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Maps of Regression Coefficients for Estimation of Global Solar Radiation using Meteorological Data for Continental Landmasses

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Abstract. This paper intends to bring to the forefront the much needed strategy for harmonizing the pockets of researches and derivations carried-out to-date across the globe, and produce a single document that assigns values of regression coefficients for estimation of global solar radiation using meteorological data, for every location on the continental landmasses.

Herewith, probe is made on the equations for estimation of global solar radiation using meteorological data, and a methodology proffered for actualizing the creation of the first single document on regression coefficients for estimation of global solar radiation using meteorological data, as a map and culminating into assigning values of regression coefficients to locations on the continental landmasses, similar to longitudes and latitude values. Taking into consideration the diversities and site-specific nature of those values.

The first set of Maps of Regression Coefficients for Estimation of Global Solar Radiation using Meteorological Data, in the World.

Keywords: Extraterrestrial Solar Radiation; Global Solar Radiation; Meteorological Data

1. Introduction

Starting with the Angstrom (1924) that relates the global solar radiation (GSR), extraterrestrial solar radiation (ESR), meteorological element data and regression coefficients, up-to its recent variations, the use of meteorological data for estimation of global solar radiation has been a tool used by various researchers, in different locations**.**

The above mentioned equation came handy as an alternative to the costly instruments, for measuring the GSR of a particular location, which is in essence so location-specific to assume universal value. Similarly, equations for deriving the values of ESR are also discussed in this paper.

Using the values extraterrestrial solar radiation (H0), mean daily, weekly, monthly, annual and 25yrs average of measured global solar radiation (H), and respective meteorological elements (temperatures and relative humidity), records for each location, the clearness indices (H/H0) will be computed, then a linear or higher equations will be formed, with values of H/H0) and respective meteorological element as variables, while the regression coefficients as constant. By solving the linear or higher order equations, the values of the constants a&b will be determined. On obtaining the values of a & b for each location a color-coding will be employed to categorize or classify locations/regions/zones with similar regression coefficient values, on a map of the world.

2. Theoretical Background

2.1. Computation of Extraterrestrial Solar Radiation (H0)

The mean daily extraterrestrial solar radiation H0) on a horizontal surface, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year may be obtained by the Klein relationship (Toğrul[1], 2009; Medugu,& Yakubu[2] 2011; Sanusi & Segun[3], 2011), as given below, using the following equations

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$$H_0 = \frac{24}{\pi} \times 3600 I_{SC}\left[1 + 0.033\cos\left(\frac{360}{365}d_n\right)\right]\left[\left(\frac{2\pi}{60}\right)\sin\varphi\sin\delta + \cos\varphi\cos\delta\sin\omega_s\right] \quad (1)$$

$$\omega_s = \cos^{-1}(-\tan\delta\tan\varphi) \quad (2)$$

The declination angle δ can be calculated by the equation

$$\delta = 23.45\sin\left[360\frac{284 + dn}{365}\right] \quad (3)$$

The values of the monthly extraterrestrial solar radiation can be taken as the values of the daily extraterrestrial solar radiation for the 15th day or calculated by taking the average of each month, i.e.

$$\hat{H}_0 = \frac{\textbf{total extraterrestrial radiation for the month}}{\textbf{number of days in the month}} \quad (4)$$

2.2. Global Solar Radiation Estimation Equations

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface (MJ m-2 day-1) using the sunshine duration data is due. Angstrom and later with Prescott have put the Angstrom correlation in more convenient form (Ahmed, Ahmad & Akhtar [4], 2009, Augustine & Nnabuchi[5], 2009; Yekinni,& Abisoye[6], 2011; Medugu & Yakubu[2], 2011; Allen, Pireira, Reas & Smith[7], 1998),

as;

$$H = \left[a + b\left(\frac{n}{N}\right)\right]H_0 \quad (5a)$$

or,

$$\hat{H} = \left[a + b\left(\frac{n}{N}\right)\right]\hat{H}_0 \quad (5b)$$

2.3. Variations of GSR Estimation Equations

Meteorological Data Models include either linear models, with single variable or multiple variables, according to Falayi, Adepitan & Rabiu[8] (2008), as in the following equations;

$$H = \left[a + b\left(\frac{n}{N_0}\right) - c(\theta) + d(RH) + e(T)\right]H_0 \quad (6a)$$

or,

$$H/H_0 = a + b\left(\frac{n}{N_0}\right) + c(\theta) + d(RH) + e(T) \quad (6b)$$

$$H/H_0 = a + b\left(\frac{n}{N}\right) + c(\theta) + d(RH) \quad (7)$$

$$\frac{H}{H_0} = a + b\left(\frac{n}{N}\right) + c(RH) \quad (8)$$

$$H/H_0 = a + b\left(\frac{n}{N}\right) \quad (9)$$

and higher order equations, like ;

$$H/H_0 = a + b\left(\frac{n}{N}\right) + c\left(\frac{n}{N}\right)^2 \quad (10)$$

Although it is found that the second and third order correlations do not improve the accuracy of estimation of global solar radiation (El-Sebaii, Al-Hazmi, Al-Ghamdi &Yaghmour[9], 2010).

The values of a,b,c,d,e ….etc are the regression coefficients of the individual equations.

2.4. Some Determined values of Regression Coefficients

According to Ahmad & Ulfat[9] (2004)

Rietveld examined several published values of regression coefficient for Angstrom-type relations and suggested use of the following correlation:

$$H/H_0 = 0.18 + 0.62\left(\frac{n}{N}\right) \tag{11}$$

Using the data of bright sunshine hours and global radiation for 48 locations around the world, Bahel et al. developed the relation

$$H/H_0 = 0.16 + 0.87\left(\frac{n}{N}\right) + 0.61\left(\frac{n}{N}\right)2 \tag{12}$$

Temperature and relative humidity based estimation is widely used since temperature and relative humidity data are measured and recorded in many weather stations. Diversity and Universal Values of Regression Coefficients

The values of a, b, c, etc, for various locations have been derived, that proves that these site specific nature of these coefficients, but only available in advanced level literature (journals and textbooks), requiring at-least a certain level (Advanced) of education to come across.

Attempts have been made to produce universal constant values of these coefficients that distinguish locations according to vegetation (plant species) cover predominant in the locations/zones. But, closer look at values and the global solar radiation thus estimated reveals an intriguing fallacy that expose the cast-in-stone readings as insufficient and unreliable, nay valid.

3. Methodology

As a Road-Map for efficient and effective conduct of the research the followings methodology will be adopted in stage and activities.

- Creation of MS Excel Equation and determining Extraterrestrial Solar Radiation (ESR) using the values of latitude of each location for the continental landmasses in the world
- Sourcing Meteorological Data records for:- Measured Global Solar Radiation, Temperature Relative Humidity
- Determining clearness indices [$\frac{H}{H_0}$] for the continental landmasses.
- Forming a linear equations with [$\frac{H}{H_0}$] and meteorological elements values as variables, for each zone of the continental landmasses.
- Determining the respective regression coefficients [a&b] for each zone or location of the continental landmass, by solving the linear equations formed above.
- Grouping the values of a & b according to ranges with suitable/colors and intensities.
- Applying color coding to world maps with emphasis on continental regions or landmass, according to the categories via various combinations of daily, weekly, monthly, annual and 25yrs meteorological elements data averages.

4. Result and Discussion

The research envisaged in this paper aimed at harmonizing the pockets of researches and derivations carried-out to-date across the globe, and produce a single document that assigns values of regression coefficients to all locations on the continental landmasses, with their diversities and specific nature taken into consideration.

Using the values extraterrestrial solar radiation (H_0), mean daily, weekly, monthly, annual and 25yrs average of measured global solar radiation (H), and respective meteorological elements (temperatures and relative humidity), records for each location, the clearness indices (H/H_0) will be computed, then a linear or higher equations will be formed, with values of H/H_0) and respective meteorological element as variables, while the regression coefficients as constant, as in;

$$y = mx + c \qquad (13)$$

$$y = \left(\frac{H}{H_0}\right) = \text{Clearness Index}$$ Where;

$m = b =$ Regression Coefficient

$x =$ meteorological element value

$c = a =$ Regression Coefficient

By solving the linear or higher order equations, the values of the constants a&b will be determined.

On obtaining the values of a & b for each location a color-coding will be employed to categorize or classify locations/regions/zones with similar regression coefficient values, on a map of the world.

The first set of Regression Coefficients for Estimation of Global Solar Radiation using Meteorological Data Maps, in the World.

These maps can assume so many forms, as;

Regression Coefficients of Linear (or Higher Order) Equations for Estimation of Global Solar Radiation using Minimum Temperature, Maximum Temperature, Minimum and Maximum Temperature Ratios, Relative Humidity, and so-on, Maps.

ie.

- $\dfrac{H}{H_0} = a + b\left(T_{MIN}\right)$
- $\dfrac{H}{H_0} = a + b\left(T_{MAX}\right)$
- $\dfrac{H}{H_0} = a + b\left(\dfrac{T_{MIN}}{T_{MAX}}\right)$
- $\dfrac{H}{H_0} = a + b(RH)$

5. Conclusion

Indeed, this research envisages revolutionalise the concept and procedures of deriving the regression coefficients (a, b, c, d,etc.) for estimation of global solar radiation using meteorological data world-over, in that it modifies and simplifies the basic approaches.

It will bring to the fore-front the assigned values of regression coefficients of all locations/zones/regions on the continental landmasses for estimation of global solar radiation, with respect to local weather/climate, similar to latitude and longitude values.

Moreover, the values of the regression coefficients so obtained can readily be put to use, by taking the readings of relevant meteorological element, using single or at least two (2) instruments (ie, thermometer and or Hygrometer), while the extraterrestrial solar radiation also has a definite value with respect to the latitude of the locations/zones/regions, substitute in the relevant linear equation and arrive at the estimated value of the global solar radiation for the locations/zones/regions.

This doesn't require any advanced level of education nor that of an advanced level instrument (ie, Pyramoneter, Radiometer/Solarimeter**,** Pyrheliometer, etc.), the instrument(s) (thermometers and/or hygrometer) to be used are cheap and widely available even in the remotest of locations, in that they may be obtained in many establishment as, primary school to mention the commonest.

Nomenclature

H = daily GSR on a horizontal surface ($MJm^{-2}day^{-1}$)
H= daily ESR on horizontal surface

$$H_{0=} = \text{daily ESR on a horizontal surface}\left(MJm^{-2}day^{-1}\right)$$

Ĥ = the monthly average daily GSRon a horizontal surface ($MJm^{-2}day^{-1}$)
Ĥ0 = the monthly average daily ESR radiation on a horizontal surface $MJm^{-2}day^{-1}$)
n = the monthly average daily number of hours of bright sunshine (hrs)
N = the monthly average daily maximum number of hours of possible sunshine (hrs)
RH=reltive humidity
Ɵ = monthly average of daily temperature
T=T_{Mmin}/T_{max}= minimum temperature to maximum temperature ratio
A,b,c,d,e…… = the regression coefficients
I_{SC}= solar constant
d= inverse relative distance Earth-Sun
ω_s =sunset hour angle s
φ =latitude
δ = solar declination
dn =number of the day in the year between 1 (1st January) and 365 or 366 (31st December)

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