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Review

Estimation of Annual Solar Radiation from measured temperatures by using Temperature-based (TB) approach in different cities in India

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ABSTRACT

This paper intends to present the methods of monthly mean daily solar radiation estimation using Temperature-based approach. The main objective of this paper is to estimate the potential of monthly solar radiation using air temperatures at three cities of Andhra Pradesh, India. Solar radiation is the principal, fundamental and abundantly available energy for many physical, chemical and biological processes. However, it is measured at a very limited number of meteorological stations in the world. Since the temperature is probably the most registered meteorological variable, correlation models based on air temperature data are especially interesting to estimate monthly average values of solar irradiation in countries with lack of direct measurements. Measured long-term monthly air temperatures including maximum (T_{max}) and minimum temperatures (T_{min}), were gathered from meteorological stations and analyzed. Three combinations of air temperatures, namely T_{max}, T_{min}, and T_{aveg} were served as inputs. The approach in this present paper seems to be adequate to the data for a region with a diverse orography on the eastern Indian coast obtained from meteorological stations supported by their web site in India.

Results: The methodology has also been applied to three city stations in order to check the procedure in places with different latitude, longitude and attitudes.

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Contents

1. Introduction

This paper aims at demonstrating the potential of solar radiation and solar systems to provide about 80% reduction for CO_2 emissions and power consumption. The data have been collected from the different parts of Andhra Pradesh with very deferent climatic conditions with a region of diverse orography on the central, southern and eastern coast of Andhra Pradesh.

To replace the shortage of direct measurements of solar irradiation, it has been traditional to resort to estimations from other climatologic variables of which more abundant information is found.

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Nomenclature

R_a	extraterrestrial radiation (kWh/m^2/day)
R_s	solar radiation (kWh/m^2/day)
P	mean atmospheric pressure at the site in kPa
P_0	mean atmospheric at sea level (101.3 kPa)
K_{rs}	coefficient
$T_{\max}$	maximum temperatures in °C
$T_{\min}$	minimum temperature in °C
T_{aver}	average temperature in °C
G	global irradiation at ground level (MJ/m^2/day)
G_0	extraterrestrial global irradiation (MJ/m^2/day)

By using the Handy formula we can calculate how much energy we receive from the Sun:

$$E = 3.6 \times 10^{-9}\, Sn\pi r^2$$

where E is solar energy in EJ, S is the *Solar* Constant in W/m^2, n is the number of hours, and r is the Earth's radius in km.

This formula is for the total solar energy intercepted by the Earth in n hours. If we want to calculate how much of the solar energy reaches the Earth's surface, we have to multiply the result by 0.58.

We can use this formula to calculate how much solar energy is reflected or absorbed by the Earth and the atmosphere and we can also calculate that our current global annual consumption of energy is equal to the average solar energy reaching the Earth's surface over a period of only 1 h and 16 min. Add to it an extra 30 min and we will have enough energy for the annual global consumption in 2020.

1.1. Solar radiation reaching the earth

The intensity of the solar radiation reaching us is about 1369 Watts per square meter [W/m^2]. This is known as the Solar Constant. It is important to understand that it is not the intensity per square meter of the Earth's surface but per square meter on a sphere with the radius of 149,596.000 km and with the Sun at its centre.

The total solar radiation intercepted by the Earth is the Solar Constant multiplied by the cross section area of the Earth. If we now divide the calculated number by the surface area of the Earth, we shall find how much solar radiation is received, on average, by a square meter of the Earth's surface. Thus, the average solar radiation S per square meter of the Earth's surface is

$$R = \frac{S\pi r^2}{4\pi r^2} = \frac{1369}{4} \approx \text{W/m}^2$$

where S in the Solar Constant in W/m^2 and r is the Earth's radius.

1.2. Solar radiation reaching the earth surface

However, our calculations are not yet finished because we have not yet considered the influence of the Earth's atmosphere. The value we have calculated is for the average solar radiation intensity at the outer regions of the Earth's atmosphere. What we want to know is how much of this radiation reaches the earth surface where we are.

On average, each square meter of the upper regions of the atmosphere receives 342 Watts of solar radiation [W/m^2]. The atmosphere absorbs on average 67 W/m^2 and reflects 77 W/m^2. About 198 W/m^2 reaches the Earth's surface, of which 168 W/m^2 is absorbed and 30 W/m^2 is reflected back to space. The total of the reflected radiation is 107 W/m^2, or 31% of the incoming radiation.

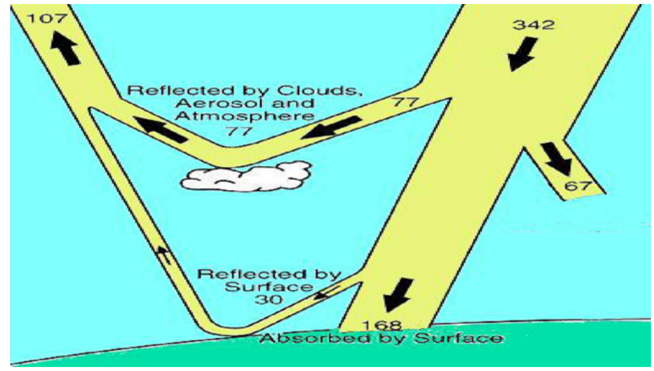

Fig. 1. The distribution of the solar radiation.
Source: Modified figure of Houghton et al. (2001).

The intensity of solar radiation depends on the time of the year and geographical positions as illustrated in Fig. 1.

For instance, Kimball (1919), Angstrom (1924), Prescott (1940), and Page (1961) correlated the solar irradiation with the sunshine duration for their estimations. Analogously, Hargreaves and Samani (1982), Bristow and Campbell (1984), and Allen (1995) used air temperature measurements. Recently, Chandel et al. (2005) proposed models both based, respectively, on the sunshine duration and on the air temperature.

The rate of energy consumption per capital has become a criterion of success in developing countries like India, providing the growing society with constant energy (Zafer et al., 2007). Fossil fuels reserves which provide the most part of energy sources of the world are limited and generally decreasing with environmental problems. India needs to encourage the non-conventional energy sources particularly solar energy to cope up with the future energy demands.

The availability of data on radiation is limited in developing countries and some limitations in measurements have also been observed in the developed countries (Samani, 2000). Some models such as ARNO (Todini, 1996) and SVAT (Yang, 2000) have postulated that radiation data. Here the acquired data is from metrological stations, where as models like SWAT (Arnold et al., 1996) and SHE (Bathurst & Cooley, 1996) generate radiation data from other readily available data. These procedures concentrate on various methods to estimate solar radiation like Temperature-based (TB) approach.

In the present work, solar radiation estimation has been done for the first time for Hyderabad, Vishakhapatnam and Anantapur, A.P, to utilize solar energy for useful purpose. (1) Hyderabad lies on the Deccan Plateau, 541 m (1776 ft) above sea level, over an area of 625 km^2 (244 mile^2). It is located at latitude 17°20′N and longitude 78°30′E. The population of the metropolitan area was estimated above 6.3 million. (2) Vishakhapatnam (Vizag) is second largest city in Andhra Pradesh with an area of 550 km^2. It is located at latitude 17°44′N, longitude 83°23′E and altitude 3.0 m. The population is 1.3 million. (3) Anantapur city in Andhra Pradesh with an area of 64 km^2. It is located at latitude 14°42′N, longitude 77°35′24″E and altitude 334.0 m. The population of the city is around 0.5 million.

2. Description of the study area

To evaluate the performance of the three cities in the estimation of solar radiation, the Sea coast area (Vishakhapatnam), Hyderabad and Anantapur has been considered. The temperature with a mean annual temperature of 38 °C, winters are relatively cold in the month of January, average monthly temperature approaches to 32 °C. The temperature data from 1999 to 2000 were studied and

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