Sun is an ultimate source of energy and solar energy plays an important role in driving the atmospheric heat engine to operate and sustain the atmospheric processes and to control the entire activity of all living organisms on Earth\(^1\). A part of the energy from the fusion process heats the chromospheres. However, the outer layer of the sun is much cooler than the interior of the sun. The radiation emerging out from the chromosphere becomes the solar radiation incident on the Earth\(^3\). The available radiation on Earth is considerably lower than the maximum value of radiation at chromosphere due to the shape, size and orientation of the earth, climatic condition (cloud cover) and the general composition of the atmosphere\(^4\). The best way of knowing the amount of solar radiation at any site is to install the sensitive measuring systems at many locations in a given region and to record the day-to-day radiation. Solar radiation data at ground level is the main requirement for solar energy application viz. engineering system designs for solar energy collection and storage, evaluation of performance of solar energy utilization/application systems\(^5\)-\(^7\). This information can be derived from the ground measurement by Pyranometer, reference cell or can be derived from satellite data\(^8\).

**MATERIAL AND METHODS**

In the present work, the monthly mean daily global solar radiation data for four locations of India for a period of fifteen years from 1986 to 2000 are used for investigation. The statistical indicators: mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) which are defined by the following equation are used to examine the performance of the global solar radiation:

\[
\text{MPE} = \frac{100}{n} \sum \left( \frac{I_{o,i} - I_{c,i}}{I_{o,i}} \right) \quad \text{1}
\]

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum \left( \frac{I_{o,i} - I_{c,i}}{I_{o,i}} \right)^2} \quad \text{2}
\]

\[
\text{MBE} = \frac{1}{n} \sum \left( \frac{I_{o,i} - I_{c,i}}{I_{o,i}} \right) \times 100 \quad \text{3}
\]

where \(I_{o,i}\) and \(I_{c,i}\) are the \(i^{th}\) observed and calculated values of solar radiation.

**Fig.-1. The four Indian stations of the study**
Table 1. Summary of four metro cities of India

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Stations</th>
<th>Latitude(N)</th>
<th>Longitude(E)</th>
<th>Altitude(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Delhi</td>
<td>28° 29'</td>
<td>77° 08'</td>
<td>273</td>
</tr>
<tr>
<td>2</td>
<td>Mumbai</td>
<td>19° 07'</td>
<td>72° 51'</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Kolkata</td>
<td>22° 35'</td>
<td>88° 27'</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Chennai</td>
<td>13° 00'</td>
<td>80° 11'</td>
<td>10</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

A comparative study between the ground measurement of IMD and satellite-derived data of NASA for the monthly average global and diffuse solar radiation recorded at four chosen metro cities of India (Fig. 1, Table-1) is performed.

COMPARATIVE STUDY OF GLOBAL RADIATION: A comparative plot of ground measured and satellite derived monthly average of daily global radiation is shown in Fig. 2 for the four metro cities of the study. It is noticed that in May, ground measured highest global radiation is 6.79 kWh/m² and lowest is 3.33 kWh/m² in December for New Delhi while for satellite-derived data, these values are 7.32 kWh/m² (April) and 3.55 kWh/m² (December) for Mumbai and New Delhi. January being the winter month has relatively low global radiation, but from February, global radiation starts to increase and has high intensity during the summer months (March, April and May). After May, it starts to decreases and has
Fig:-3. MPE, MBE and RMSE of ground measured and satellite-based data of global radiation for four different stations.

Fig:-4. Comparison between the ground measured and satellite based data of diffuse radiation.
comparatively low values in rainy months, i.e. July, August and September. In the post-monsoon month of October, it is relatively high. Again in winter months of November and December, global radiation decreases.

Fig.-3 presents the statistical indicators for global radiation of four metro cities in India. The MPE values have the range 0.93% (New Delhi) to -18.34% (Mumbai) for the global radiation. MBE and RMSE have lowest values of -0.09 kWh/m² and 0.25 kWh/m² for New Delhi. The highest value of MBE is 0.87 kWh/m² whereas RMSE is 0.89 kWh/m² for Mumbai. The negative and positive values of MPE and MBE represent underestimation and overestimation respectively.

COMPARATIVE STUDY OF DIFFUSE RADIATION: Analysis of the ground measurements and satellite derived data of diffuse radiation are shown in the Fig.-4. The average values of diffuse radiation for ground measurements is found highest (11.83 kWh/m²) in the month of July for New Delhi as depicted by the figure. While the smallest diffuse radiation is 4.87 kWh/m² (New Delhi) i.e. found in the month of January. This high value of diffuse radiation might be due to fog during this month. Similarly, for satellite-derived data the highest diffuse radiation is 1.58 kWh/m² (June) and the smallest diffuse radiation is 0.73 kWh/m² (January) noticed for same as the location New Delhi. The diffuse radiation by satellite-measurement is much less in comparison to ground measurement, which is due to the reason of atmospheric conditions such as dust, pollution and aerosol particles.

A comparison between ground measured and satellite derived data of diffuse radiation along with the three statistical indicators is shown in Fig.- 5. The highest values of MPE and RMSE are 86.62 (%) and 7.64 (kWh/m²) respectively for Mumbai. On the other hand, highest MBE of -7.58 (kWh/m²) is found for Chennai. The lowest values for MPE, MBE, and RMSE parameters are 86.2 % (Chennai), -6.89 kWh/m² (New Delhi) and 7.13 kWh/m² (Kolkata) respectively. The MPE and MBE show that the underestimation and overestimation respectively, while the RMSE values indicating very good agreement between
measured and satellite derived values of the diffuse radiation.

CONCLUSION

The main conclusions of the present investigations are as follows:

(i) The highest amount of global radiation was observed in the month of May at New Delhi for ground measurement and similarly, highest amount found for satellite measurement in the month of April for Mumbai. The ground measured and satellite derived data has lowest global radiation in the month of December at New Delhi. The global radiation produces the best agreement with the measured data over the period from March to July for New Delhi.

(ii) The statistical predictors viz. MPE, MBE, RMSE indicates that there is a very good agreement between measured and satellite derived global radiation for New Delhi while high errors are found for Mumbai.

(iii) Ground measured diffuse radiation has a smallest and highest amount in the month of December and July respectively for the same location of New Delhi. Similarly for satellite derived data minimum and maximum average value are observed for the month of January and June respectively for the city New Delhi.

(iv) Statistical parameters MPE, MBE and RMSE present a comparison between ground measurements and satellite-derived data values for diffuse radiation. The peak errors are found for Mumbai (MPE and RMSE), and Chennai (MBE) while the least errors are found for New Delhi (MBE), Kolkata (RMSE) and Chennai (MPE).

(v) The comparative study results indicates that the matching between the ground measurement and satellite derived data is better for global radiation than the diffuse radiation data.

REFERENCES