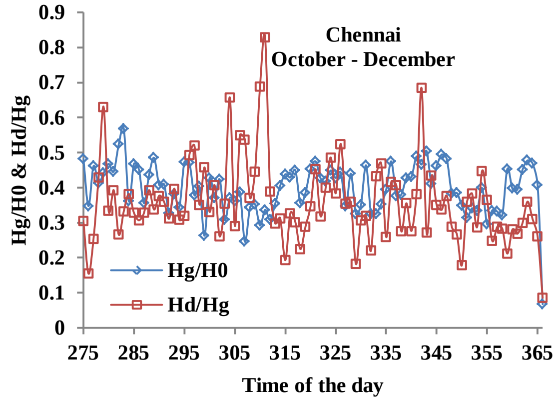

Fig. 10 Variation of Clearness and Cloudiness index with respect to day of the year

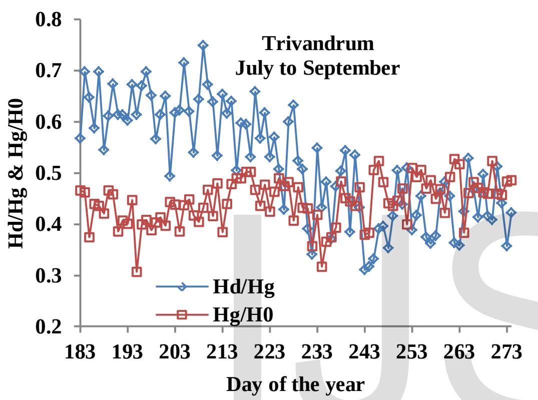

Fig. 8 Variation of Clearness and Cloudiness index with respect to day of the year

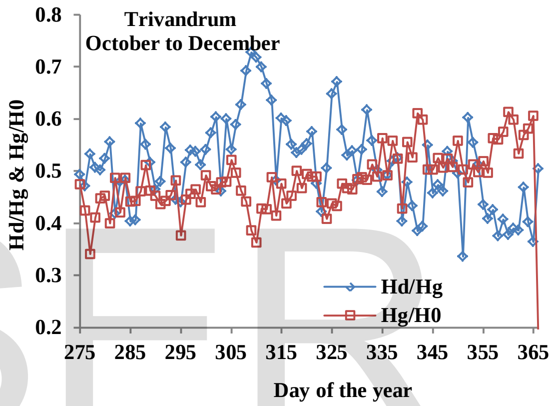

Fig. 11 Variation of Clearness and Cloudiness index with respect to day of the year

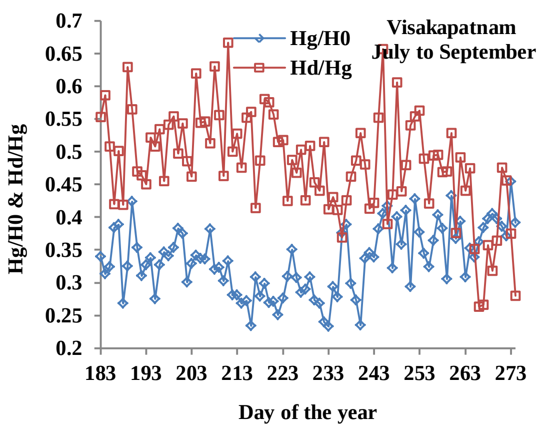

Fig. 9 Variation of Clearness and Cloudiness index with respect to day of the year

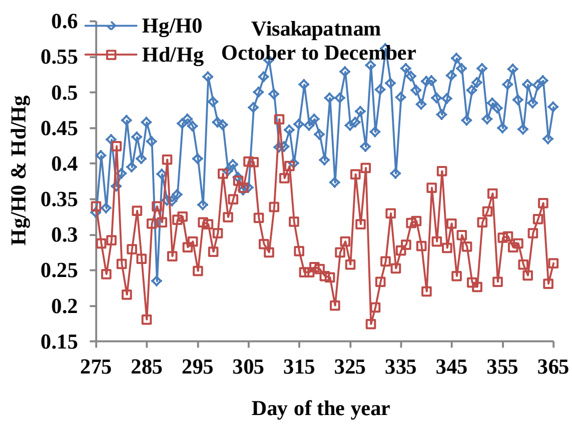

Fig. 12 Variation of Clearness and Cloudiness index with respect to day of the year

Figs. 1-3 represent the variation of clearness and cloudiness index during the month from January to March for Chennai, Trivandrum and Visakapatnam. From the figures it is understood that the clearness index for the locations is higher than the cloudiness index due to the absence of cloud or little and the atmosphere is almost clean. Figs. 4-6 represents the clearness and cloudiness index of the locations during the month from April to June. For Chennai (Fig. 4), it is seen that in April and May the clearness index exceeds the cloudiness index due to the clear sky. From Fig. 5 for Trivandrum, the clearness and cloudiness index in the month of April and May have comparable values due to the turbidity in the atmosphere. In Visakapatnam, the clearness index is higher than the cloudiness index in the month of April and May due to clear sunny days. Figs. 7-12 represents the variation of both the index during the month from July to December. It is clear that for all the three locations, the cloudiness index is almost higher than the clearness index. This is due to the fact that the atmosphere is occupied by the sufficient amount of clouds and dust. Hence the variations are due to the atmospheric conditions as mentioned by Babutunde and Aro [3].

With these comparisons, it is concluded that the two ratios are antiphase with each other throughout the year for the considered locations. It is also confirmed that the clearness index is higher in clear sunny days as the cloudiness index has low value and vice-versa in cloudy days.

Relation between H_d/H_g and H_g/H_0

The graph of daily average H_d/H_g against the corresponding values of H_g/H_0 for the three locations has been plotted and shown in the Figs. 13-15 by using the data from 1993-2007. Linear and polynomial regressions of H_d/H_g on H_g/H_0 have been found and presented. The linear and polynomial equations for H_d/H_g for the three locations have been used to find the values of cloudiness index for all the days in the year. Graphs have been drawn for measured and calculated cloudiness index by using the linear and polynomial equations for all the days in a year and depicted in Figs. 16-18.

Results have shown that, both the ratios lead to a simple mathematical relation

$$H_d/H_g + H_g/H_0 = 1 \quad (2)$$

Though the ratios are not linearly related, it has shown a significant agreement of the relations given by Eq. 2. It has been found that the sum of H_d/H_g and H_g/H_0 for the three locations is equal or approximately equal to unity during most of the days in the year. The validation of the Eq. 2 can be established inspite of slight differences in few days of the year. Hence it can be found that, the diffuse radiation ratio can be derived in terms of clearness index for all the three locations as

$$H_d/H_g = 1 - H_g/H_0 \quad (3)$$

From Eq.3, it is clear that the maximum value of cloudiness index is 1 if the clearness index H_g/H_0 is 0. This means that the atmosphere is not clear and solar radiation entering the atmosphere gets scattered due to dust particles, clouds and turbidity of the atmosphere before reaching the ground surface of the earth. In the other way, it is also seen that the maximum value of clearness index is 1 leading to the absence of diffuse radiation. The atmosphere is clear and clean without dust particles and clouds providing the clear path way for solar radiation to reach the surface of the earth. Thus the ratio H_d/H_g can be expressed in terms of H_g/H_0.

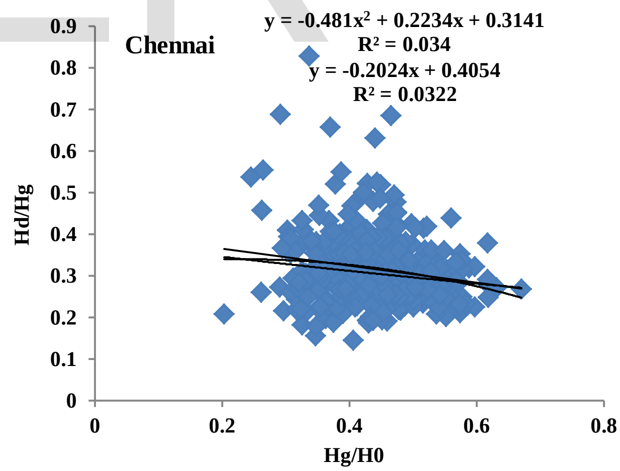

Fig. 13 Variation of H_d/H_g with respect to H_g/H_0 for Chennai

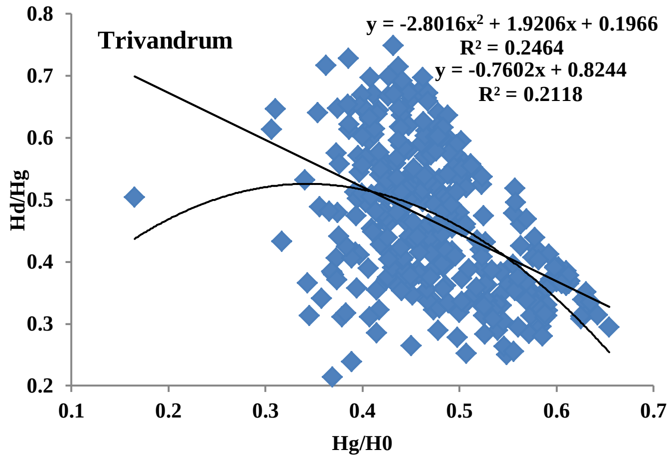

Fig. 14 Variation of H_d/H_g with respect to H_g/H_0 for Trivandrum

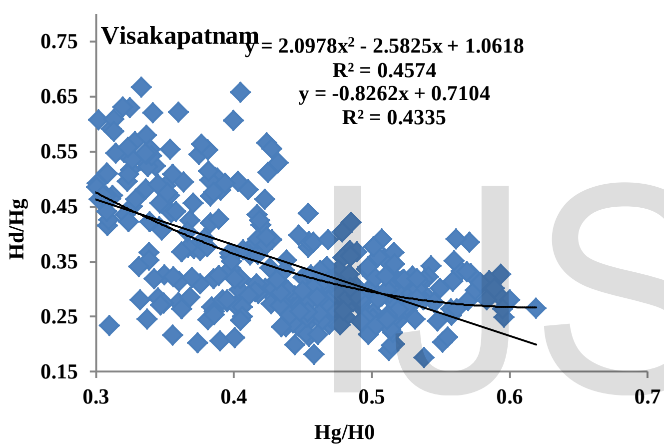

Fig. 15 Variation of H_d/H_g with respect to H_g/H_0 for Visakapatnam

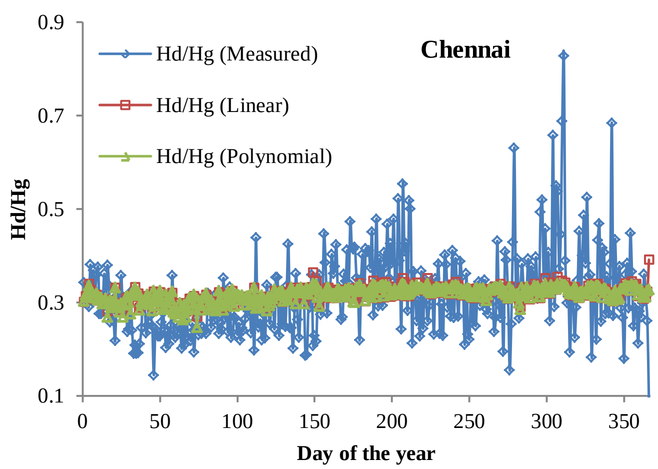

Fig. 16 Variation of cloudiness index in Chennai

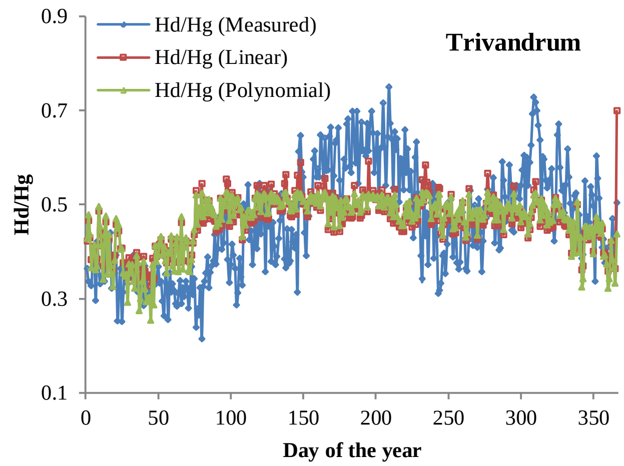

Fig. 17 Variation of cloudiness index in Trivandrum

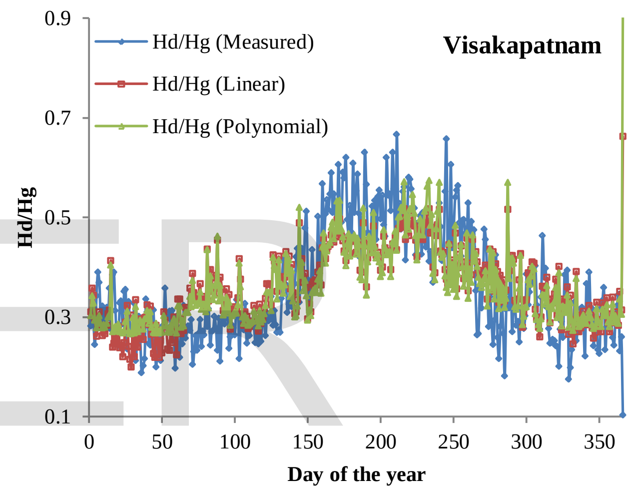

Fig. 18 Variation of cloudiness index in Visakapatnam

The linear and polynomial equations derived for the cloudiness index in terms of clearness index for the three locations and are

For Chennai

Linear

$H_d/H_g = -0.202\, H_g/H_0 + 0.405$

Polynomial

$H_d/H_g = -0.481\, (H_g/H_0)^2 + 0.223\, (H_g/H_0) + 0.314$

For Trivandrum

Linear

$H_d/H_g = -0.760\, H_g/H_0 + 0.824$

Polynomial

$H_d/H_g = -2.801\, (H_g/H_0)^2 + 1.920\, (H_g/H_0) + 0.196$

For Visakapatnam

Linear

$H_d/H_g = -0.826\, H_g/H_0 + 0.710$

Polynomial

$H_d/H_g = 2.097 (H_g/H_0)^2 – 2.582 (H_g/H_0) + 1.061$

Comparisons between measured and calculated values of cloudiness index in terms of clearness index have been made for the three locations viz., Chennai, Trivandrum and Visakapatnam by finding the percentage average standard deviation between them for both linear and polynomial equations. From the results it has been found that the percentage average standard deviation for both the linear and polynomial equations between the measure and calculated values for the three locations is less than 10% on average. Results have been presented in Table. 2

Table. 2

Location	Linear Average Standard Deviation (%)	Polynomial Average Standard deviation (%)
Chennai	9.15	7.44
Trivandrum	6.71	5.59
Visakapatnam	10.39	8.69

Thus the percentage deviation of the calculated values from the measured ones made an optimistic hope to use the equations when measured radiation are not available in that locations and in other places having similar climatic conditions.

5 CONCLUSION

The linear and polynomial equations for cloudiness index in terms of clearness index for the three locations viz., Chennai, Trivandrum and Visakapatnam are found to be easy and reliable to predict when diffuse radiations are not available in the locations. Moreover the equations can also be used for the locations having similar climatic conditions with least error. The two ratios clearness and cloudiness index can be used to identify the different atmospheric conditions i.e., the cleanliness of the atmosphere in summer gives higher value of clearness index than the cloudiness index and in winter due to clouds and dust particles, the cloudiness index has higher value when compared to the clearness index. The two parameters are inversely proportional in all the locations and thus diffuse radiation can be estimated when measured global radiation alone is available.

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