Angstrom-Prescott model based Regression Coefficient Calculation for the Region of Botucatu, Brazil

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Abstract- **The primary source of energy for all surface phenomena and life on earth is the energy of sun. Solar radiation is the radiant form of energy from the sun and provides light and heat for the earth. The amount and intensity of solar radiation that a location receives depends on a variety of factors like latitude, season, time of day, cloud cover and altitude. The computed solar radiation from the extraterrestrial direct and diffuse components of the solar radiation taking the sunshine duration, temperature and relative humidity into consideration is Global Solar Radiation.**

In this work, the estimation of Regression Coefficient (a and b) for the region of Botucatu, State of Sao Paulo, Brazil using Angstrom- Prescott Method (1924) for the year 2015 is to be done. The data are collected from the Solar Radiometric Station situated at the College of Agricultural Sciences (FCA), University of the State of São Paulo (UNESP), located in Botucatu. The estimation of Regression Coefficient is to be done on Origin 6.0 Professional Software. The sunshine hour data is manually read by the Sunshine Record Card in Heliograph and the Global solar radiation is recorded with the help of Pyranometer and Campbell Scientific CR3000 data logger in the solar radiometric station. The data of Global solar radiation and sunshine hour collected and fed to software to provide results of Regression coefficient for the region of Botucatu in the year 2015.

Keywords: Angstrom- Prescott Method (1924), Campbell Scientific CR3000 data logger, Global Solar Radiation, Origin 6.0 Professional, Pyranometer, Regression Coefficient (A-P), Solar Radiometric Station.

I. INTRODUCTION

As the heat and the light required by all growing plants are supplied by solar radiation, the sunshine hours is important in plant growth. Light can in large measure replace heat, while heat cannot entirely replace light in this process. The quality and the quantity of the sun-light transmitted to growing plants are both dependent upon atmospheric conditions, as well as upon the season of the year. They vary from place to place and from month to month [1].

The distributions of crops are influenced by sunshine, directly through radiation, and indirectly through its effect upon air temperatures. Abundant sunshine is required of most plants because it furnishes the required energy for certain chemical activities within growing plants, as well as promotes evaporation from the foliage.

II. LOCATION OF RADIOMETRIC STATION – BOTUCATU, SAO PAULO, BRAZIL

Botucatu is a city in the southeastern part of Brazil and is situated 224.8 km from São Paulo city. It has an area of 1,482.64 km^2 (572 sq mi). It lies on top of a plateau which is 804 meters high. The region has subtropical-humid weather, with hot wet summers and dry cold winters. The temperature rarely falls below 2 °C (36 °F) during winters.

The Solar Radiometric Station is situated at the College of Agricultural Sciences (FCA), São Paulo State University (UNESP), located in Botucatu (22º8′S latitude,48º26′W longitude and 786 m altitude). Botucatu is a municipality located in the mid western region of São Paulo state. The high altitude gradient between 400 and 500 m in the lowest region and between 700 and 900 m in the mountainous region can be seen in the city. The changes in air temperature and winds are caused because of these differences. Agriculture and solarimetric projects are very favorable because of the topography and climate in the region.

III. TYPES OF SOLAR RADIATION

A. Direct Solar Radiation

The measure of the rate of solar energy arriving at the Earth's surface from the Sun's direct beam, on a plane perpendicular to the beam is called direct solar radiation and is basically measured by a pyrheliometer which is mounted on a solar tracker. The Sun's beam is always directed into the instruments field of view during the day is ensured by the tracker. The pyrheliometer has a field of view of five degree. It is necessary to obtain the horizontal component of the direct solar irradiance in order to use this measurement for comparison with global and diffuse irradiances. By multiplying by the cosine of the Sun's zenith angle by the direct solar radiation, this can be achieved.

B. Diffused Solar Radiation

The measure of the rate of incoming solar energy on a horizontal plane at the Earth's surface resulting from scattering of the Sun's beam due to atmospheric constituents is called as diffused solar radiation. It is measured by a pyranometer, with its glass dome shaded from the Sun's beam. An occulting disc or a shading arm attached to a solar tracker is used for shading. The field of view of the pyrheliometer should be same as the angle subtended by the shading disc of the diffuse pyranometer. To ensure accuracy of measurement, it is important that the dome of the pyranometer is always fully shaded from the Sun's beam and should be checked for correct alignment on a regular basis. As diffuse solar radiation is a component of global solar radiation, diffuse solar radiation should be less than or equal to global radiation measured at the same time. When the contribution from direct solar radiation is zero then Global and diffuse radiation will be equal that is, when the Sun is obscured by thick cloud, or the sun is below the horizon.[5][6]

C. Global Solar Radiation

The measure of the rate of total incoming solar energy both direct and diffuse on a horizontal plane at the Earth's surface is called Global solar radiation. To measure this quantity with limited accuracy, a pyranometer sensor can be used. By summing the diffuse and horizontal component of the direct radiation, the most accurate measurements are obtained [7].

D. Extraterrestrial Radiation

Extraterrestrial radiation is the solar radiation incident outside the earth's atmosphere. On an average the extraterrestrial irradiance is 1367 W/m^2. It is usually expressed in irradiance units (Watts per square meter) on a plane normal to the sun.

IV. ANGSTROM – PRESCOTT EQUATION

The methodology for calculating the global solar radiation used was the methodology proposed by **Angstrom-Prescott (1924)**. This methodology presents the following equation [2][3]:

$$R_g = R_o\left[a + b * \left(\frac{n}{N}\right)\right] \qquad (1)$$

Where: Rg → global solar radiation, in MJ / m² day;
Ro → Solar radiation reaching the top of the atmosphere, in MJ / m² day;
a → coefficient a of the Angstrom equation;
b → coefficient b of the Angstrom equation;
n → number of hours of sunshine (hours), as measured by a heliograph.
N → calculated photoperiod.

To calculate global solar radiation using various parameters, several empirical models have been developed. The earliest model used for estimating global radiation was developed by Angstrom (1924), in which clear sky radiation data and the sunshine duration data were used [4].

V. SOFTWARE USED FOR CALCULATING REGRESSION COEFFICIENT

Origin 6.0 Professional is a proprietary computer program for interactive scientific graphing and data analysis. OriginLab Corporation produced this software, which runs on Microsoft Windows. Origin includes various 2D/3D plot types graphing support. Some independent open source clones like SciDAVis are inspired by it.

Origin include statistics, signal processing, curve fitting and peak analysis in data analysis. Based on the Levenberg–Marquardt algorithm, the Origin's curve fitting is performed by a nonlinear least squares fitter. Origin imports data files in various formats such as ASCII text, Excel, NI TDM, etc. It also exports the graph to various image file formats such as JPEG, GIF, EPS, TIFF, etc. For accessing database data via ADO, there is also a built-in query tool.

Origin is primarily a GUI software with a spreadsheet front end. Origin's worksheet is column oriented unlike popular worksheets like Excel. Associated attributes like name, units and other user definable labels are on each column. Origin uses column formula for calculations instead of cell formula. Origin also has a scripting language (LabTalk) for controlling the software, which can be extended using a built-in C/C++-based compiled language (Origin C). The open-source library liborigin can read Origin project files (.OPJ). Originlab maintains also a free component (Orglab) that can be used to create (or read) OPJ files.

VI. STEPS TO CALCULATE REGRESSION COEFFICIENT

The followings steps for estimating regression coefficients are:

- Calculation of Declination angle of the sun using the formula:

$$\delta = 23.45° \sin\left[\frac{360(n-80)}{365}\right] \qquad (2)$$

Where:
δ → Declination Angle
n → No. of days from 1st Jan

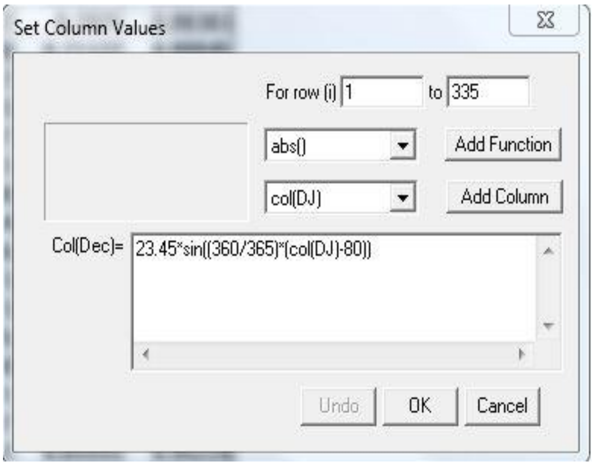

Fig. 1. Setting equation for Column of Declination Angle

- Calculation of Daily Hour Angle using formula:

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \qquad (3)$$

Where:
δ → Declination Angle
φ → Latitute Angle
ω_s → Hour Angle

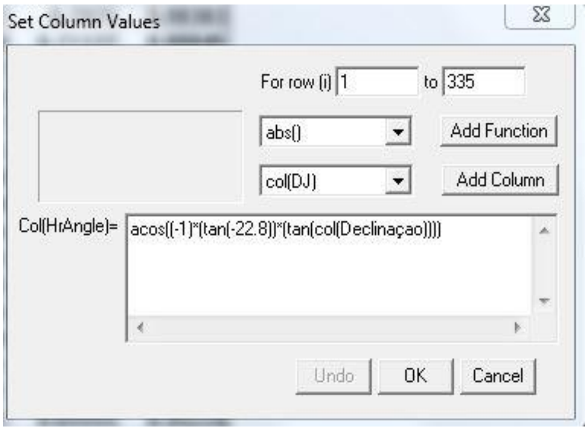

Fig.2. Setting equation for Column of the Hour Angle

- Calculation of Extraterrestrial Radiation using the formula:

$$H_0 = 37.6\,(\omega_s^* \sin\varphi \sin\delta + \cos\varphi \cos\delta) \qquad (4)$$

Where:
δ → Declination Angle
φ → Latitute Angle
ω_s → Hour Angle
H_0 → Extraterrestrial Radiation

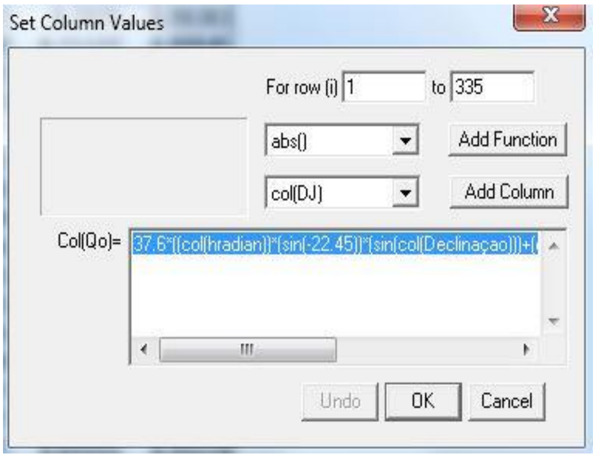

Fig.3. Setting equation for Column of Extraterrestrial Radiation

- Calculation of Photoperiod using the formula:

$$N = 2\,\omega_s\,/15 \qquad (5)$$

Where: N → Photoperiod
ω_s → Hour Angle

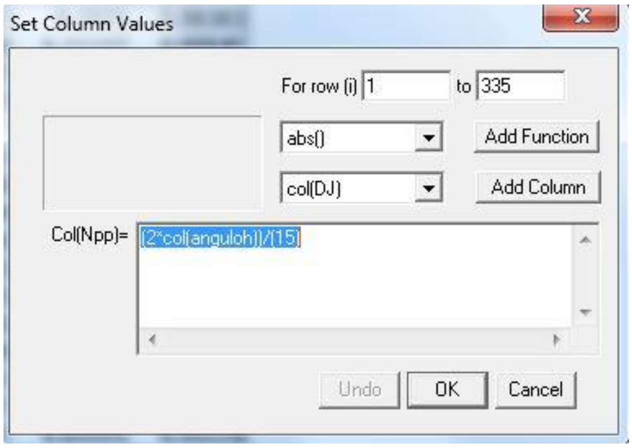

Fig. 4. Setting equation for Column of Photoperiod

Day	January '15	February '15	March '15	April '15	May '15	June '15	July '15	August '15	September '15	October '15	November '15	December '15
1	7:12	08:20	11:15		10:25	01:00	0	09:50	10:10	05:30	0	04:50
2	08:12	08:00	11:30		10:40	0	0	10:00	10:08	09:35	02:20	05:15
3	09:12	11:05	11:10		06:00	06:55	0	10:00	09:45	0	01:50	02:00
4	10:12	01:30	08:35		00:30	09:05	0	11:55	07:30	03:00	02:05	06:55
5	11:12	01:05	08:12		07:15	09:45	0	09:15	04:07	11:20	00:25	05:45
6	12:12	03:10	02:50		09:15	09:55	07:30	09:50	05:45	11:15	01:10	02:00
7	13:12	09:20	02:00		09:45	09:40	0	09:55	04:00	10:45	01:55	03:00
8	14:12	10:10	00:50		09:20	08:12	0	09:50	0	10:35	01:30	07:50
9	15:12	04:30	01:05		10:45	09:10	02:00	09:55	06:55	05:40	03:05	02:40
10	16:12	09:15	08:10		03:50	09:42	09:30	09:50	0	03:45	08:30	01:00
11	17:12	07:05	04:35		01:40	09:45	0	09:25	00:15	02:30	02:50	06:50
12	18:12	10:10	05:30		08:15	07:40	10:00	09:50	01:00	06:10	09:30	05:10
13	19:12	06:50	01:35		08:00	09:20	08:50	10:05	10:20	10:10	03:20	05:10
14	20:12	04:40	0		09:20	09:15	08:15	10:00	07:20	11:00	08:55	01:20
15	21:12	02:40	06:00		01:42	0	04:10	09:35	09:55	08:25	06:50	03:30
16	22:12	02:40	06:15		09:35	08:00	03:40	10:10	10:25	09:20	00:50	01:30
17	08:40	00:25	08:00		06:00	06:10	0	09:40	08:20	08:00	06:55	06:45
18	11:20	00:35	0		00:40	07:45	09:45	02:15	10:10	09:20	08:50	09:50
19	11:55	06:15	0		02:55	03:20	09:45	10:05	10:40	11:05	08:30	03:00
20	09:00	01:05	01:30		03:10	08:25	09:40	10:30	10:45	09:15	00:55	00:40
21	05:45	11:15	03:00		08:35	09:15	00:28	08:35	09:30	08:10	07:40	05:55
22	07:30	11:15	03:00		10:30	09:40	06:20	10:15	10:45	05:35	08:45	03:30
23	05:50	10:25	09:45		06:45	07:35	07:30	09:25	10:05	01:30	0	12:25
24	12:30	09:15	10:50		07:50	06:30	08:05	01:55	10:25	11:00	0	03:20
25	09:40	04:52	10:48		09:30	08:10	05:15	01:20	06:25	07:45	0	01:30
26	06:00	09:40	09:30		09:10	09:30	03:30	09:20	01:15	05:45	01:25	01:45
27	10:10	07:35	06:15		08:40	09:35	08:40	0	09:30	02:50	08:20	0
28	05:55	09:05	05:50		0	08:55	10:00	06:25	01:40	04:15	07:50	01:10
29	05:45		02:20		08:35	09:05	10:05	10:35	04:22	10:45	07:08	0
30	05:15		03:40		05:20	05:50	10:00	10:30	05:05	11:00	03:55	0
31	10:30		09:15		00:05		09:50	10:00		0		01:05

Table.1.Total Sunlight hour from Heliograph for the year 2015

- Total Sunlight hour should be measured using Heliograph and reading Heliograph Recorder tape.

- The Global solar radiation should be recorded using a Data Logger.

	DJ[Y]	eclinaçao[Y]	anguloh[Y]	hradian[Y]	Qo[Y]	fotop[Y]	n[Y]	Global[Y]	kT[Y]	IsolN[X]
1	1	-22.93054	100.24349	1.74958	41.28194	13.3658	7.2	23.67154	0.57341	0.53869
2	2	-22.84266	100.19926	1.74881	41.26692	13.35599	6.83	22.12749	0.5362	0.51123
3	3	-22.748	100.15169	1.74798	41.25066	13.35356	5.25	19.98965	0.48459	0.39315
4	4	-22.6466	100.10082	1.74709	41.23314	13.34678	0	15.9901	0.3878	0
5	5	-22.53849	100.04667	1.74614	41.21434	13.33956	4.83	22.19503	0.53853	0.36208
6	6	-22.42371	99.98928	1.74514	41.19425	13.3319	3.17	18.40666	0.44683	0.23778
7	7	-22.30228	99.92868	1.74408	41.17286	13.32382	8.17	26.71785	0.64892	0.61319
8	8	-22.17424	99.86491	1.74297	41.15013	13.31532	8.75	27.11561	0.65894	0.65714
9	9	-22.03962	99.79801	1.7418	41.12606	13.3064	11.75	28.89112	0.7025	0.88303
10	10	-21.89848	99.72801	1.74058	41.10062	13.29707	10.75	29.23148	0.71122	0.80845
11	11	-21.75085	99.65496	1.73931	41.07379	13.28733	10.5	27.43717	0.668	0.79023
12	12	-21.59678	99.57889	1.73798	41.04555	13.27719	8.5	27.41893	0.66801	0.6402
13	13	-21.4363	99.49986	1.7366	41.01588	13.26665	8.17	28.29297	0.68981	0.61583
14	14	-21.26947	99.4179	1.73517	40.98476	13.25572	6	22.55351	0.55029	0.45263
15	15	-21.09634	99.33305	1.73369	40.95217	13.24441	12.25	29.3698	0.71717	0.92492
16	16	-20.91696	99.24538	1.73216	40.91807	13.23272	12	29.454	0.71983	0.90684
17	17	-20.73138	99.15492	1.73058	40.88245	13.22066	8.67	27.46636	0.67184	0.65579
18	18	-20.53966	99.06172	1.72895	40.84527	13.20823	11.33	28.07073	0.68725	0.8578
19	19	-20.34185	98.96584	1.72728	40.80653	13.19545	11.92	29.05473	0.71201	0.90334
20	20	-20.13801	98.86731	1.72556	40.76619	13.18231	9	27.52585	0.67521	0.68273
21	21	-19.92821	98.7662	1.7238	40.72422	13.16883	5.75	23.12018	0.56773	0.43664
22	22	-19.7125	98.66255	1.72199	40.6806	13.15501	7.5	22.87881	0.5624	0.57013
23	23	-19.49095	98.55641	1.72013	40.63531	13.14085	5.83	17.2707	0.42502	0.44365
24	24	-19.26362	98.44784	1.71824	40.58832	13.12638	12.5	26.60752	0.65555	0.95228
25	25	-19.03059	98.33688	1.7163	40.5396	13.11158	9.67	26.1555	0.64518	0.73752
26	26	-18.79192	98.22359	1.71433	40.48913	13.09648	6	19.98698	0.49364	0.45814

Table.2. Data fetched for calculating regression coefficient.

VII. RESULTS AND DISCUSSIONS

The graph is plotted between the Total sunlight hours divided by Photoperiod on X-axis and the Global solar radiation divided by Extraterrestrial radiation on Y-axis.

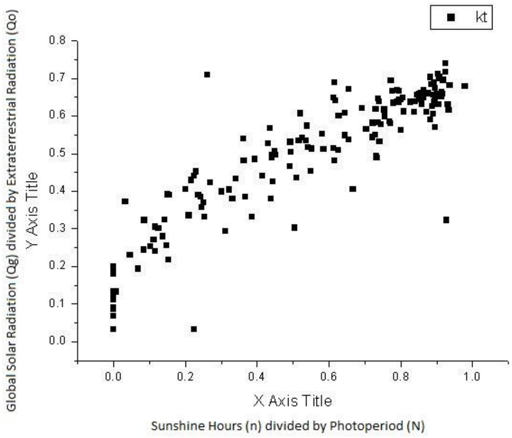

Fig.5. Graph plotted between the Total sunlight hours divided by Photoperiod and the Global solar radiation divided by Extraterrestrial radiation.

After plotting the graph between the Total sunlight hours divided by Photoperiod on X-axis and the Global Solar Radiation divided by Extraterrestrial Radiation on Y-axis, a linear graph is to be found to get the value of Regression Coefficient of A-P Equation a and b for the region of Botucatu.

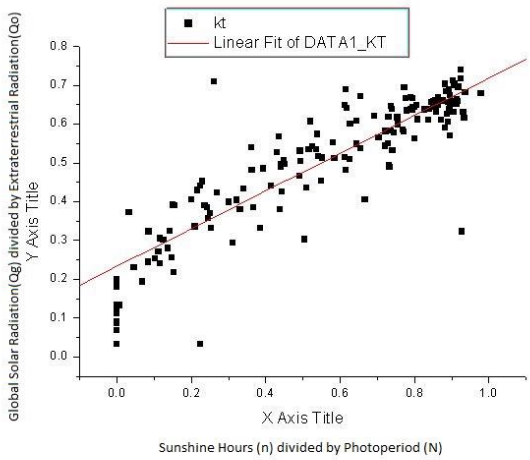

Fig.6. Linear Fit Regression Graph plotted between the Total sunlight hours divided by Photoperiod and the Global solar radiation divided by Extraterrestrial radiation.

The value of Regression Coefficient (a and b) was estimated using Origin 6.0 Professional Software for the region of Botucatu, State of São Paulo, Brazil for the year 2015.

The value of A was estimated to be 0.23325 with an error of 0.00883 and the value of B to be 0.48552 with an error of 0.01404.

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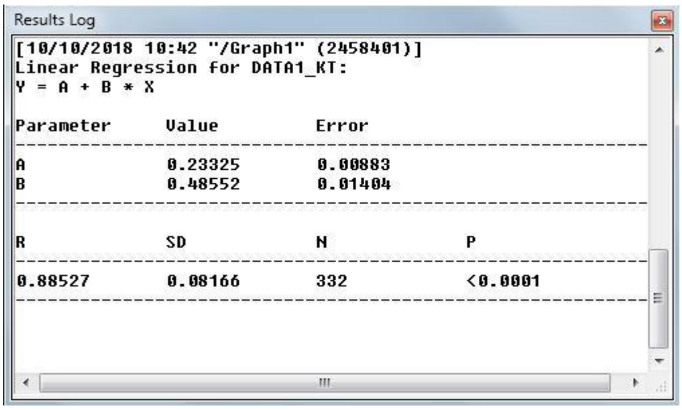

Results Log

[10/10/2018 10:42 "/Graph1" (2458401)]
Linear Regression for DATA1_KT:
Y = A + B * X

Parameter	Value	Error	
A	0.23325	0.00883	
B	0.48552	0.01404	
R	SD	N	P
0.88527	0.08166	332	<0.0001

Fig.7.The value of Regression coefficient for Botucatu for the year 2015.

VIII. CONCLUSION

The data for estimating of Regression Coefficient (a and b) for the region of Botucatu, State of Sao Paulo, Brazil was collected from the Solar Radiometric Station situated at the College of Agricultural Sciences (FCA), University of the State of São Paulo (UNESP), located in Botucatu. The data collected was the Global Solar Radiation with the help of Pyranometer and Campbell Scientific CR3000 data logger which provides the data for Global Solar Radiation for every 5 minutes. The data logger grabs a value for Global Solar Radiation every 12 seconds and integrates them and forms an average of the data and provides a value of Global Solar Radiation every 5 minutes. The other data collected was Daily Sunshine Hour data from the Sunshine Recorder also called as Heliograph. The Sunshine record card was read for the year of 2015 and was tabulated (Table 1). With the help of the Origin 6.0 Professional Software, the declination angle, hour angle, Extraterrestrial Radiation and Photoperiod was calculated for each day of the year 2015. Graph was plotted between the Total sunlight hours divided by Photoperiod on X-axis and the Global Solar Radiation divided by Extraterrestrial Radiation on Y-axis (Fig.5). After the Linear Fit of the Graph (Fig.6) the value of Regression Coefficient (a and b) for the region of Botucatu, State of Sao Paulo, Brazil for the Year 2015 was estimated. The value of A was estimated to be 0.23325 with an error of 0.00883 and the value of B to be 0.48552 with an error of 0.01404.

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