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Prediction of solar radiation with air temperature data in a coastal location in Tamilnadu

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सार – इस शोध पत्र का मुख्य उद्देश्य तमिलनाडु राज्य के तटीय स्थान अन्नामलै नगर में दैनिक सौर विकिरण का आकलन करने के लिए हरग्रीव्स विकिरण फार्मूला की कार्य प्रणाली का मूल्यांकन करना है। भारत मौसम विज्ञान विभाग की अन्नामलै नगर में स्थित वेधशाला में प्रेक्षित अधिकतम तापमान (*T*max) और न्यूनतम तापमान (*T*min) के आँकड़ों का उपयोग करके हरग्रीव्स विकिरण फार्मूला द्वारा दैनिक सौर विकिरण की गणना की गई है और इसमें समायोजन गुणांक (K_{RS}) 0.19 नियोजित किया गया है। प्रतिदिन प्रेक्षित धूप के घंटेवार आँकड़ों को लेकर आंग्सट्रॉम–प्रेसकॉट फार्मूला के उपयोग से भी दैनिक सौर विकिरण की गणना की गई है। दोनों फार्मूलों से प्राप्त किए पूरे वर्ष के सौर विकिरण के मानों में अधिक अंतर पाए गए हैं इसलिए विचाराधीन स्थान के अध्ययन के लिए समायोजन गुणांक (K_{RS}) निर्धारित किया गया है जिससे कि निर्धारित समायोजन गुणांक के उपयोग से दैनिक सौर विकिरण का सही ढंग से पूर्वानुमान दिया जा सके और इससे संबंधित वाष्पोज्सर्जन का भी सही ढंग से आकलन किया जा सके।

ABSTRACT. The objective of this study is to evaluate the performance of the Hargreaves' Radiation formula in estimating daily solar radiation for an Indian coastal location namely Annamalainagar in Tamilnadu State. Daily solar radiation by Hargreaves' Radiation formula was computed using the observed data of maximum temperature, *T*max and minimum temperature, *T*min, sourced from the India Meteorological Observatory located at Annamalainagar and employing the adjustment coefficient K_{RS} of 0.19. Daily solar radiation was also computed using Angstrom-Prescott formula with the measured daily sunshine hour data. The differences between the daily solar radiation values computed using the formulae were more pronounced in year around. Hence, the adjustment coefficient K_{RS} is calibrated for the study location under consideration so that the calibrated K_{RS} could be used to better predict daily solar radiation and hence better estimation of reference evapotranspiration.

Key words – Solar radiation, Hargreaves' radiation formula, Adjustment coefficient.

1. Introduction

Solar Radiation is one of the principal weather parameters affecting evapotranspiration. Knowledge of local solar radiation is essential for many applications in the fields of agriculture and irrigation engineering. It is required respectively for developing crop growth models and for design of irrigation systems. Architectural design of buildings, design of green buildings and design of solar systems also warrant solar radiation data. Costs, maintenance and calibration of measuring instruments slacken the availability of this useful information. This limited coverage of radiation data dictates the need to develop models to estimate on the basis of more readily available data (Al-Lawati *et al*. 2003; Almorox and Hontoria, 2004).

2. Background

Many empirical models are available for computation of solar radiation, using variables such as sunshine hours (Angstrom, 1924), air temperature (Hargreaves and Samani, 1982), precipitation (De jong and Stewart, 1993), relative humidity (Elagib *et al*. 1998) and cloudiness (Black, 1956). Sunshine duration is the most commonly employed parameter for estimating global solar radiation. Most of the models available for estimating solar radiation use the ratio (*n*/*N*) of actual

duration of sunshine and maximum possible duration of bright sunshine (Al-Lawati *et al*. 2003). The most widely used empirical method is that proposed by Angstrom (1924). He proposed a linear relationship between the ratio of average daily global solar radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration. The problem of determining clear sky global irradiance was bypassed by Prescott, who suggested using extraterrestrial radiation intensity values instead (Almorox and Hontoria, 2004). Accurate estimation of evapotranspiration demands accurate estimation of net radiation, R_n which in the difference between incoming solar radiation and out going radiation turn warrants an accurate estimation of solar radiation, *Rs*. If measured data on actual duration of sunshine hours are available for the location under consideration, then *Rs* can be computed using Angstrom-Prescott formula given by Equation 1 (Allen *et al*, 1998) :

$$R_s = \left\{ a_s + b_s \left(\frac{n}{N} \right) \right\} R_a \qquad (1)$$

where R_s is the solar or short-wave radiation in MJ m^{-2} day^{-1}, n is the actual duration of sunshine in hours, N is the maximum possible duration of bright sunshine or daylight in hours, n/N is the relative sunshine duration; R_a is the extraterrestrial radiation in $MJm^{-2}day^{-1}$ computed as a function of the latitude and the day of the year (Duffie and Beckman, 1991), a_s and b_s are the Angstrom constants. Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s will vary. Where no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters, the values a_s = 0.25 and b_s = 0.50 are recommended (Allen *et al.*, 1998).

However, in the absence of measured data on daily sunshine hours (n), solar radiation cannot be computed with the calculation procedures previously outlined. In such a situation, solar radiation could be derived from air temperature.

The difference between the maximum and minimum air temperatures is related to the degree of cloud cover in a location and hence can be used as the indicator of the fraction of extraterrestrial radiation that reaches the earth's surface. This principle has been utilized by Hargreaves and Samani (1982) to develop estimates of reference evapotranspiration using only air temperature data.

The Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions is given by Equation 2.

$$R_s = K_{RS} \ (T_{\max} - T_{\min})^{0.5} \ R_a \qquad (2)$$

where R_a extraterrestrial radiation in $MJm^{-2}day^{-1}$, $T_{\max}$ is the maximum air temperature in °C, T_{min} is the minimum air temperature in °C and K_{RS} is the adjustment coefficient.

The square root of the temperature difference is closely related to the daily solar radiation in a given location. The adjustment coefficient K_{RS} is empirical and differs for 'interior' or 'coastal' regions. For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, $K_{RS} \approx 0.16$ and for 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, $K_{RS} \approx 0.19$.

The temperature difference based method is recommended for locations where it is not appropriate to adapt radiation data from a regional station, either because of nonexistence of homogeneous climate conditions, or because of non-availability of data. As the study location for this work is a coastal region, this method can be employed for estimation of solar radiation, R_s, in the absence of measurement of data on actual hours of daily sunshine, n. Al-zoheiry *et al*. (2006) addressed the important need of model having a capacity to predict solar radiation for locations with no or very few data. Hargreaves' Radiation formula was used to estimate the daily solar radiation at three locations in Nigeria namely Owerri, Umudike and Uturu by Chineke (2002), Chineke (2008) and Chiemeka (2008) respectively.

The objective of this study is to evaluate the performance of the Hargreaves' Radiation formula for the Indian coastal location namely Annamalainagar in Tamilnadu State.

3. Materials and methods

The location taken for the study was Annamalainagar, a township near the temple Town of Chidambaram in Cuddalore District of Tamilnadu State, India. The Latitude and Longitudes of Annamalainagar are respectively 11° 24′ N and 79° 44′ E. The daily data on Maximum temperature, Minimum temperature and actual hours of sunshine for thirty one years 1977 to 2007 were collected from IMD, Annamalainagar for the study. Two basic models were used in the analysis: the Hargreaves and Samani model with adjustment coefficient K_{RS} = 0.19; a model with monthly mean K_{RS} values that are obtained as the mean of linear fit values of K_{RS} generated for the corresponding months of different years of study. The daily data pertaining to thirty one years (1977 to 2007) were used to find monthly mean K_{RS} values as detailed herein.

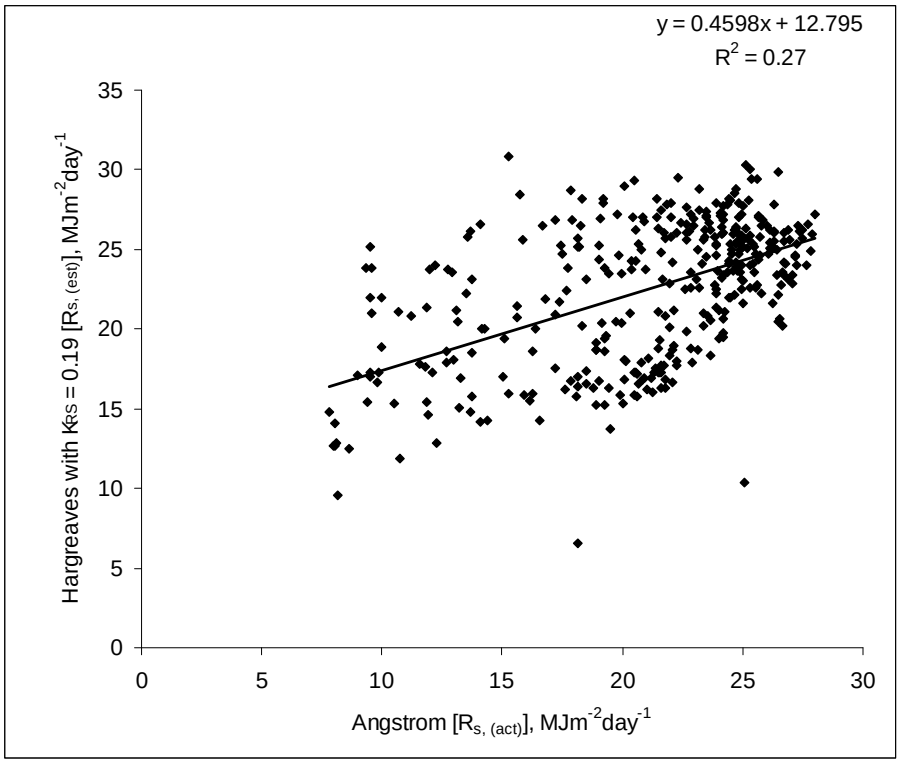

Fig. 1. Solar Radiation in the year 1989 - Hargreaves formula with adjustment coefficient K_{RS} = 0.19 *vs.* Angstrom formula

The Hargreaves radiation formula was rewritten as

$$R_s/R_a = K_{RS} (T_{max} - T_{min})^{0.5}$$

This expression was considered linear where R_s/R_a was the dependent variable and

$(T_{max} - T_{min})$ the independent variable yielding

$$K_{RS} = (R_s/R_a) / (T_{max} - T_{min})^{0.5}$$

Here, R_s is the value of solar radiation estimated using Equation 1. From the daily values of K_{RS} generated using the above equation for every month of a year, the linear fit value for each month of the years was determined. Then mean K_{RS} for each month of a year is worked out as the average of the linear fit K_{RS} values of the particular month in the various years.

For validation of the derived monthly mean K_{RS}, daily solar radiation was computed employing the derived monthly mean K_{RS} in Equation 2. The daily solar radiation computed in this way was compared with that estimated using Equation 1. The reduction in error in prediction of daily solar radiation due to the derived monthly mean K_{RS} in Hargreaves' Radiation formula was demonstrated statistically.

4. Results and discussion

Fig. 1 shows the degree of linear depends between daily solar radiation values for the year 1989 computed using the Angstrom-Prescott formula and the Hargreaves' radiation formula. The daily solar radiation obtained from measured sunshine hours using the Angstrom-Prescott formula are considered as actual. From herein, actual solar radiation [$R_{s\ (act)}$] refers to the solar radiation obtained using the Angstrom-Prescott formula and predicted solar radiation [$R_{s\ (est)}$] refers to that obtained using the Hargreaves' radiation formula. From Fig. 1 it is evident that the differences between actual solar radiation and predicted solar radiation are significant and on most days of the year, the solar radiation predicted using Hargreaves' radiation formula with adjustment coefficient of 0.19 are lower than the actual solar radiation. Out of 365 days, the Hargreaves formula underestimated the solar radiation for 216 days, the underestimation being significant in the months May to September.

The value of 0.4598 for the slope of the liner fit between [$R_{s\ (act)}$] and [$R_{s\ (est)}$] shows that the average degree of underestimation of solar radiation by the Hargreaves formula is around 55%.The R-squared value of the liner fit obtained between the Angstrom-Prescott formula and Hargreaves formula with K_{RS} = 0.19 is only

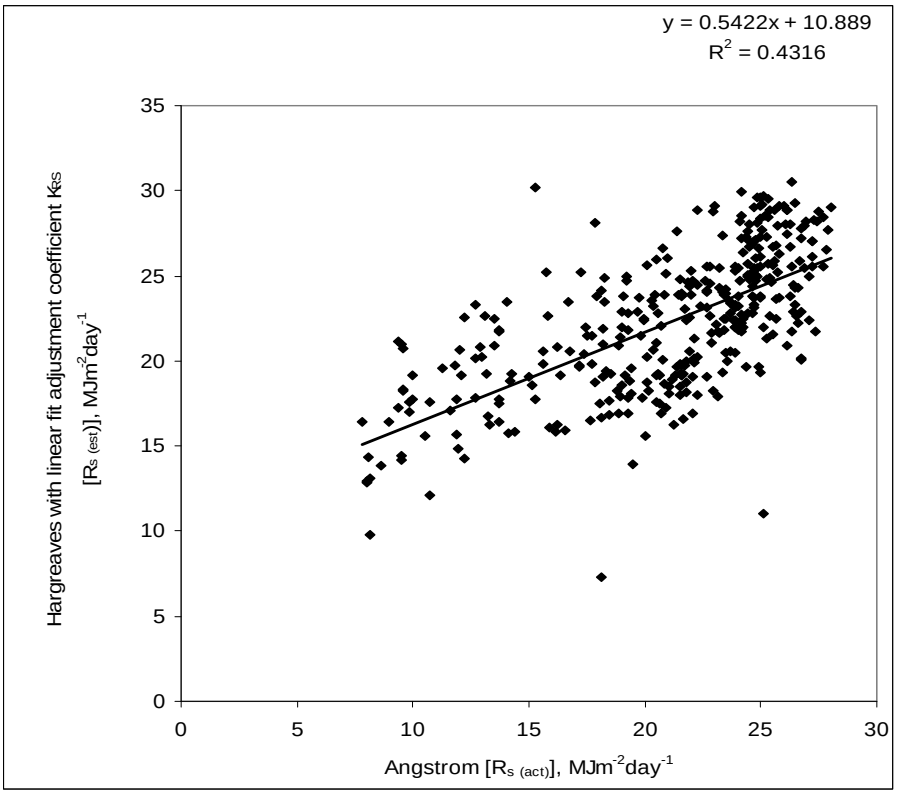

Fig. 2. Solar Radiation in the year 1989 - Hargreaves formula with linear fit adjustment coefficients K_{RS} derived for each month *vs*. Angstrom formula

TABLE 1

Linear fit values of adjustment coefficient K_{RS} derived for each month of the year 1989

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
K_{RS}	0.211	0.202	0.200	0.203	0.173	0.143	0.158	0.150	0.153	0.174	0.192	0.211

TABLE 2

Mean adjustment coefficient K_{RS} derived for each month of a year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean K_{RS}	0.213	0.216	0.209	0.203	0.186	0.168	0.158	0.165	0.179	0.182	0.193	0.211

0.27 indicating a weak linear trend between the two formulae.

Table 1 shows the linear fit values of K_{RS} generated for each month of the year 1989. The fitted K_{RS} values were found to vary in a shorter range between 0.211 for the first month (January) and 0.203 for the fourth month (April). The fitted K_{RS} values tended to show a decreasing trend from the fourth month (April) to the eighth month (August).

For August the fitted value of K_{RS} was found to be the least at 0.150. Then, there was a rapid increasing trend in fitted K_{RS} values from 0.153 in the ninth month (September) to 0.211 in the last month (December). The same trend was observed in the linear fit values of K_{RS} values generated for other years too.

The mean K_{RS} for each month of a year worked out as the average of the linear fit K_{RS} values of the corresponding month in the various years are shown in

TABLE 3

Mean Absolute Error; Mean Percent Absolute Error and Root Mean Square Error values of models

Year	Mean Absolute Error(MAE)		Mean Percentage Absolute Error(MPAE)		Root Mean Square Error (RMSE)	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
1977	3.395	2.988	19.3	17.0	3.967	3.702
1978	4.012	3.149	23.5	18.9	4.407	3.828
1979	3.593	3.195	21.2	19.1	4.082	3.860
1980	2.971	2.840	16.5	15.4	3.631	3.516
1981	3.844	3.226	22.3	19.1	4.314	3.876
1982	3.326	2.735	19.2	15.2	3.949	3.560
1983	2.911	2.112	15.4	11.4	3.635	2.985
1984	3.492	3.034	18.4	16.0	3.878	4.756
1985	4.073	3.956	21.3	20.7	4.121	4.191
1986	3.306	3.070	18.3	17.1	3.899	3.793
1987	3.714	3.201	21.1	18.3	4.588	4.284
1988	3.811	3.164	22.9	19.1	4.232	3.809
1989	3.736	3.147	22.3	18.9	4.102	3.797
1990	3.757	3.062	25.4	21.6	4.234	3.797
1991	3.062	2.864	18.9	16.9	3.718	3.631
1992	3.595	3.238	23.4	20.8	4.125	3.909
1993	3.324	2.940	22.0	20.1	3.940	3.732
1994	3.484	3.295	22.1	20.6	4.072	3.904
1995	3.951	3.312	26.4	22.9	4.321	3.891
1996	3.366	2.958	20.6	17.8	4.038	3.747
1997	3.315	2.942	19.1	16.7	3.907	3.658
1998	3.748	2.993	22.9	18.5	4.348	3.831
1999	3.345	2.940	20.6	18.4	4.086	3.793
2000	3.795	3.178	23.0	19.3	4.302	3.923
2001	3.176	2.998	20.0	18.6	3.961	3.868
2002	3.474	2.856	20.9	17.8	4.053	3.664
2003	4.055	3.158	27.5	22.2	4.583	4.019
2004	3.582	3.169	24.5	21.5	4.225	3.962
2005	4.207	3.884	33.7	31.5	4.905	3.647
2006	3.520	3.211	21.9	19.8	3.954	3.756
2007	3.382	2.970	21.7	18.9	4.007	3.764

Model 1: Using K_{RS}=0.19

Model 2: Using derived monthly mean K_{RS} values

Table 2. Similar to the monthly K_{RS} values obtained for the year 1989, the monthly mean K_{RS} values shown in Table 2 showed minor variations from the first month January to the fourth month April with values ranging between 0.213 in April and 0.216 in February. The lowest monthly mean K_{RS} (0.158) was obtained for the seventh month of July whereas the lowest monthly K_{RS} (0.143) in the year 1989 was recorded in the sixth month of June. Then, as found in the year 1989, there was a rapidly increasing trend in the monthly mean K_{RS} values starting from August at 0.165 and reaching 0.211 in the last month of the year (December).

Fig. 2 shows the degree of linear dependence between daily solar radiation values for the year 1989 computed using the Angstrom-Prescott formula and the

Hargreaves' radiation formula with linear fits of K_{RS} values generated for the month of the year 1989.

From Fig. 2, it is observed that the differences between actual solar radiation and predicted solar radiation are significant and on 187 days of the year the solar radiation predicted using Hargreaves' radiation formula with linear fit adjustment coefficients K_{RS} generated for each month are lower than the actual solar radiation estimated using the Angstrom-Prescott formula. But, compared to the differences between the solar radiation estimated using Hargreaves formula with adjustment coefficient K_{RS} = 0.19 and the actual radiation, the differences are much lower. The comparatively higher value of 0.5422 for the slope of the linear fit between [$R_{s\ (act)}$] and [$R_{s\ (est)}$] shows that the average degree of underestimation of solar radiation by the Hargreaves formula with linear fit adjustment coefficients K_{RS} is lower around 45% compared to 55%. The higher R-squared value of 0.43 for the linear fit obtained between the Angstrom-Prescott formula and Hargreaves formula with linear fit values of adjustment coefficient K_{RS} indicates a moderate linear dependence between the two formulae.

Table 3 shows the comparison of statistics namely, mean absolute error (MAE), mean percent absolute error (MPAE) and root mean square error (RMSE) in prediction of daily solar radiation using the Hargreaves formula with adjustment coefficient K_{RS} = 0.19 and the Hargreaves formula with derived monthly mean K_{RS} values (shown in Table 2). From Table 3 it is evident that, the performance of Hargreaves formula with derived monthly mean K_{RS} values is better than that of Hargreaves formula with K_{RS} = 0.19 in terms of the error statistics namely, MAE, MPAE and RMSE. The MAE, MPAE and RMSE in prediction of daily solar radiation were distinctly lower in all the years while using Hargreaves formula with derived monthly mean K_{RS} values than using Hargreaves formula with K_{RS} = 0.19.

5. Conclusion

The performance of the Hargreaves' Radiation formula in estimating daily solar radiation for the Indian coastal location namely Annamalainagar in Tamilnadu State, was evaluated. Two basic models were used in the analysis: (*i*) the Hargreaves model with adjustment coefficient K_{RS} = 0.19 and (*ii*) a model with monthly mean K_{RS} values that were obtained as the mean of linear fit values of K_{RS} generated for the corresponding months of different years of study. The daily solar radiation estimated using the two models differed from the actual daily solar radiation computed using the Angstrom-Prescott formula. But, the second model employing the derived monthly mean adjustment coefficient K_{RS} values yielded better results than the first model in all years, according to the error statistics namely, MAE, PMAE and RMSE. Hence, when data on measured daily sunshine hours are not available, it is recommended that the second model with locally derived monthly mean K_{RS} values could be used to better predict solar radiation in meteorologically homogeneous areas close to the study location.

References

Al-Lawati A., Dorvlo ASS and Jervase, J. A., 2003, "Monthly average daily solar radiation and Clearness index contour maps over Oman", *Energy Conversion and Management,* **44,** 691-705.

Al-zoheiry A., Brown, L. A., Sobojejo, A., Keener, H. and Matte, M. T., 2006, "Modeling daily solar radiation using available meteorological data in Ohio for applications with alternative energy sources fro micro-irrigation", *American society of Agricultural and biological engineers annual international meeting presentation,* Paper number: 062081.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M., 1998, "Crop evapotranspiration: guidelines for computing crop water requirements", *FAO Irrigation and Drainage*, Paper **56**, FAO, Rome.

Almorox, J. and Hontoria, C., 2004, "Global solar radiation estimation using sunshine duration in Spain", *Energy Conversion and Management,* **45,** 1529-1535.

Angstrom, A., 1924, "Solar and terrestrial radiation", *Quarterly Journal of Royal Meteorological society,* **50,** 121-125.

Black, J.N., 1956, "The distribution of solar radiation over the earth's surface", *Arch Met Geoph Biokl,* **7,** 165-189.

Chineke, T. C., 2002, "A robust method of evaluating the solar energy potential of a data sparse site", *The Physical Scientist*, **1,** 1, 59-69.

Chineke, T. C., 2008, "Equations for estimating global solar radiation data in sparse regions", *Renewable Energy*, **33,** 827-831.

Chiemeka, I. U., 2008, "Estimation of solar radiation at Uturu, Nigeria", *International Journal of Physical Sciences,* **3,** 5, 126-130.

De Jong, R. and Stewart, D. W., 1993, "Estimating global radiation from common meteorological variables in western Canada", *Canada Journal of Plant Sciences*, **73**, 509-518.

Duffie, J. A. and Beckman, Wr., 1991, "Solar engineering for thermal processes", Second edition, *John Wiley & Sons*, Inc., New York, NY.

Elagib, N. A., Babiker, S. F. and Alvi, S. H., 1998, "New empirical models for global solar radiation over Bahrain", *Energy conversion and management*, **39**, 8, 827-835.

Hargreaves, G. H., Samani, Z. A., ASCE 1982, "Estimating potential evapotranspiration", *Journal of Irrigation and Drainage Division,* **108**, 1 IR3, 223-230.

Presocott, J. A., 1940, "Evaporation from a water surface in relation to solar radiation", *Trans. R. Soc. Sci. Australia,* **64,** 114-125.