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GLOBAL SOLAR RADIATION ESTIMATE IN MATO GROSSO DO SUL SUMMER – BRAZIL

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ABSTRACT

Solar radiation is a very important meteorological component of the hydrological, energetic, architectonic and agro environmental processes. However, the instruments that are responsible for their measurement have a high cost of acquest and maintenance. Therefore, empirical models have been developed for estimating the solar radiation and then, reducing costs. The objective of this research was to evaluate the efficiency of four empirical models of global solar radiation estimate (Annandale, Bristow-Campbell, Hargreaves-Samani and Weiss), applied to the cities of Amambai, Dourados, Itaquiraí, Ivinhema, Jutí, Rio Brilhante and Ponta Porã, MS state - Brazil. The climate data used by empirical equations were collected by automatic weather stations located in each of these cities and belonging to the network of meteorological stations of Instituto Nacional de Meteorologia (INMET) between the years 2017 and 2018. The values that were obtained by the estimation models were compared with solar radiation collected by the weather station and thus, the efficiency of each model was evaluated. The square root of the mean square error, correlation coefficient and concordance index. Only in the cities of Itaquiraí and Ivinhema one of the four models was recommended, which is the Bristow-Campbell. In others cities, none of the models can be applied for estimating the solar radiation, because the results of the methods were not satisfactory.

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INTRODUCTION

Solar radiation is the driving force for many physicochemical and biological processes that occur on Earth, such as plant transpiration, light for photosynthesis, water evaporation and the formation of clouds in the atmosphere. irrigated crops, climate change, among others (SOUZA *et al*., 2017). There are two ways to determine the amount of global solar radiation, the first being direct measurement, performed with the aid of instruments such as the pyranometer, and the second through indirect measurement involving empirical equations using climate data and heliographs (CRESESB, 2018).The types of sky cover as cloudy, partly and clear are used in some methodologies to obtain global solar radiation (CHEN *et al.* 2019). The clear sky conditions the result at high temperatures during the day (maximum temperature), because the atmosphere is transparent to solar radiation; and at low temperatures at night (minimum temperature) because longwave radiation is less absorbed by the atmosphere (ALLEN *et al*., 1997).BRISTOW & CAMPBELL (1984) created an empirical algorithm for estimating global solar

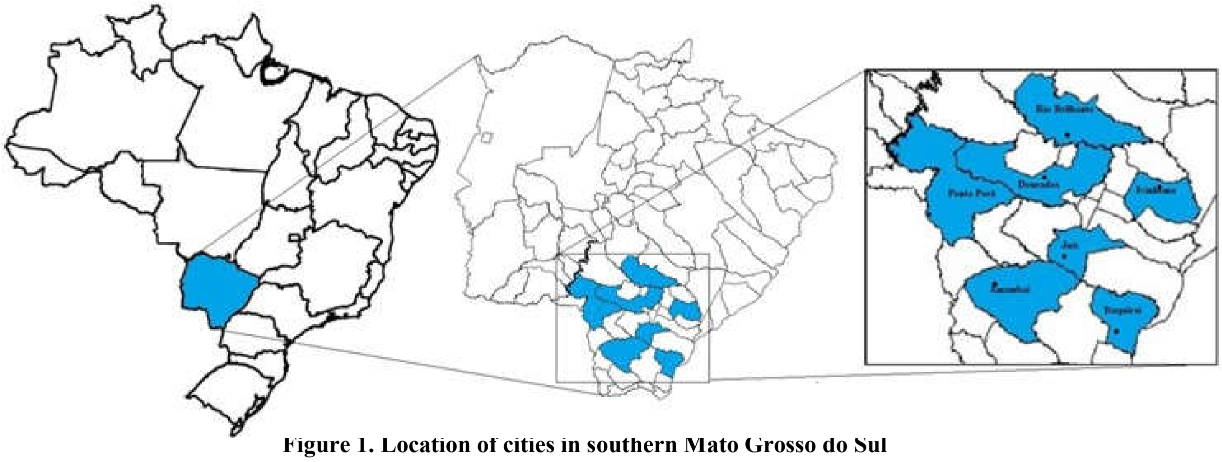

Figure 1. Location of cities in southern Mato Grosso do Sul

radiation only from daily maximum and minimum air temperatures and total daily precipitation. Another method used is that of HARGREAVES & SAMANI (1982), who proposed a simple model for estimating global solar radiation using maximum and minimum air temperatures, extraterrestrial radiation and a location adjustment coefficient (Kr). However, ALLEN (1997) mentions that the adjustment coefficient (Kr) employed in the method is empirical and varies with time, place and climate.Since indirect measurement of solar radiation from a given location results in an estimated value, not always accurately, empirical models need to be adjusted for each region.Thus, the present study aimed to evaluate four empirical models of global solar radiation in some municipalities of Mato Grosso do Sul / Brazil, in the summer season.

MATERIALS AND METHODS

The present work was carried out with the help of meteorological data obtained from December 21, 2017 to March 20, 2018 by meteorological stations belonging to the National Institute of Meteorology (INMET), located in Amambai, Dourados, Itaquiraí, Ivinhema, Jutí, Ponta Porã and Rio Brilhante, MS / Brazil (Figure 1).

Were collected hourly data from INMET (www.inmet.gov.br) of global solar radiation, maximum and minimum temperatures. With the aid of Excel ® software, the average daily solar radiation for each city was calculated using the models described in Equations 1 to 4.The solar radiation estimated by the model of ANNANDALE *et al.* (2002) (Equation 1) is a modification of the model of HARGREAVES & SAMANI (1982), with the addition of altitude.

$$Rs_{An} = 0{,}16\ (1+2{,}7x10^{-5}ALT)(T_x-T_n)^{0{,}5}R_a \qquad (1)$$

Where,
RsAn = global solar radiation estimated by Annandale model (MJ m^{-2} day^{-1});
ALT = mean altitude above sea level (m);
Tx = maximum air temperature (ºC);
Tn = minimum air temperature (°C);
Ra = solar radiation at the top of the atmosphere (MJ m^{-2} day^{-1}).

BRISTOW & CAMPBELL (1984) proposed Equation 2 to calculate solar radiation, where the main variable is temperature, in an exponential function.

$$Rs_{BC} = 0{,}7\ \left[1-\exp\left(-0{,}005(\Delta t)^{2{,}4}\right)\right]Ra \qquad (2)$$

Where,
Rs_{BC} = global solar radiation estimated by the Bristow-Campbell model (MJ m^{-2} day^{-1});
Δt = maximum and minimum temperature function equation for each specific day (ºC);

The model of HARGREAVES & SAMANI (1982) is in equation (3). It is based on atmospheric transmittance caused by air temperature variation.

$$Rs_{HS} = 0{,}16(T_x-T_n)^{0{,}5}Ra \qquad (3)$$

Where,
Rs_{HS} = global solar radiation estimated by Hargreaves-Samani model (MJ m^{-2} day^{-1});
In continental regions the value 0.16 is used as the empirical coefficient.

Already the model of WEISS *et al.* (2001) is applied in various agricultural regions of the United States, calculated with Equation 4.

$$Rs_{We} = 0{,}75\left[1-\exp\left(-0{,}226\frac{\Delta t^2}{Ra}\right)\right]Ra \qquad (4)$$

Where,

Rs_{We} = global solar radiation estimated by the Weiss model (MJ m^{-2} day^{-1}).

Statistical indicators

To measure the effectiveness of global solar radiation estimation models, the Person correlation coefficient (Equation 5) and the Willmott agreement index (Equation 6) were used.

$$r = \sqrt{1 - \left[\frac{\sum (Pi - Oi)^2}{\sum (Oi - O)^2}\right]} \qquad (5)$$

$$d = 1-\left[\frac{\sum (Pi - Oi)^2}{\sum(|P_i-\bar{O}| + |O_i-\bar{O}|)^2}\right] \qquad (6)$$

Where,
Pi = values estimated by the models;
Hi = observed values;
O = average of observed values;
N = number of observations.

The criterion used to evaluate and indicate which is the best model of solar radiation estimation for each municipality was to relate the magnitude of their accuracy, being the indicators, the correlation coefficient (r) and the agreement index (d) being able to state that the model recommended model for a given city was one that presented the valuesof "r" and "d" equal to or greater than 0.60 (WILLMOTT, 1981).

Table 1. Estimated solar radiation values (MJ m^{-2} day^{-1}) and statistical indices of the evaluated models, in the summer of 2017/2018 for the cities studied

Methods	Medium	Maximum	Minimum	RQME	β_1	β_2	r	d
				Amambai				
Annandale (An)	22.56	27.90	13.18	6.24	0.173	18.665	0.400	0.450
Bristow-Campbell (BC)	23.40	29.00	4.10	6.48	0.326	16.051	0.440	0.590
Hargreaves-Samani (HS)	22.29	27.57	13.03	6.24	0.171	18.449	0.400	0.450
Weiss (We)	17.08	25.27	2.97	8.14	0.314	9.993	0.490	0.470
				Dourados				
Annandale (An)	20.43	26.37	7.94	6.55	0.291	13.490	0.400	0.470
Bristow-Campbell (BC)	19.59	28.45	0.06	8.24	0.591	5.507	0.460	0.540
Hargreaves-Samani (HS)	20.19	26.06	7.84	6.66	0.287	13.333	0.400	0.460
Weiss (We)	13.52	24.92	0.08	11.83	0.459	2.572	0.480	0.300
				Itaquiraí				
Annandale (An)	21.89	27.17	16.55	4.31	0.282	15.570	0.598	0.627
Bristow-Campbell (BC)	22.41	28.83	11.15	4.22	0.49	11.406	0.661	0.753
Hargreaves-Samani (HS)	21.63	26.86	16.36	4.36	0.278	15.389	0.598	0.620
Weiss (We)	15.75	24.99	6.76	8.08	0.397	6.857	0.544	0.403
				Ivinhema				
Annandale (An)	21.34	26.64	15.96	5.64	0.227	16.022	0.592	0.529
Bristow-Campbell (BC)	21.53	28.27	9.55	5.26	0.427	11.515	0.659	0.708
Hargreaves-Samani (HS)	21.10	26.33	15.77	5.74	0.224	15.837	0.592	0.516
Weiss (We)	14.76	24.70	6.11	10.19	0.309	7.501	0.541	0.319
				Juti				
Annandale (An)	21.79	26.86	15.07	5.81	0.224	16.446	0.535	0.521
Bristow-Campbell (BC)	22.20	28.74	5.91	5.87	0.370	13.41	0.513	0.638
Hargreaves-Samani (HS)	21.54	26.55	14.89	5.90	0.222	16.275	0.535	0.510
Weiss (We)	15.64	25.33	3.82	10.13	0.261	9.439	0.406	0.294
				Ponta Porã				
Annandale (An)	20.56	25.88	13.63	4.81	0.199	16.333	0.393	0.476
Bristow-Campbell (BC)	19.93	27.96	4.00	5.39	0.444	10.492	0.461	0.617
Hargreaves-Samani (HS)	20.32	25.58	13.48	4.84	0.198	16.144	0.393	0.469
Weiss (We)	13.39	24.50	2.72	9.27	0.315	6.697	0.426	0.279
				Rio Brilhante				
Annandale (An)	22.26	28.36	16.17	5.57	0.237	16.72	0.574	0.565
Bristow-Campbell (BC)	23.09	29.09	9.67	5.54	0.328	15.404	0.536	0.646
Hargreaves-Samani (HS)	22.00	28.03	15.99	5.63	0.234	16.527	0.574	0.556
Weiss (We)	16.50	25.57	6.19	9.18	0.246	10.734	0.416	0.332

RQME = square root of mean error, β1 = angular coefficient, β2 = linear coefficient, r = correlation coefficient and d = agreement index

RESULTS AND DISCUSSION

In Amambai, as in other cities, the Bristow-Campbell (BC) and Weiss (We) models obtained angular coefficients (β1) higher than those of Annandale (An) and Hargreaves-Samani (HS), however. all indicate poor accuracy in representing observed solar radiation (Rs) observed data (Table 1). Regarding the evaluated methods, the observed result indicates unsatisfactory adjustment, considering the analyzed period, which is characterized, for the most part, by a period of heavy cloudiness, making it difficult for global solar radiation to arrive the earth's surface (MOOJEN *et al.,* 2012). Adopting only "r" as a criterion for defining model quality is not appropriate, as the model does not establish the type and magnitude of differences between a default value and a value predicted by estimation models (JIANG *et al.,* 2019).The highest inclination was verified in the city of Dourados, MS, using the BC model, where the angular coefficient was 0.591, however the scattered radiation observed with the observed showed great variability. Comparing the average values of solar radiation observed from the INMET station and the results of global solar radiation estimation models, we find that the We estimation model presented very low values for all municipalities (Table 1). In Amambai the average value of Rs estimated by the An, BC and HS models (Table 1) is very close to the observed Rs, which was 22.53 MJ m^{-2} day^{-1} (INMET), however in Amambai the values estimated by the models, presented correlation coefficient (r) of 0.444; 0.402; 0.402 and 0.486 respectively and the agreement index (d) of 0.591; 0.452; 0.449 and 0.468 for BC, An, HS and We, respectively.

In this case, all values of "r" were close to each other, however, below the recommendation value. In general for all municipalities, it was observed that the An and HS models always presented the same value of "r" in the evaluated periods, since both models are based on the square root difference between the maximum and minimum temperature and perhaps the same. altitude of cities do not have significant values to cause significant changes in the values of Rs estimated by the model of An. We model showed the highest RQME values for all municipalities when compared to the other models, indicating worse model performance (Table 1). RODRIGUES *et al.* (2008) estimated Rs based on daily thermal amplitude by Hargreaves & Samani method for Limoeiro do Norte-CE city/ Brazil and found "r" of 0.59. In the city of Dourados, the results obtained by BC An, HS and We models, in relation to the coefficients "r" were, respectively: 0.456; 0.403; 0.403 and 0.478, corroborating this Author. It was observed that the highest agreement index (d) was found by the BC model, with "d" worth 0.537. The An, HS and We models presented agreement indexes of 0.474; 0.464 and 0.304 respectively (Table 1).According to BARBERO *et al.* (2019) the occurrence of cloudiness during the rainy season partially justifies the smaller amount of insolation, since the solar reflectivity of clouds is much higher than the reflectivity of the cloudless atmosphere, which facilitates greater or lesser transmittance. In Itaquiraí it was possible to point out the values found for the “r” by the BC, An, HS and We models, being, respectively, 0.621; 0.598; 0.598 and 0.544. Therefore, it can be stated that the BC model has the largest “r” among the models. Only We model cannot be recommended in this city. Among all solar radiation estimation models, BC presented the highest correlation coefficient and agreement index. The values of “r” in Ivinhema for BC, An, HS and We models are respectively: 0.629; 0.592; 0.592 and 0.541.

The BC model presented the highest “d” among the estimation models, in the value of 0.708 and An presented the agreement index with value of 0.529, HS of 0.516 and We of 0.319.Comparing the global solar radiation values estimated by the HS method in relation to the values measured at the INMET weather station, MASSIGNAM (2007) obtained values for the accuracy coefficient “d” ranging from 0.67 in the locality of Itajaí to 0 , 86 in Urussanga-SC / Brazil. For Rio Brilhante the An and HS models presented the highest “r”, but were smaller than 0.60. Therefore, neither of these two methods can be recommended for estimating solar radiation in this city. The BC model presented the highest agreement index (0.646), but it was not a recommended estimation model for Rio Brilhante either, because its “r” was less than 0.60.Given these results, the empirical models proved to be mostly inaccurate as they are based only on temperature and radiation at the top of the atmosphere. KISI *et al.* (2019) point out the air temperature having a positive correlation with solar radiation. The thermal amplitude proposed by HARGREAVES & SAMANI (1982) is based on the fact that this factor promotes a cloudiness, because when compared to clear days, cloudy days tend to decrease in maximum air temperature. due to the low level of solar radiation, and increased minimum temperature measurements. According to data observed in Aquidauana-MS, in the absence of Rs data for any time of year, the Bristow-Campbell estimation proved to be better. However, the Annandale and Hargreaves-Samani method are only indicated for estimating solar radiation during the dry season (OLIVEIRA *et al.,* 2014).

Conclusions

In the municipalities of Amambai, Dourados, Jutí, Rio Brilante and Ponta Pora, none of the four models (Bristow-Campbell, Annandale, Hargreaves-Samani and Weis) are recommended for estimating global solar radiation. In the cities of Itaquiraí and Ivinhema it may be recommended to use the Bristow-Campbell model to estimate global solar radiation. The evaluation of the efficiency of empirical global solar radiation estimation models proved to be an important analysis as it presented differences between the results for the same site.

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