Mausam, (1990), **41**, 1, 125-130

551.521.1 (549.3)

An estimate of solar radiation over Bangladesh

M. H. HUSSAIN

Bangladesh Agric. Univ., Mymensingh

and

S. A. CHOWDHURY

Bangladesh Met. Dept., Dhaka

(*Received 26 July 1988*)

सार — बंगलादेश में भूमंडलीय सौर विकिरण वितरण का संशोधित अंगस्ट्रोम समीकरण के साथ आकलन किया गया है। ढाका के पांच वर्षों के आंकड़ों के आधार पर बंगलादेश के लिए समाश्रयण सूत्र को व्युत्पन्न किया गया है। फिर इस समीकरण का अनुप्रयोग वर्ष में बारह महीने के लिए भूमंडलीय सौर विकिरण के अभिकलन के लिए बंगलादेश में 6 स्टेशनों से धूप और मेघच्छन्नता के आंकड़ों के लिए किया गया है।

भूमंडलीय सौर विकिरण का स्थानिक वितरण पूरे देश में लगभग एक समान पाया गया। भूमंडलीय सौर विकिरण मार्च-अप्रैल में 19.68 एम जे एम$^{-2}$ दिन$^{-1}$ अधिकतम से अधिक और जनवरी में 12.56 एम जे एम$^{-2}$ दिन$^{-1}$ से कम न्यूनतम पाए गए।

एक वर्ष के 12 महीनों के लिए निर्गामी दीर्घतरंग विकिरण के मानों को एलबीडो के कल्पित मान के साथ आकलित नेट विकिरण मानों और ब्रन्ट के आनुभविक समीकरण का प्रयोग करते हुए अभिकलित किया गया है।

यह देखा गया कि देश द्वारा औसत लघु तरंग फ्लक्स 5860 एम जे एम$^{-2}$ वर्ष$^{-1}$ से कम है। जबकि औसत नेट विकिरण मान 4190 एम जे एम$^{-2}$ वर्ष$^{-1}$ से कम है।

ABSTRACT. Global solar radiation distribution over Bangladesh has been estimated with a modified Ångström equation. Based on data for five years at Dhaka, a regression formula has been derived for Bangladesh. This equation is then applied to sunshine and cloudiness data from 6 stations in Bangladesh for the computation of global solar radiation for the twelve months of a year.

Spatial distribution of global solar radiation is found to be nearly uniform over the whole country. Global solar radiation is seen to be maximum exceeding 19.68 MJm^{-2}day^{-1} in March-April and minimum, less than 12.56 MJm^{-2} day^{-1} in January.

Values of outgoing long wave radiation for the twelve months of a year have been computed using Brunt's empirical equation and net radiation values calculated with an assumed value of albedo.

It is seen that the average short wave flux received by the country is less than 5860 MJm^{-2} year^{-1} while the average net radiation value is less than 4190 MJm^{-2} year^{-1}.

1. Introduction

Successful exploitation of solar energy for the improvement of agricultural yield and industrial growth, go a long way to meet the energy demands of the developing and energy-deficit countries. However, for the proper designing of any equipment using solar energy at any locality, adequate data on the available solar energy at that locality in different seasons of the year is of fundamental importance. Considerable attention has, therefore, been given for the understanding and mapping of radiation climate of different regions of the world. Maps on spatial distribution of global and net radiation have been prepared by various authors, *e.g.*, Fritz and MacDonald (1949), Drummond and Vowinkel (1957), Mani *et al.* (1962), Mani *et al.* (1967), Ganesan (1970), Notoridou and Lalas (1979) over different regions on the basis of instrumental measurements and estimates using empirical formulae. Maps for global and net radiation on global scale (Budyko 1956, Black 1956) are also available but these are not detailed enough for use in determining the local climatic characteristics of small areas.

Global solar radiation is being systematically measured at only one centre in Bangladesh, namely, Bangladesh Rice Research Institute, (BRRI), Joydevpur, Dhaka. No data is available on the distribution of solar radiation over the whole country.

In the present paper estimates of global and net total radiation have been made using sunshine data at 6

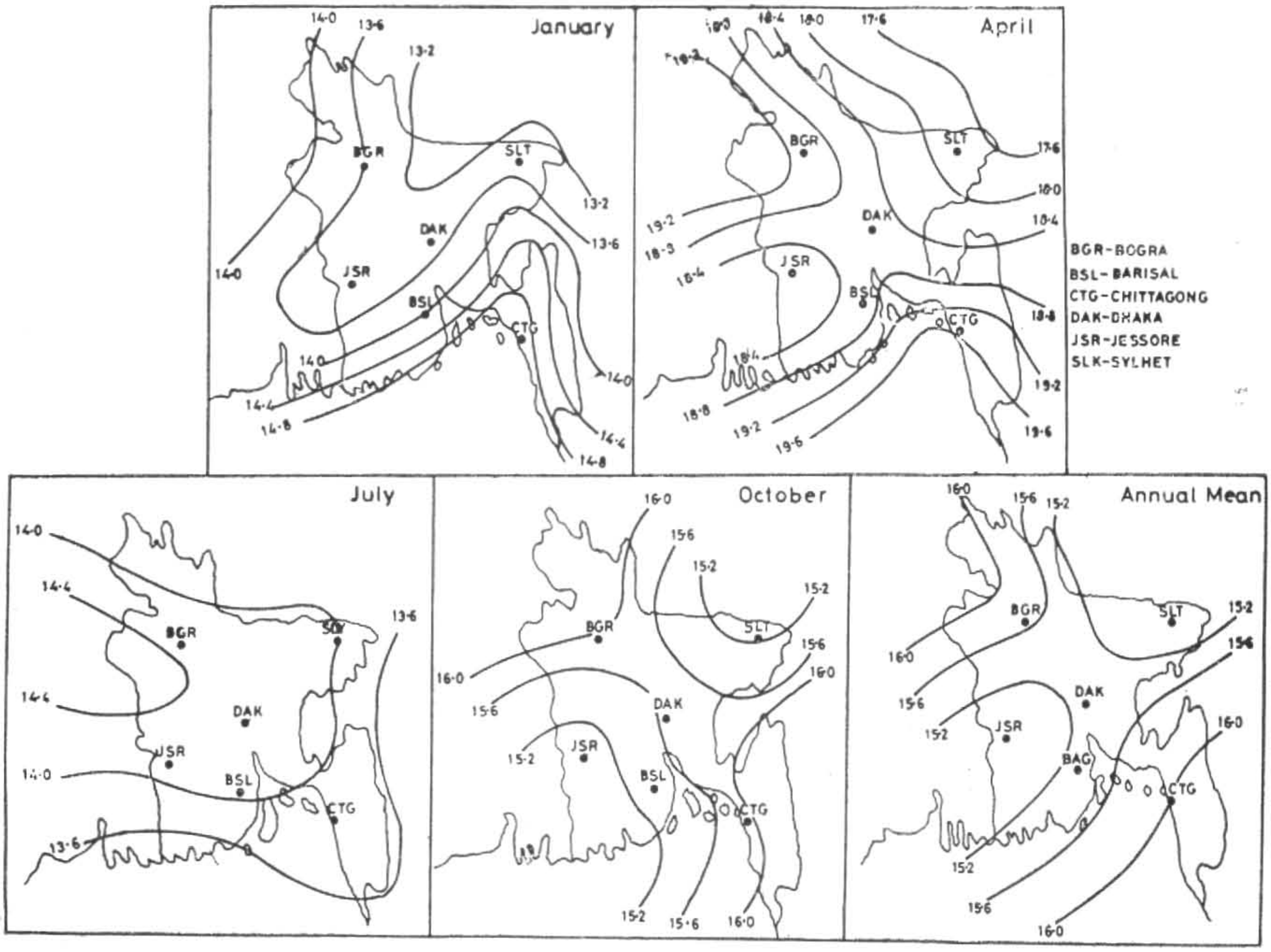

Fig. 1. Global radiation, MJm^{-2} day^{-1}

stations with the help of a modified Ångström equation and computed values of outgoing long wave radiation. Maps showing the annual and seasonal distribution over the country have been prepared and the results discussed.

2. Global solar radiation

Ångström (1924) developed the following empirical linear equation for computation of global solar radiation

$$Q = Q_0\,(a' + b'\; n/N) \qquad (1)$$

where Q, Q_0 are the average daily global radiation actually received on a horizontal surface on any day and a cloudless day respectively, n and N are actual and the maximum possible duration of sunshine hours and a' and b' are constants. The coefficients a' and b' can be computed by plotting the monthly mean values of Q/Q_0 against the corresponding values of n/N for each month of the year and then carrying out regression analysis.

The values of a' and b' as calculated by different investigators for different regions have been found to vary widely which may lead to very high percentage of error in estimating global radiation. Large and unsystematic variations in the estimated values of a' and b' computed with monthly data was also reported by Goh (1979) for Singapore. The variation of a' and b' may be due to its dependence on the type, thickness and height of the cloud. Besides Q_0 instead of being constant, varies as a result of absorption by water vapour, scattering and diffuse reflection by aerosols. Therefore, it is suggeste to use modified Ångström equation for the regions where the randomness in the changes of meteorological factors is predominant.

Q_0 in the Eqn. (1) may be replaced by Q_A which is the radiation received on a horizontal surface at the top of the atmosphere or which would be received on the earth's surface in the absence of atmospheric depletion,

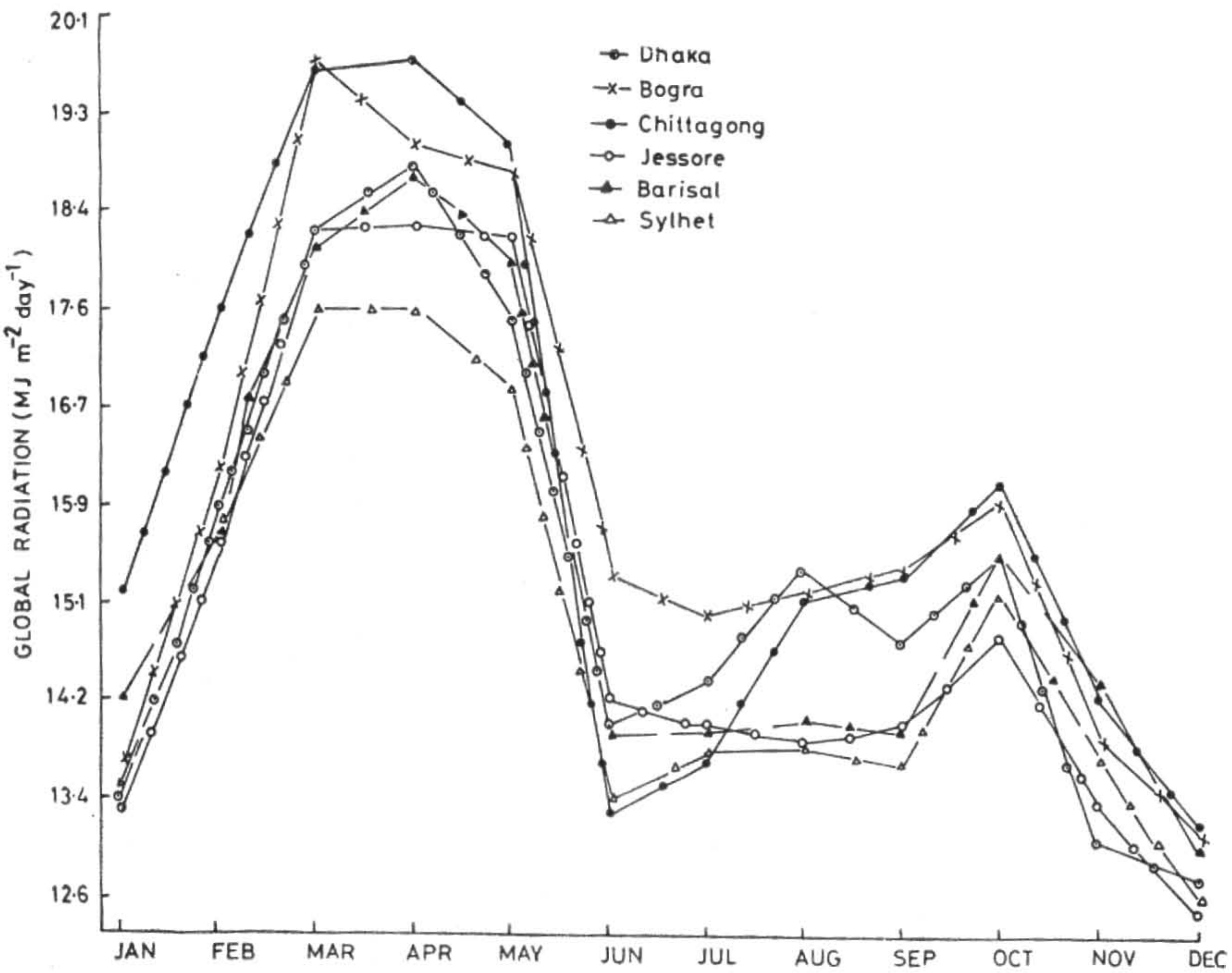

Fig. 2. Annual march of global radiation, MJm^{-2} day^{-1}

Ångström equation, thus modified, takes the following form :

$$Q = Q_A \; (a + b \, n/N) \qquad (2)$$

where a and b are new sets of constants.

3. Data utilised

Global solar radiation data was available for only one station, namely, Dhaka (Lat. 23.4°N). These were recorded at BRRI, Joydevpur, Dhaka by a Moll-Gorczynski pyranometer. Data for 5 years up to December 1980 were used in the present study.

The mean monthly values of Q_A for the latitudes of 6 stations, *e.g.*, Dhaka (23.4°N ; 7 m a.msl), Chittagong (22.1°N. 26 m a.msl), Bogra (24.51°N; 18 m a.msl), Barisal (22.4°N ; 2 m a.msl), Sessore (23.1°N ; 6 m a.msl), and Sylhet (24.54°N ; 32 m a.msl) were obtained for the specific latitudes and dates from *Smithsonian Meteorological Table* (List 1958). These are based on the value of 1353.7 W. m^{-2} for the solar constant. Daily values of N for the corresponding latitudes of the 6 stations were obtained from the interval between sunrise and sunset given in the *Nautical Almanac and Indian Ephemeris* and mean monthly values were worked out. Daily values of n for the 6 stations were obained from the Meteorological Office, Shere Banglanagar, Dhaka. These were recorded at each of the 6 stations by the Campbell-Stokes recorder.

Regression analysis was carried out between the monthly mean values of Q/Q_A and n/N and the values of the coefficients a and b were computed. It was found that the variations in the values of the coefficients between the years were small ; a ranged from 0.20 to 0.24 and b from 0.41 to 0.47. The annual mean values for the coefficients a and b were found to be 0.21 and 0.44 respectively. The modified Ångström equation then takes the following form :

$$Q = Q_A/(0.21 + 0.44 \; n/N) \qquad (3)$$

The correlation coefficient r, between the parameters Q/Q_A and n/N was 0.93.

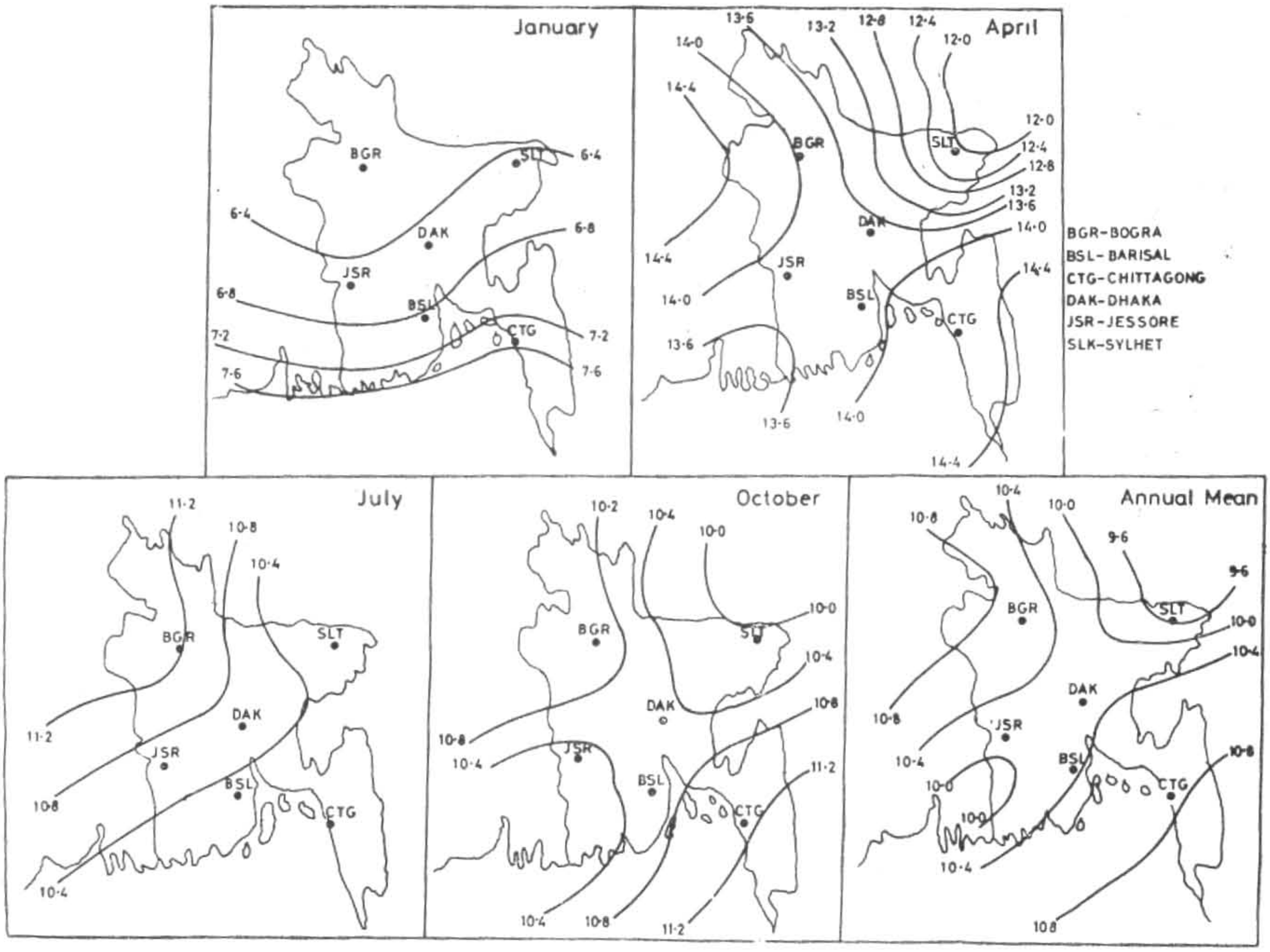

Fig. 3. Outgoing radiation, MJm^{-2} day^{-1}

TABLE 1

Monthly average of global solar radiation (MJm^{-2}) at Dhaka (Lat. 23.4° N, 7 m a. msl)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Instrumentally measured values											
14.8	16.3	17.2	18.0	17.5	14.1	14.8	14.9	12.7	14.9	12.3	12.6
Computed values using Eqn. (3)											
13.4	15.9	18.3	18.8	17.5	14.0	14.4	15.4	14.8	15.5	13.4	12.8

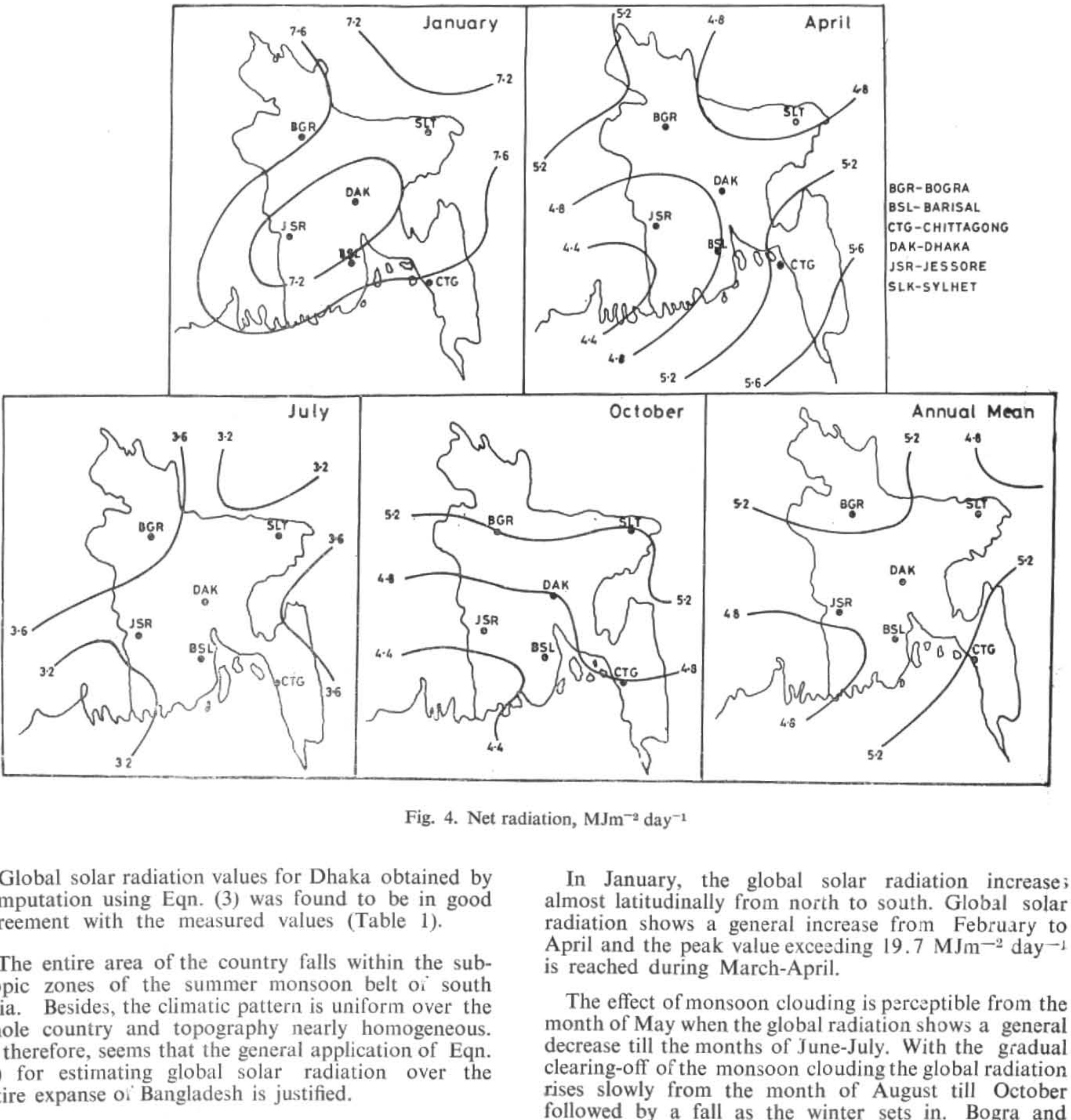

Fig. 4. Net radiation, MJm^{-2} day^{-1}

Global solar radiation values for Dhaka obtained by computation using Eqn. (3) was found to be in good agreement with the measured values (Table 1).

The entire area of the country falls within the subtropic zones of the summer monsoon belt of south Asia. Besides, the climatic pattern is uniform over the whole country and topography nearly homogeneous. It, therefore, seems that the general application of Eqn. (3) for estimating global solar radiation over the entire expanse of Bangladesh is justified.

4. Distribution of global solar radiation

Fig. 1 shows the geographical distribution of global solar radiation for the whole year and for the four representative months January, April, July and October. Isolines are drawn every 0.4 MJm^{-2}. The mean annual global solar radiation shows nearly uniform distribution over the entire land mass of the country. This is expected because of the homogeneity of the topography as well as the climatic pattern. Global solar radiation shows a maximum during the summer months (Mar-May) and a minimum during winter months. The incoming short wave flux is low for the country ranging from 4185 to 5320 MJm^{-2} yr^{-1}. This is in conformity with the observation of Mani *et al.* (*op-cit*).

In January, the global solar radiation increases almost latitudinally from north to south. Global solar radiation shows a general increase from February to April and the peak value exceeding 19.7 MJm^{-2} day^{-1} is reached during March-April.

The effect of monsoon clouding is perceptible from the month of May when the global radiation shows a general decrease till the months of June-July. With the gradual clearing-off of the monsoon clouding the global radiation rises slowly from the month of August till October followed by a fall as the winter sets in. Bogra and Chittagong receive the highest global radiation of the order 19.7 MJm^{-2} day^{-1} in March-April while the lowest value, less than 12.6 MJm^{-2} day^{-1} is received at Jessore in the month of January. These features are plotted in Fig. 2.

5. Distribution of net terrestrial radiation

In the present study outgoing long wave radiations for the 6 stations were estimated in the same way as Ganesan (*op-cit*) did using the empirical equation following Brunt :

$$Q_b = 1440\,\sigma T_a^4(0.47 - 0.67\sqrt{e_d})(0.1+0.9\,n/N) \quad (4)$$

where, Q_b = outgoing long wave radiation in cal cm^{-2} day^{-1}

e_d = mean surface vapour pressure (hPa)

T_a = mean air temperature (in °K)

σ = Stefan constant

Q_b was then converted into $\mathrm{MJm^{-2}\ day^{-1}}$

Mean air temperature was calculated from maximum and minimum temperatures at screen height recorded at the six stations. Mean surface vapour pressure for the corresponding temperature was obtained from the Smithsonian table.

Fig. 3 shows the salient features of the outgoing long wave radiation. It is maximum in January, maximum value being of the order of 8.4 $\mathrm{MJm^{-2}\,day^{-1}}$, and as expected fairly uniform over the whole country. The outgoing long wave radiation is considerably reduced during March-April when the mean air temperature, generally obtained in the country exceeds 30°C and the humidity is relatively high. However, the minimum values for the outgoing long wave radiation, less than 3.3 $\mathrm{MJm^{-2}\ day^{-1}}$ are obtained in June-July, the typical monsoon months. From the transitional month of October onwards, outgoing long wave flux shows a tendency of smooth increase for the rest of the years.

6. Distribution of net radiation

Net radiation represents the balance between the short wave energy absorbed by the earth and the net terrestrial radiation.

In the present paper, net radiation was estimated from the combined Eqns. (3) and (4) and an assumed value of albedo (α). The equation for net radiation then becomes :

$$\begin{aligned} R &= Q\,(1-\alpha) - Q_b \\ &= Q_A\,(1-\alpha)\,(0.21+0.44\,n/N) - 1440\,T_a^4\,(0.47- \\ &\quad -0.67\sqrt{e_d})\,(0.1+0.9\,n/N) \end{aligned} \qquad (5)$$

where, R = net radiation, $\mathrm{cal\ cm^{-2}\ day^{-1}}$

Albedo of different underlying surfaces have been listed by various authors, *e.g.*, Budyko (*op-cit*), Kondratyev (1969) and Montieth (1975). For an underlying surface of rice and wheat fields, both Budyko and Kondratyev give the values of albedo ranging between 0.10 & 0.25. Since Bangladesh is essentially an agricultural land it is justifiable to adopt an average value of 0.18 for the albedo of underlying cover of rice fields in estimating net radiation.

Fig. 4 gives the distribution of net radiation for the four representative months as well as the whole year.

The distribution pattern of net radiation is very similar to that of global radiation. In January net radiation increases almost latitudinally from north to south.

From February the net radiation begins to increase over the whole country until April-May when the peak value, exceeding 13.8 $\mathrm{MJ\ m^{-2}\ day^{-1}}$ is reached. The distribution is nearly uniform except for the north eastern zone of the country where a relatively lower-peak, less than 12.6 $\mathrm{MJ\ m^{-2}\ day^{-1}}$ is observed because of higher incidence of clouding.

With the onset of monsoon, net radiation flux decreases in June and remains nearly static through the months till September. During this period, higher net radiation flux are obtained in the northern regions while the lower values are found in the northeastern region of the country.

In October, the transitional month, the distribution of net radiation flux begins to decline over the whole country. It continues to decrease through the month of November to December-January when the net radiation flux becomes lowest.

On the whole, the spatial distribution of net radiation energy is uniform. The country receives on the average, a net radiation flux of the order of 3850 $\mathrm{MJm^{-2}}$ annually.

7. Conclusion

Values obtained for solar radiation distribution over Bangladesh by the modified Ångström equation may be taken as adequate for conversion of solar energy by means of low grade thermal devices as well as agricultural requirements. However, regression formulae may be worked out with new sets of data from representative centres covering the entire expanse of the country. Arrangements should, therefore, be made for a well co-ordinated continuous measurements of the solar radiation flux for the whole spectrum and in selected spectral intervals, at a number of stations covering the whole country.

Acknowledgements

The authors are thankful to Mr. M. F. Qayyum, Deputy Director, Bangladesh Meteorological Department, Abhawa Bhawan, Agargaon, Dhaka, Bangladesh for the help and assistance provided by him in carrying out this investigation. Authors are also thankful to Mrs. Jahanara Akhter and Mr. Mohammad Zaid Ali of Bangladesh Meteorological Department for their help in drawing the diagrams and typing out the manuscript respectively.

References

Angström, A., 1924, *Quart. J.R. met. Soc.*, **50**, pp. 124-125.

Black, J.N., 1956, *Arc. Met. Geoph. Biokl. Serie*, B. **7**, pp. 165-189.

Budyko, M.I., 1956, *Heat balance of the earth's surface*, Leningrad.

Drummond, A.J. and Vowinkel, E., 1957, *J. Met.*, **14**, pp. 343-353.

Fritz, S. and MacDonald, T.H., 1949, *Heating and Ventilating*, **46**, p. 69.

Ganesan, H.R., 1970, *Indian J. Met. Geophys.*, **21**, 4, pp. 629-636.

Goh, T.N., 1979, *Solar Energy*, **22**, 2, pp. 105-110.

Kondratyev, K. Ya, 1969, *Radiation in the atmosphere*, Academic Press.

List, R.J., 1958, *Smithsonian Meteorological Tables*, 6th revised ed.

Mani, A., Chacko, O. and Venkiteswaran, S.P., 1962, *Indian J. Met. Geophys.*, **13**, 3, pp. 337-366.

Mani, A., Chacko, O., Desikan, V. and Krishnamurty, V., 1967, *Indian J. Met. Geophys.*, **18**, 2, pp. 171-183.

Montieth, J.L., 1975, *Principles of Environmental Physics*, Edward Arnold.

Notaridou, V.A. and Lalas, D.P., 1979, *Solar Energy*, **22**, 6, pp. 505-513.