CHAPTER 1

INTRODUCTION

Solar radiation data is a fundamental input for solar energy applications such as photovoltaics, solar thermal systems and passive solar design. The data should be contemporary, reliable and readily available for design, optimization and performance evaluation of solar technologies for any particular geographical location. As solar energy is accepted as a key alternative energy source for the future, solar energy is being critically considered for satisfying significant part of the energy demand in India and around the World. In this respect, the importance of solar radiation data for design and efficient operation of solar-energy system has been acknowledged.

As solar irradiance passes through a clean and dry atmosphere, it gets attenuated by permanent atmospheric constituents, whose content is nearly invariable. Due to this, solar irradiance at the earth's surface can be expressed as a function of optical thickness only. The attenuation processes are completely defined by the standard compositions of the ideal atmosphere. Two additional attenuation mechanisms take place in a real atmosphere, namely, absorption by water vapour and scattering by aerosol particles also known as atmospheric turbidity. The determination of turbidity is one of the important factors in climate modeling, climate change and in pollution studies. Specific solar radiation information is to estimate atmospheric turbidity, which is a measure of the total amount of aerosol integrated through the vertical atmospheric column.

Solar radiation is the principle energy source for physical, chemical and biological processes on the earth's surface that drives processes as diverse as snow melting, evapotranspiration and crop growth. It also provides the energy for soil heat flux, soil temperature, surface and air temperature, water loss through evaporation and transpiration, plant and animal activity. The amount of solar energy reaching
the earth's surface is mainly affected by solar geometry, geomorphologic and clmatic factors. Solar geometry and geomorphologic factors control the radiation characteristics of terrain, particularly slope gradient and slope aspect. Climatic factors influencing solar radiation include cloud and other atmospheric conditions such as dust and aerosols, and these effects can be locally significant. Recently, scholars around the world have been attempting to study solar radiation as an important variable in modeling.

The amount of solar radiation received by the surface is controlled at the global scale by the geometry of the earth, atmospheric transmittance and the relative location of the sun. At the local scale, radiation is additionally controlled by surface slope, aspect and elevation. Estimation of clear sky solar radiation for sloped surface is important in remote sensing applications involving energy balance, which needs estimation of total energy striking surface. Most of the solar radiation information comes from weather stations located in flat areas, so estimation of solar radiation in sloped surface is generally based on model.

Effective harnessing and use of solar energy which is free, clean and abundant in most places throughout the year are of importance to the world due to high fossil fuel costs and atmospheric pollution. Due to the cost and difficulty in measuring, solar radiation data are not readily available. For solar energy utilization, these data are important for effective research in solar-energy, hence there is the need to develop an alternative ways of generating these data. Solar radiation data provide information on how much of the sun's energy strikes a surface at a location on earth during a particular time period.

Daily global solar radiation is considered as the most important parameter in the performance prediction of renewable energy systems, particularly in sizing photovoltaic power systems, agriculture and building design applications. The meteorological parameters which are used as the input of radiation models are the important key to choose the proper radiation models at any location particularly, in the middle-east
countries, where the number of solar observation sites is poor. Among the meteorological parameters, sunshine duration, latitude and cloud cover are the most widely and commonly used data to predict daily global solar radiation and its components at any location of interest.

The other input parameters such as air temperature, relative humidity and altitude of the location also influence total solar radiation at the surface. In cold and severe cold regions, passive solar designs and active solar systems help lower the reliance on conventional heating by fossil fuels. In tropical and subtropical climates, solar heat gain is a major cooling load component, especially in cooling-dominated buildings.

Generation of renewable solar energy has long depended on solar radiation measurements to provide data for resource assessment, solar system monitoring, and radiative model development or validation. The quantity and quality of measured solar radiation data has varied greatly. Current radiometers still use old technology with relatively small fundamental improvements. Unfortunately, for many developing countries, solar radiation measurements are not easily available due to the cost, maintenance and calibration requirements of the measuring equipment. Therefore, it is important to estimate the solar radiation based on readily available meteorological data. These data include extraterrestrial radiation, sunshine hours, mean temperature, soil temperature, and relative humidity, number of rainy days, altitude, latitude, total precipitation, cloudiness and evaporation.

The most commonly used parameter for estimating global solar radiation is sunshine duration which can be easily measured to obtain reliable data. The design of a solar energy conversion system needs exact knowledge regarding the availability of global solar radiation which is composed of direct and diffuse radiation. Sunshine hours are measured at many locations around the world, while global radiation is measured at selected locations only. In order to overcome this defect, scientists have developed many empirical equations. Recently several empirical formulas using various parameters have been considered to estimate the solar radiation around the
world. Determination of solar energy capacity for a region requires extensive radiation measurements of high quality to be made at a large number of stations covering major climatic zones of the region.

The knowledge of the solar resource of earth’s surface is essential for planning any solar energy system at a selected location. Several algorithms and models have been developed during the last three decades for estimating the solar irradiance at the earth’s surface from images. Generally, it can be grouped into physical and pure empirical or statistical models. Statistical models are simpler, as they do not need extensive and precise information on the composition of the atmosphere, and rely on simple statistical regression between satellite information and solar ground measurements.

Direct applications of solar energy include solar drying and solar water heating while indirect applications include generation of electricity using solar photovoltaic systems. Assessing the performance of these solar systems is necessary in order to optimize their layout and size. Such a procedure requires a database of solar radiation for locations for which the systems are being assessed. Solar radiation data is also required in modeling a building's thermal performance and as input into ecological and crop models. Solar radiation data can be provided through measurements, but it is difficult to have measurements from all locations of interest. Compared to precipitation, temperature and wind of meteorological parameters, the observed irradiance data is scarce. For this reason, many different methods have been used to estimate radiation from sunshine duration records, since the latter are more readily available.

Figure 1.1 describes various types of interactions in the atmosphere. Solar radiation intensity arriving at the earth’s surface is mostly affected by the presence of dust particles, ozone, water vapors, carbon dioxide, pollen and clouds present in the atmosphere. The solar potential at any location predominantly depends upon the solar radiation received on the surface of the earth, availability of land and water and other climatic parameters.
Effective harnessing and utilization of solar energy is of high importance to the world especially at the time of rising fuel costs and environmental effects such as depletion of the ozone layer and green house effects. Measured values of Horizontal Global Solar Radiation (HGSR) are usually the best source of information and needed for effective research in solar energy utilization. The measurements of this parameter are done only at few locations. For places where no measured values are available, a common practice is to assess this parameter using appropriate correlations. The Angstrom correlation has served as a basic approach to estimate global radiation for a long time. The energy received at the earth's surface is more important than in the extra-terrestrial energy for utilization of solar energy.

Two types of solar radiation data are widely available. The first is monthly average daily total radiation on a horizontal surface; $\overline{H}$, the second is hourly total radiation on a horizontal surface; $I$, for each hour for extended periods such as one or more years. The $\overline{H}$ data are widely available.
1.1 PROBLEM IDENTIFICATION

Solar energy is accepted as an alternative energy source for the future. The scarcity of hourly solar radiation data which is available in only 46 locations in India, presents difficulties in assessing the potential of solar energy applications. Among the meteorological parameters, sunshine duration, latitude and cloud cover are the most widely and commonly used data to predict daily global solar radiation and its components at any location of interest. The irradiance outside the atmosphere depends on the time of the year, the time of the day and latitude, whereas the irradiance that reaches the earth’s surface is strongly modified by the scattering and absorption by cloud masses of various sizes. The other input parameters such as air temperature, relative humidity and altitude of the location influence total solar radiation at the surface. Among the different locations, Coimbatore, Tamilnadu is selected with available datas to analyze the global solar radiation by considering influencing factors such as air temperature, relative humidity, air pressure, wind velocity, suspended particulate matter and sunshine hours.

In order to solve the problem defined at the beginning of this research work, the following objectives were set.

- To measure the quantum of global solar radiation based on three years data.
- To identify the factors influencing global solar radiation.
- To assess the amount of explanation provided by each variable on GSR.
- Mathematical modeling of global solar radiation for four seasons.

1.2 SOLAR RADIATION

The radiant energy from the sun covers the entire electromagnetic spectrum. The atmospheric interference restricts this spectrum to 290nm to 3000nm which is called solar radiation. Solar Radiation is received at the earth’s surface in an attenuated form due to absorption and scattering as it passes through earth’s
atmosphere. Absorption occurs primarily because of the presence of ozone, water vapour, other gases (CO$_2$, NO$_2$, CO, O$_2$, CH$_4$ and particulate matter). Solar Radiation is classified as per the details and the terminology used is presented here.

- Direct or Beam radiation
- Diffuse radiation
- Global or Total Solar radiation
- Terrestrial radiation
- Reflected solar radiation
- Solar constant
- Albedo of the surface
- Atmospheric turbidity
- Aerosol
- Suspended Particulate Matter (SPM)
- Latitude
- Longitude
- Altitude
- Relative Humidity

1.2.1 Direct or Beam radiation

Solar radiation at earth's surface without change of direction is called direct or beam radiation. It expressed as watts per square metre (W/m$^2$).

1.2.2 Diffuse radiation

Solar radiation that gets scattered while passing through the earth's atmosphere is referred to as diffuse radiation and it includes both reflected solar radiation and solar radiation re-reflected from the earth. Assessing the climate helps define system requirements for solar projects. Seasonal weather patterns affect heating and cooling requirements as well as the solar resource. During winter, heat loss is affected by the ambient temperature. The colder it is outside, the faster a solar collector will lose
heat, thus reducing its efficiency. Low temperatures also increase heat loss from the building. Lower the daily average outdoor temperature, higher the heating requirement will be. Winter heating requirements usually increase when there is less solar energy available. For this reason, it is better to design solar based projects to capture the maximum amount of energy from the sun during the winter season.

1.2.3 Global or Total Solar radiation

Global solar radiation comprises both the direct and diffuse components and is of interest for flat-panel and tracking PV power generation systems. The amount of solar radiation received is influenced by the location of the receptor on the earth's surface and by its orientation. It is important to note the concentrating systems use the direct beam component of global solar radiation. As with many renewable energy solutions, weather conditions such as cloud, haze, and fog play an integral role in system performance.

Direct or normal beam radiation data is less readily available than other solar energy data. The most common type of PV system in India is the flat-panel collector or module, which is typically inclined at a latitude angle. It is used as the best compromise between minimizing cost and maximizing annual energy collection.

1.2.4 Terrestrial radiation

At much lower temperatures (around 270K on an average), earth and its atmosphere emit radiant energy in the infra-red region from 4 to 50μm called terrestrial radiation.

1.2.5 Reflected solar radiation

Reflected solar radiation is part of global solar radiation that is reflected by the receiving surface. (mainly the earth’s surface and diffusely by the atmospheric layer between the surface and the point of measurement.)
1.2.6 Solar constant

The solar constant is the quantum of solar energy per unit time at the mean distance of the earth from the sun, received on a unit area of a surface normal to the sun outside the atmosphere. The world meteorological organization has fixed the value of solar constant at 1367 W/m².

1.2.7 Albedo of the surface

Albedo of the surface is the ratio of the reflected solar radiation to the incident global solar radiation. It is the same as the reflectance, however its use is restricted to ‘solar’ wavelengths, viz. 290 to 3000nm.

1.2.8 Atmospheric turbidity

The direct solar radiation on a given surface depends on the depletion it undergoes through the passage of atmospheric column. The depletion is caused by pure air molecules and other suspended particulate matter in the atmosphere. The suspended particulate matter is a combination of substances, such as water vapor, dust, haze and smoke, or generally termed as aerosol particles. The turbidity of the atmosphere is defined as the reduced transparency of the atmosphere due to absorption and scattering of the radiant energy by solid or liquid particles, other than clouds, held suspended in the atmosphere.

1.2.9 Aerosol

It is a colloid suspension of fine solid particles or liquid droplets in a gas. Examples are clouds, and air pollution such as smog and smoke. Aerosols are present throughout the boundary layer at number concentrations depending upon factors such as location, atmospheric conditions, annual and diurnal cycles and presence of local sources. The highest concentrations are usually found in urban areas, reaching up to $10^8$ and $10^9$ particles per cc.
1.2.10 Suspended Particulate Matter (SPM)

SPM are finely divided solids or liquids are formed in the atmosphere by transformation of gaseous emissions that may be dispersed through the air from variety of sources, such as combustion processes, industrial activities or natural sources, power plants and diesel trucks.

1.2.11 Latitude

Latitudes are imaginary lines drawn parallel to the equator running from west to east. Latitude of a place is the distance either north or south of the equator which is measured as an angle whose apex is at the center of the earth. One degree of latitude is approximately equal to 111 kilometers.

1.2.12 Longitude

Longitudes are imaginary lines drawn across the equator connecting North Pole and South Pole. The distance of a place east or west of the meridian of Greenwich or the prime meridian as an angle is known as longitude of a place.

1.2.13 Altitude

Elevation of a place above mean sea level is termed as Altitude.

1.2.14 Relative humidity

It is the ratio between the amounts of water vapour present in the air to the amount of water vapour the air can hold. It is expressed in percentage.
1.3 THESIS ORGANIZATION

This research is focused on the analysis of global solar radiation in Coimbatore, Tamilnadu carried out during the year of 2009, 2010 and 2011.

Chapter 1 presents with the application of solar energy, types of interactions in the atmosphere, objectives of the work and definition of the problem.

In Chapter 2, the background of the research is presented through a detailed literature survey. The various existing estimation techniques of global solar radiation at different locations are reported in this chapter.

A detailed energy scenario in Tamilnadu is represented in Chapter 3. Various power capacities, both sector wise and technology wise installed across Tamilnadu are discussed. An overview of Indian Meteorological Department and Agro Climatic Research centre are elaborated.

Various factors influencing global solar radiation are analyzed and interpreted in Chapter 4. With respect to four seasons, measured data are collected from ACRC and CPCB for three years 2009, 2010 and 2011 are tabulated for Coimbatore, Tamilnadu. Using ANOVA, significant variables on global solar radiation is identified and described. Percentage of explanation by each variable and a linear mathematical model is presented to predict the global solar radiation for four seasons. Preliminary results that were obtained are discussed in Chapter 5. Chapter 6 concludes the project by discussing the potential benefits and future enhancements.