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Calculated the diffuse and direct parts of global solar radiation in Baghdad city for the period (1983-2005) depending on clearness index by applying the two world models of Liu -Jordan

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Abstract

In this paper solar radiation was studied over a region of Baghdad (Latitude 33.3° and longitude 44.4°). The two parts of global solar radiation: diffuse and direct solar radiation were estimated depending on the clearance index of measured data (Average Monthly mean global solar radiation). Metrological data of measured (average monthly mean diffuse and direct solar radiation) were used to comparison the results and show the agreement between them. Results are determined by applying Liu and Jordan two models (1960). Excel 2007program is used in calculation, graphics and comparison the results.

Key words

solar radiation,
clearness index,
diffuse fraction,
direct fraction.

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حساب الجزأين المنتشر والمباشر للإشعاع الشمسي الإجمالي لمدينة بغداد للفترة (1983-2005) بالاعتماد على دليل الوضوحية بتطبيق موديلي ليو- جوردون العالميان

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الخلاصة

في هذا البحث تمت دراسة الإشعاع الشمسي فوق منطقة بغداد (خط عرض 33.3° وخط طول 44.4°). إن جزأي الإشعاع الشمسي الإجمالي: الإشعاع الشمسي المنتشر والمباشر قد تم تخمينهما بالاعتماد على دليل الوضوحية للبيانات المقاسة (متوسط المعدلات الشهرية للإشعاع الشمسي الإجمالي). إن بيانات الأنواء الجوية المقاسة (متوسط المعدلات الشهرية للإشعاع الشمسي المنتشر والمباشر) قد تم استخدامها لمقارنة النتائج وتبيان مدى التوافق بينهما. تم استخلاص النتائج بواسطة تطبيق موديلي ليو – جوردون (1960). تم استخدام برنامج أكسل 2007 في الحسابات والمخططات والمقارنات للنتائج.

1. Introduction

The radiation from the sun is the primary natural energy source of the planet Earth. Other natural energy sources are the cosmic radiation, the natural terrestrial radioactivity and the geothermal heat flux from the interior to the surface of the Earth, but these sources are energetically negligible as compared to solar radiation. When the spoken is of solar radiation, It means the electromagnetic radiation of the Sun. The energy distribution of electromagnetic radiation over different wavelength is called Spectrum. The electromagnetic spectrum is divided into different spectral ranges (Fig.1).

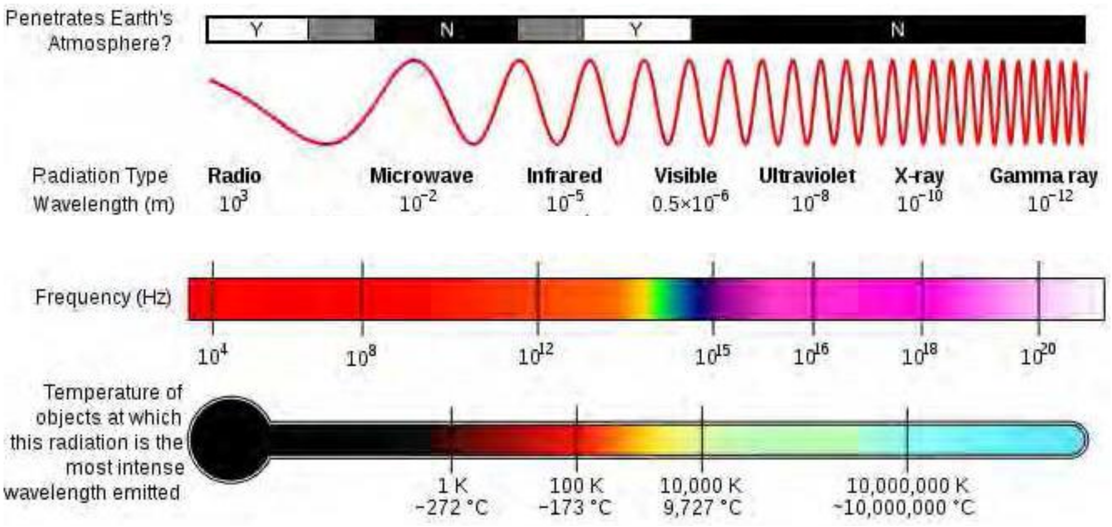

Fig.1: Spectral ranges of electromagnetic radiation[1].

The quantity of solar radiation reaching the earth's surface varies dramatically as a function of changing atmospheric condition as well as the changing position of the sun through the day [2].

Solar radiation received at the surface is of primary importance for the purpose of building solar energy devices, estimating crop productivity, etc. However, direct measuring is not available in many cases, so numerical technique becomes aneffective alternative to estimate global radiation through observed meteorological data.

1.2 Solar radiation

The solar radiation, through atmosphere, reaching the earth’s surface can be classified into two components: beam radiation and diffuse radiation. Beam radiation is the solar radiation propagating along the line joining the receiving surface and the sun. It is also referred to as direct radiation. Diffuse radiation is the solar radiation scattered by aerosols, dust and molecules, it does not have a unique direction. The total radiation is the sum of the beam and diffuses radiation and is sometimes referred to as the global radiation. When the amount of diffuse radiation reaching the earth’s surface is less than or equal to 25% of global radiation, the sky is termed as clear sky.[3].

1.3 Monthly variation of clearness index

Clearness index $(K_t)$is defined as the ratio of the observation (measured horizontal terrestrial solar radiation) (I_t), to the calculated (predicted horizontal extraterrestrial solar radiation)(I_o). Clearness index is a measure of solar radiation extinction in the atmosphere, which includes effects due to clouds but also effects due to radiation interaction with other atmospheric constituents. To develop the model for the clearness index, the insolation on ahorizontal surface for a few locations is measured over a period of time encompassing all seasons and climatic conditions. Different values of the clearness index at different stations may be as a result of different atmospheric contents of water vapour and aerosols. It can be seen from the above expressions that the extra-terrestrial horizontal insolation is a function of latitude and the day of year only. Hence, it can be calculated for any location for any given day. However, the calculated insolation does not take any atmospheric effects into account.[1]

$$K_t = \frac{I_t}{I_o} \qquad (1)$$

Where: I_t is the measured horizontal terrestrial solar radiation.

I_o is the predicted horizontal extraterrestrial solar radiation.

1.4 Variation of diffuse solar radiation

Several models for estimating the diffuse component based on the pioneer works of Angstrom (1924) and Liu and Jordan (1960). These models are usually expressed in either linear or polynomial fittings relating the diffuse fraction (I_d) with the clearness index and combining both clearness index (K_t) and relative sunshine duration to derive empirical models to estimate hourly, daily and monthly diffuse solar radiation from values of the global solar radiation. The diffuse solar radiation I_d can be estimated by an empirical formula which correlates the diffuse solar radiation component I_d to the daily total radiation I. The ratio, I_d / I, therefore, is an appropriate parameter to define a coefficient, that is, cloudiness or turbidity of the atmosphere [1].

Values of global and diffuse radiations for individual hours are essential for research and engineering applications. Hourly global radiations on horizontal surfaces are available for many stations, but relatively few stations measure the hourly diffuse radiation. Decomposition models have, therefore, been developed to predict the diffuse radiation using the measured global data.

The models are based on the correlations between the clearness index (K_t), the diffuse fraction K_d, the diffuse coefficient K_D or the direct transmittance K_b all are dimensionless where:

$$K_t = \frac{I_t}{I_o},\ K_d = \frac{I_d}{I_t},\ K_D = \frac{I_d}{I_o},\ K_b = \frac{I_b}{I_o}$$

I_t, I_b, I_d and I_o being the global, direct, diffuse and extraterrestrial irradiances, respectively, on a horizontal surface (all in MJ m^{-2}) [4].

1.5 Liu and Jordan model

The relationships permitting the determination, for a horizontal surface, of the instantaneous intensity of diffuse radiation on clear days, the long-term average hourly and daily sums of diffuse radiation, and the daily sums of diffuse radiation for various categories of days of differing degrees of cloudiness, with data from 98localities in the USA and Canada (19_ to 55_N latitude), were studied by Liu and Jordan. In Liu and Jordan model, the transmission coefficient for total radiation on a horizontal surface is given by the intensity of total radiation (i.e. direct Ib plus diffuse Id) incident upon a horizontal surface It divided by the intensity of solar radiation incident upon a horizontal surface outside the atmosphere of the Earth Io. The correlation between the intensities of direct and total radiations on clear days is given by[5]

$$k_D = 0.271 - 0.2939 k_b \qquad (2)$$

$$k_t = (I_b + I_D)/I_o = k_b + k_D \qquad (3)$$

$$k_D = 0.384 - 0.416 k_t \qquad (4)$$

2. Sunshine regions

2.1 Iraqi geography

Iraq is located in the Middle East between latitudes 29° 5' and 37° 22' N and longitudes 38° 45' and 48° 45' Elevation; It is bounded By: Turkey to the north, Iran to the east, Jordan, Syria and the Saudi Arabia to the west, and the Arabian Gulf, Kuwait and Saudi Arabia to the south.

2.1.1 Weather in Iraq

Iraq as a Middle Eastern country is one of those countries which are situated on yellow belt of earth that can receive the maximum light during the day and different months in the year. Iraq climate describe as hot weather in summer and cold in the winter season. A typical meteorological data set is not available in Iraq, mainly due to the lack of sufficient raw data. [6].

Fig. 2: Illustrated Iraq country region and Baghdad city location.

2.2Baghdad geography

Baghdad is the capital of the Republic of Iraq, Located along the Tigris River. Baghdad is situated at 33.34° North latitude, 44.4° East longitude and 41 meters elevation above the sea level. Baghdad is a very large town in Iraq.

3. Methodology

Metrological data (measured average monthly mean global solar radiation for Baghdad at a period (1982-2000)) was used in this paper to derive direct and diffuse solar radiation. Also NASA measured metrological data (average monthly mean diffuse and direct solar radiation for a period (1983-2005)) (as shown in Table 1 and Fig. 3) were used to comparison the results and show the agreement between them.

Fig. 2: Illustrated a center region of Baghdad city location.

Two models were applied to Baghdad to estimate the diffuse and direct solar radiation:

3.1 Liu and Jordan model was applied on Baghdad city in this work (because Baghdad city is located at the latitude (33.34^o), in the range of the Latitude of the world locations that the model was applied in (19_ to 55_N latitude) to calculate diffuse and direct parts of measured global solar radiation at 2008 as following below:

1. The clearness index K_t (dimensionless) was calculated by dividing the mean of monthly measured global solar radiation I_t to the extraterrestrial solar radiation I_o as shown in Table 1.

2. The clearness index K_t was applied in Equation (4) and the diffuse coefficient K_D (dimensionless), was determined as shown in Table 2.

3. Equation (2) was applied to determined the direct transmittance K_b (dimensionless) as shown in Table 2.

4. Equation (1) was applied on K_b to determined K_D again to experiment the results of equation (4) (the reality of the determined the values of K_D first) in Liu and Jordan model then when the results (from the two equations (2 and 4)) were comparison, the values were closely to each other.

The resulted K_D from equation (4) was signaled as K_{D1} and K_{D2} to that results from equation (2). As shown in Table 4 and Fig.4.

5.The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), the Root Mean Square Bias Error (RMSE) as shown in Table 6.

The expressions for the MBE (MJ.m^{-2}day^{-1}) and RMSE (MJ.m^{-2} day^{-1}) [7] as follows:

$$RMSE = \left(\left[\sum \left(I_{cal.} - I_{abs.}\right)^2\right]/M\right)^{1/2} \qquad (5)$$

$$MBE = \left[\sum_{i=1}^{M}(I_{cal} - I_{abs})\right]/M \qquad (6)$$

Where $I_{cal.}$:The calculated solar radiation.

$I_{obs.}$:The observed solar radiation.

M :No. of observation.

The Mean Bias Error gives an idea of the divergence between the monthly average daily radiation values estimated by the model used and the measured value. A positive value shows over estimation and a negative value is under estimation. Over estimation of an individual observation will cancel under estimation in a separate observation. It gives the long term performance of the correlation by allowing a comparison of the actual deviation between calculated and measured values term by term.

The Root Mean Bias Error yields the same idea of the divergence between the monthly average daily radiation values estimated by the model used and the measured values as given by MBE. However the information is relevant to the short-term performance. The ideal value for MBE would be Zero. RSME can never be negative and the lower the value the more accurate the estimate.

4. Results and discussions

For this study, Baghdad city at the center of Iraq was chosen to calculate the components of the global solar radiation by applying Liu and Jordan two models (depended on the latitude). The obtained results by these theoretical methods were comparison with the real data (measured data). The measured data are shown in Table 1 and illustrated in Fig. 3.

Then the correlation between K_t, K_{D1}, K_{D2}, K_b are illustrated in Figure 4.

As shown in Fig. 5 and 6 a comparison between the calculated diffuse, direct solar radiation and the ratio I_d / I_b, I_d / I_t and I_b / I_t were illustrated.

In Table 5 the final results were obtained (the values of the calculated and measured I_d and I_b) and Fig. 7 illustrated the calculated and measured values of diffuse and direct solar radiation.

Generally the two models gives a successful and closely results were obtained between measured and calculated values as shown in table 6the Mean Bias Error (MBE) and the Root Mean Square Bias Error (RMSE) were applied to test the quality of the calculated values of diffuse and direct solar radiation.

Then as shown in Fig. 7 the best results in calculated I_d were appeared at the months: MAR, SEP, OCT and NOV.

And the best results in calculated I_b were appeared at the months: AUG, MAR, SEP, OCT and NOV.

Table1: Extraterrestrial solar radiation and a metrological measured data (average monthly mean global, diffuse and direct solar radiation).

Month	I_o	$I_{t(avg.)}$	$I_{d(avg.)}$	$I_{b(avg.)}$
JAN	18.77237	7.81911	2.573655	5.706801
FEB	23.56372	11.08018	3.303183	8.798478
MAR	30.10203	15.13341	4.882802	11.4369
APR	36.48675	19.35763	7.210699	12.92973
MAY	40.93584	23.11891	8.238137	16.77627
JUN	42.81599	26.82848	7.712122	22.43464
JUL	41.94486	25.99446	7.983688	19.14535
AUG	38.33927	22.81493	6.335531	18.43754
SEP	32.39337	18.32308	5.135813	13.61666
OCT	25.53175	13.01779	4.1056	8.180331
NOV	19.87673	8.681024	2.958793	5.519288
DEC	17.34823	6.851588	2.402869	4.751126

Table 2: Clearance index was applied in equation (5) for Baghdad city at a period (1983-2005) and Jordan model was applied to calculate K_D, I_d, K_b, I_b and I_d / I_b.

Month	I_o	I_t	$K_t = I_t / I_o$	$K_D = 0.384 - 0.416 K_t$	$I_d = K_D * I_O$	$K_b = K_t - K_D$	$I_b = K_b * I_O$	I_d / I_b
JAN	18.7724	7.81911	0.408865	0.213912	4.015641	0.194953	3.659723	1.097253
FEB	23.5637	11.08018	0.465742	0.190251	4.483024	0.275491	6.491601	0.690588
MAR	30.102	15.13341	0.514276	0.170061	5.11919	0.344214	10.36155	0.494056
APR	36.4868	19.35763	0.551905	0.154408	5.633828	0.397498	14.50339	0.388449
MAY	40.9358	23.11891	0.587881	0.139442	5.708158	0.448439	18.35724	0.310949
JUN	42.816	26.82848	0.623748	0.124521	5.331477	0.499228	21.37493	0.249427
JUL	41.9449	25.99446	0.626748	0.123273	5.170661	0.503475	21.1182	0.244844
AUG	38.3393	22.81493	0.617975	0.126922	4.866113	0.491053	18.8266	0.25847
SEP	32.3934	18.32308	0.579693	0.142848	4.627324	0.436845	14.15088	0.326999
OCT	25.5317	13.01779	0.524883	0.165649	4.229303	0.359234	9.171867	0.461117
NOV	19.8767	8.681024	0.447237	0.197949	3.934584	0.249288	4.955029	0.794059
DEC	17.3482	6.851588	0.385492	0.223635	3.879675	0.161857	2.807931	1.381685

Table 3: The direct transmittance kb resulted from equation (3) was applied in equation (2).

Month	$K_b = K_t - K_D$	$K_{D2} = 0.271 - 0.2939 K_b$	$K_{D1} = 0.384 - 0.416 K_t$	$\lvert K_{D1} - K_{D2} \rvert$
JAN	0.194953	0.213703	0.213912	0.000209
FEB	0.275491	0.190033	0.190251	0.000218
MAR	0.344214	0.169835	0.170061	0.000226
APR	0.397498	0.154175	0.154408	0.000232
MAY	0.448439	0.139204	0.139442	0.000238
JUN	0.499228	0.124277	0.124521	0.000244
JUL	0.503475	0.123029	0.123273	0.000244
AUG	0.491053	0.12668	0.126922	0.000243
SEP	0.436845	0.142611	0.142848	0.000237
OCT	0.359234	0.165421	0.165649	0.000228
NOV	0.249288	0.197734	0.197949	0.000215
DEC	0.161857	0.22343	0.223635	0.000205

Table 4: The average monthly mean of diffuse fraction I_d / I_t and direct fraction I_b / I_t.

Month	I_d / I_t	I_b / I_t
JAN	0.523186	0.476814
FEB	0.40849	0.59151
MAR	0.330681	0.669319
APR	0.279772	0.720228
MAY	0.237194	0.762806
JUN	0.199633	0.800367
JUL	0.196686	0.803314
AUG	0.205384	0.794616
SEP	0.24642	0.75358
OCT	0.315592	0.684408
NOV	0.442605	0.557395
DEC	0.580129	0.419871

Table 5: The values of the calculated and measured I_d and I_b.

Month	Calculated I_d	Measured I_d	Calculated I_b	Measured I_b
JAN	4.015641	2.573655	3.659723	5.706801
FEB	4.483024	3.303183	6.491601	8.798478
MAR	5.11919	4.882802	10.36155	11.4369
APR	5.633828	7.210699	14.50339	12.92973
MAY	5.708158	8.238137	18.35724	16.77627
JUN	5.331477	7.712122	21.37493	22.43464
JUL	5.170661	7.983688	21.1182	19.14535
AUG	4.866113	6.335531	18.8266	18.43754
SEP	4.627324	5.135813	14.15088	13.61666
OCT	4.229303	4.1056	9.171867	8.180331
NOV	3.934584	2.958793	4.955029	5.519288
DEC	3.879675	2.402869	2.807931	4.751126

Table 6: The mean bias error (MBE), the root mean square bias error (RMSE) were applied to test the quality of the calculated values of diffuse and direct solar radiation.

MBE	(I_d meas.)& (I_d cal.)	-0.48699
	(I_b meas.)& (I_b cal.)	-1.6285
RMSE	(I_d meas.)& (I_d cal.)	1.621761
	(I_b meas.)& (I_b cal.)	1.476873

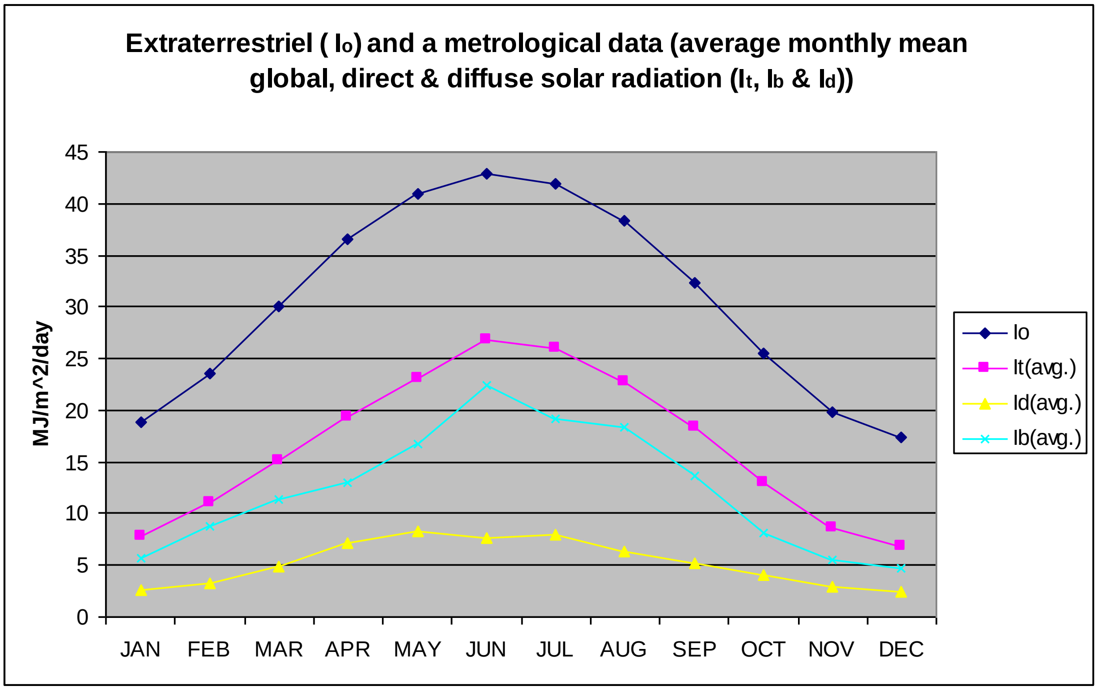

Fig. 3: Illustrated the monthly distribution of the extraterrestrial I_o ***and metrological data*** $(I_t \ , \ I_b \ , \ I_o)$

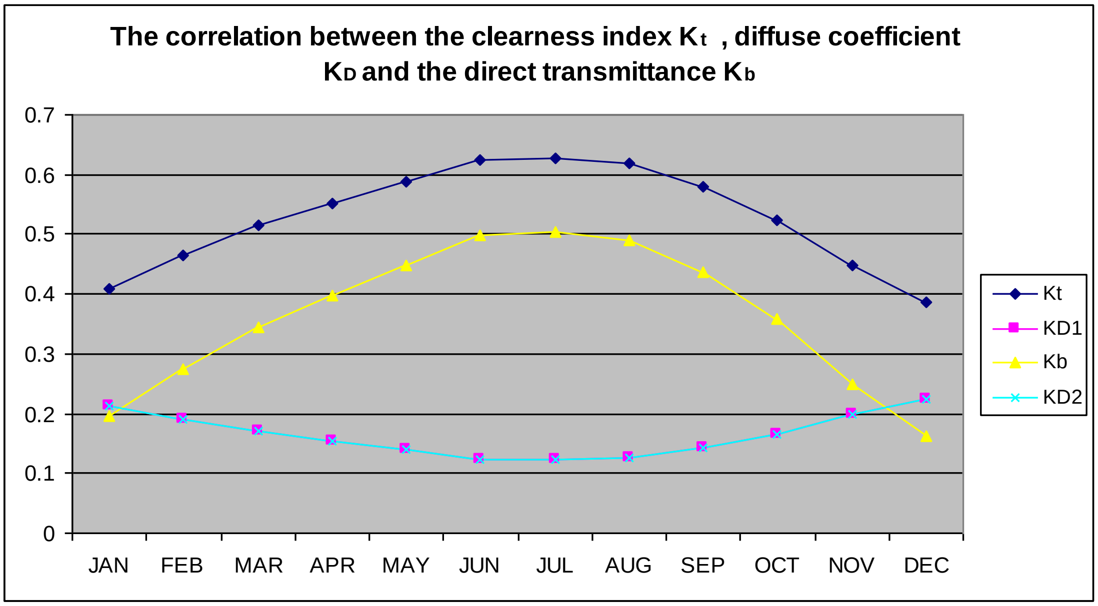

Fig. 4: Illustrated the correlation between K_t , K_{D1}, K_{D2}, K_b.

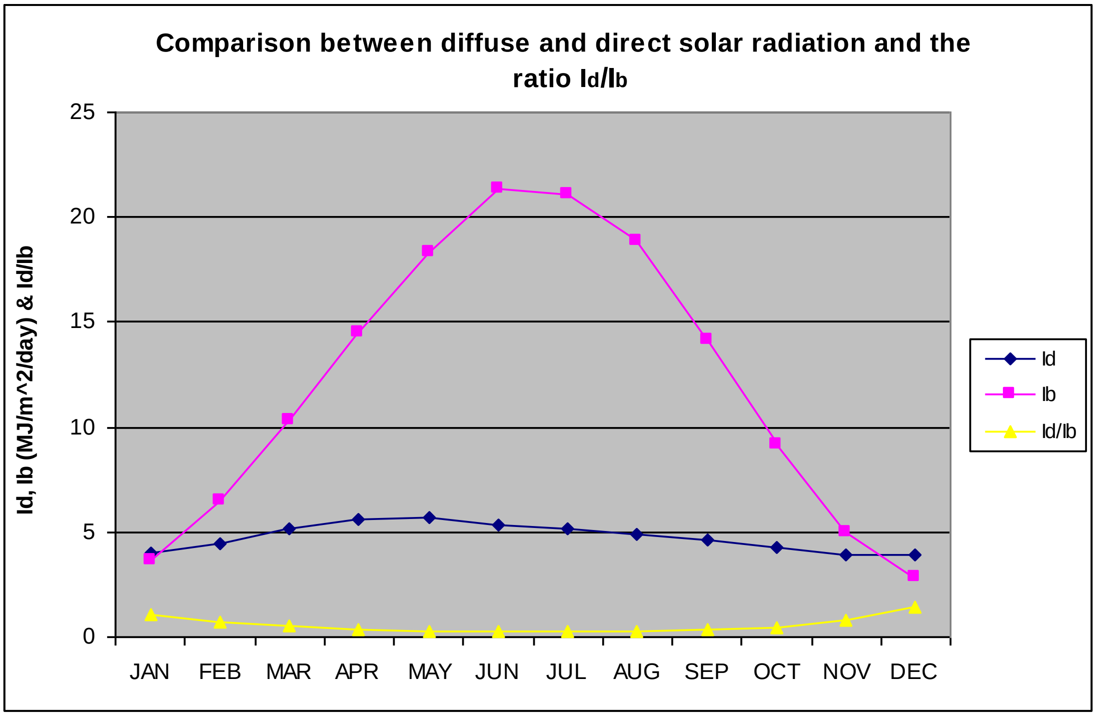

Fig. 5: Illustrated a comparison between the calculated diffuse, direct solar radiation and the ratio I_d / I_b.

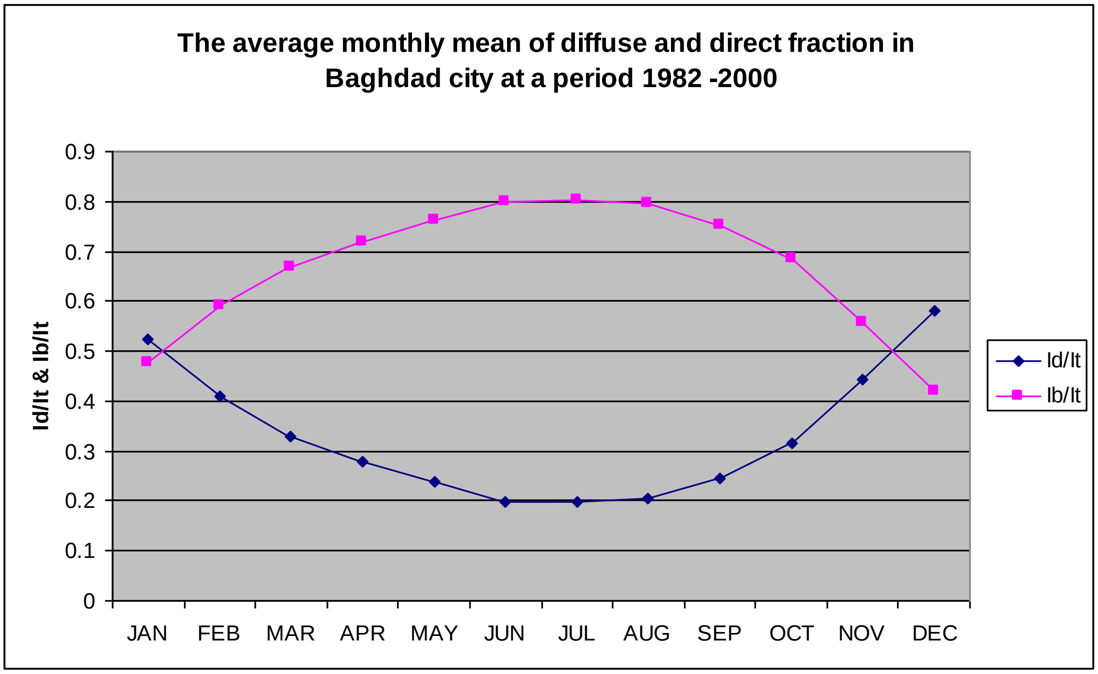

Fig. 6: Illustrated the monthly distribution between diffuse and direct fraction in Baghdad at (1982-2000).

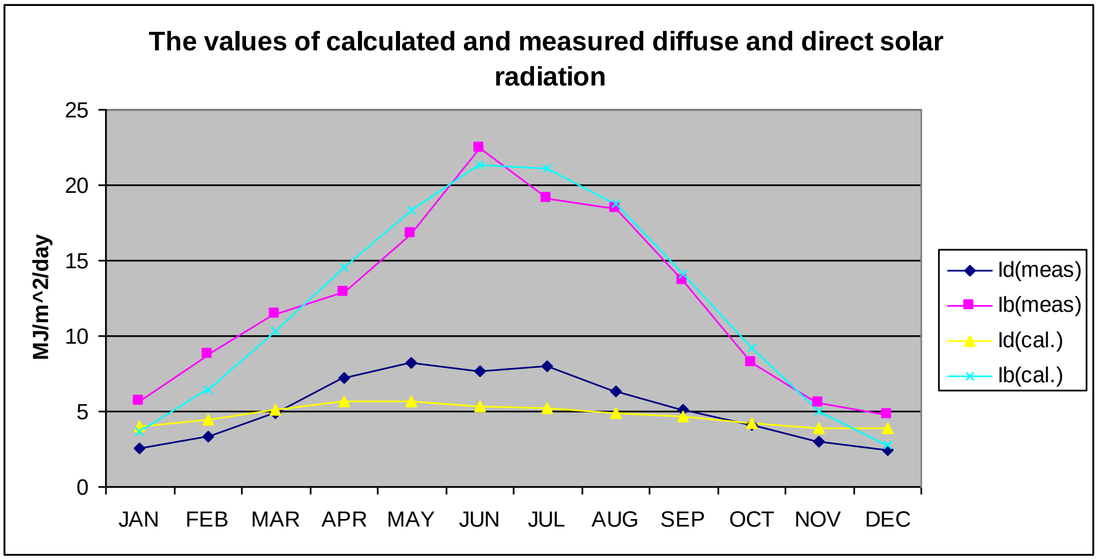

Fig. 7: Calculated and measured values of diffuse and direct solar radiation.

5. Conclusion

The metrological and NASA measured data of average monthly mean solar radiation of Baghdad city at a period (1983-2005) is used in this work. Liu and Jordan two models were used in this study to examine the variation of diffuse solar radiation for Baghdad.

Monthly variation of clearness index K_t, diffuse ratio K_{D1}, K_{D2} and K_b were employed in this study to estimate the two parts (diffuse and direct solar radiation).

These models can be used in all locations selected in Iraq. The two models provide a good estimation for I_b and I_d for all on the horizontal surface and can be said the modelsper form well.

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