

Prediction and Assessment of Direct and Diffuse Radiation Fractions for Hourly, Daily and Monthly Average Global Radiation at Different Latitude Locations in Libya

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Abstract: As in today's world, the dramatic increase in world's population, the rapid depleting of conventional fuels (Fossil Fuels) as well as the environmental impact have left us no choice but to discover alternative energy sources. In fact, this would ensure a better and safer life on this earth and this will only be accomplished by using the best option of nonconventional and non-exhaustible sources of energy, which is the solar energy. The current study is aimed at evaluating the availability and potentiality of direct and diffuse solar radiations in three different locations in Libya within different latitudes. Three different locations with different values of measured daily solar radiation are opted for comparison purposes. This daily solar radiation data are used to create an hourly database of solar radiation. The mathematical framework for the prediction and assessment has been chosen to be the Microsoft Excel. The resultant monthly, daily and hourly diffuse fraction relative to their clearance indexes have been in very good agreement with existing research. Moreover, one of the main findings of this attempt is that this study has claimed and justified the usefulness of direct radiation in operating the concentrating solar power (CSP) plants, attributed to its overall magnitude of approximately 75% of the global radiation, particularly at the summer season.

التنبؤ والتقييم للإشعاع الشمسي النسبي المباشر والمنتشر لتوسط الإشعاع الكلي الساعي واليومي والشهري في مواقع مختلفة في ليبيا

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ملخص: كما هو الحال في عالم اليوم، فإن الزيادة الهائلة في عدد سكان العالم، والنضوب السريع للوقود التقليدي (الوقود الأحفوري)، فضلا عن التأثير البيئي، لم يترك لنا أي خيار سوى اكتشاف مصادر بديلة للطاقة. في واقع الأمر، هذا من شأنه أن يضمن حياة أفضل وأكثر أمانا على هذه الأرض، وهذا لن يتحقق إلا باستخدام أفضل خيارات مصادر الطاقة غير التقليدية وغير القابلة للنفاد (المستدامة)، وهي الطاقة الشمسية. تهدف الدراسة الحالية إلى تقييم مدى توافر وإمكانية الإشعاعات الشمسية المباشرة والمنتشرة في ثلاثة مواقع

مختلفة في ليبيا ضمن خطوط عرض مختلفة. تم اختيار ثلاثة مواقع ذات قيم مختلفة للإشعاع الشمسي اليومي المقاس وذلك لغرض المقارنة. حيث استخدمت بيانات الإشعاع الشمسي اليومي لإنشاء قاعدة بيانات للإشعاع الشمسي الساعي. وقد تم اختيار الإطار الرياضي للتنبؤ والتقييم ليكون ميكروسوفت إكسيل (Microsoft Excel). وكانت نتائج الإشعاع الشمسي المنتشر النسبي الشهري واليومي والساعي بالنسبة إلى مؤشرات الوضوح في اتفاق مقبول جدا مع البحوث القائمة. وعلاوة على ذلك، فإن أحد النتائج الرئيسية لهذه الدراسة قد اقرت وبررت فائدة الإشعاع الشمسي المباشر في تشغيل محطات الطاقة الشمسية المركزة، ويعزى ذلك إلى حجمها الإجمالي البالغ حوالي 75% من الإشعاع الكلي، وخاصة في موسم الصيف.

Keywords: global radiation, diffuse radiation, direct radiation, diffuse fraction, clearness index

1. INTRODUCTION

Solar radiation data are available in several forms. The information about radiation data is important in their understanding and use: whether they are instantaneous measurements (irradiance) or values integrated over some period of time (usually hour or day); the time or time period of the measurements; whether the measurements are of beam, diffuse, or total radiation; the instruments used; the receiving surface orientation (usually horizontal, sometimes inclined at a fixed slope, or normal to the beam radiation); and, if averaged, the period over which they are averaged (e.g., daily radiation or monthly averages of daily radiation). There are several studies being tackled through the literature whose contributions are related to the current study. Orgill and Hollands conducted a study to mainly examine hourly diffuse radiation on a horizontal surface. The study established an equation to calculate an hourly ratio of diffuse to total radiation obtained in a horizontal surface. The study also included a comparison between the results of the new recommended correlation equation and the outcomes of corresponding equations; which finally showed very good agreement. The latter equation was of interest to be embodied in the new solar energy computer programs [1].

Gordon and Hochman carried out a study based in Bet Dagan Israel, to investigate the correlation of beam and global radiation on hourly, monthly and annual basis based on approximately 3000 days. The simultaneous measurements of hourly horizontal global and normal beam radiation over the above-mentioned place and time were thoroughly analysed. Furthermore, by a proper averaging of the one-to-one beam-global correlation matrices, the results

were compared with existing correlations applied to U.S. radiation data. The main finding of this study was that the accuracy of prediction of annual energy for solar collector systems was achieved and results were found to be generally more appropriate than those obtained by computer simulations [2].

An attempt was achieved by Garrison, who studied available measurements of hourly direct normal solar radiation and total hemispherical solar radiation on a horizontal surface for Albuquerque, New Mexico; Fort Hood, Texas; Livermore, Calif.; Maynard, Mass.; and Raleigh, North Carolina and measurements of hourly total hemispherical and diffuse radiation on a horizontal surface for Highett, Australia. The author expressively investigated the relationships between total and diffuse radiation and distributions and mean values that are allied to these quantities. The study is considered to be a very good platform in terms of solar energy data particularly for the above locations [3].

Collares-Pereira and Rabl recalibrated the correlations between diffuse and hemispherical, and between hourly values and daily totals of solar radiation, which are originated by Hottel, Whillier, Liu and Jordan. The calibration was achieved by utilizing pyrheliometer data taken from five stations in the U.S. The Liu and Jordan approach was found to be valid for the range of data obtained and numerical inaccuracies of the original correlations were discovered to arise from: (a) dependence on uncorrected measurements (b) use of a single value particularly for extra-terrestrial pyranometer of whole month and (c) disregarding of seasonal variations in diffuse/hemispherical ratio. Results based on the new expression were found to be in good agreement with results obtained from Canada,

India and Israel. The new correlations showed a good approximation in terms of the independency of the latitude. Furthermore, they confirmed that the original formulas of Liu and Jordan significantly predicts a small diffuse component. A better accuracy of nearly 3% was achieved with the use of least squares fit to the data. Moreover, the study provided a very good framework for the determination of both: radiation availability, and heating and cooling loads of buildings [4].

Benson et al. used an accurate 200 Wire 2 threshold pyrheliometer instrument whose main function is to measure the duration of bright sunshine. Daily and monthly regressions for direct, diffuse and global solar radiation component against sunshine duration were accomplished. The data showed a linear relationship between the diffuse/global and sunshine duration, whereas direct normal, direct horizontal, and global components were formed on a quadratic regression basis. The study also documented and observed effects of rainfall, particularly in overcast conditions [5].

Spitters et al. carried out a study to model canopy photosynthesis and showed how of importance to distinguish between the direct and diffuse components of incident global radiation. Therefore, the authors established an equation to compute the share of both components from only the measured daily global radiation. The share of diffuse component was originated from the ratio of global to extra-terrestrial radiation; whose relation was originally linked to a summary of literature data and radiation measurements based in Netherland. On the one hand, the study reported that 15 per cent of the diffuse flux was mainly received from directions close to the sun, hence this circum-solar must be added to the direct flux, especially for clear skies. However, for same weather conditions, the diffuse fraction was documented to be as large as approximately 40% for the total global radiation. On the other hand, the partitioning between direct and diffuse radiation under any weather conditions (clear or overcast skies) was treated, in the past, by a short period within the day. This severely led to clear underestimation of the share of the diffuse

component in the total global irradiation. One of the main outcomes of this study was that this approach is of great benefit for crop growth models [6].

Gopinathan developed correlations of montly mean-hourly global and diffuse solar radiation on a horizontal surface to hourly sunshine, based on a statistical procedure. Measured data from literature on solar radiation and sunshine duration were reported for several years based in two stations located in the southern African region. The study concluded that the developed correlations were examined under different data of different locations, and showed excellent agreement between calculated and measured data. Hence, it is a valid method that is applicable and reliable for a wide range of data [7].

Eras et al. carried out a study on establishing a relationship between hourly diffuse fraction and hourly clearance index (Kr). The study was based on Hourly pyrheliometer and pyranometer data reported at four stations. The relationship was compared to a work attempted by Orgill and Holands, where a set of data based in Hightt Australia was examined. The comparison showed very good agreement within a few percent discrepancy. It is of worth mentioning here that the framework for this study was to use the so-called transient simulation program (TRANSYS) associated with several correlations to identify the annual performance of solar energy systems. However, one of the drawbacks of this study was the neglection of the random distribution of hourly diffuse fraction. This surly would demonstrate the independency of the simulation results [8].

However, in this study the vast majority of radiation data available are for horizontal surfaces, including both direct and diffuse radiation. Two types of solar radiation data are widely available. The first is monthly average daily total radiation on horizontal surface \bar{H} . The second is hourly total radiation on a horizontal surface I in each hour for extended periods such as one or more years. However, this study is focused on three different places in Libya, over a period of 8 years (1982-1989): The first one is located in a desert region close to Sabha, the second is placed in the south western region of

Libya - Ghdamis, the third is based in the coastal region of the country -Tripoli. Figure 1 shows the daily global solar radiation on a horizontal surface \bar{H} which ranges between 5 and 7 kWh/m².day. In general, the potentiality of solar energy in Libya is evident from the above mentioned annual average of global solar irradiance. As a consequence of being the available data of solar radiation in the current study found in the form of daily radiation (H for each location), a procedure is needed to convert these data into hourly databases. Several approaches have been proposed in the literature to create synthetic hourly radiation databases. The

statistical nature of solar radiation is analyzed by Boland [9] and Tovar-Pescador [10]. The mentioned methodologies result in artificial or synthetic series of solar radiation that is indistinguishable from real series. Taking into consideration the number of clear days in Libya, a simpler procedure based on utilizability and clear day models was selected to develop the solar radiation modeling in this study. The approach of Duffie and Beckman model is adopted to be implemented in this study [11], which is in general based on the Liu and Jordan generalized distributions of cloudy and clear days, later modified by Bendt, and then by Hollands and Huget.

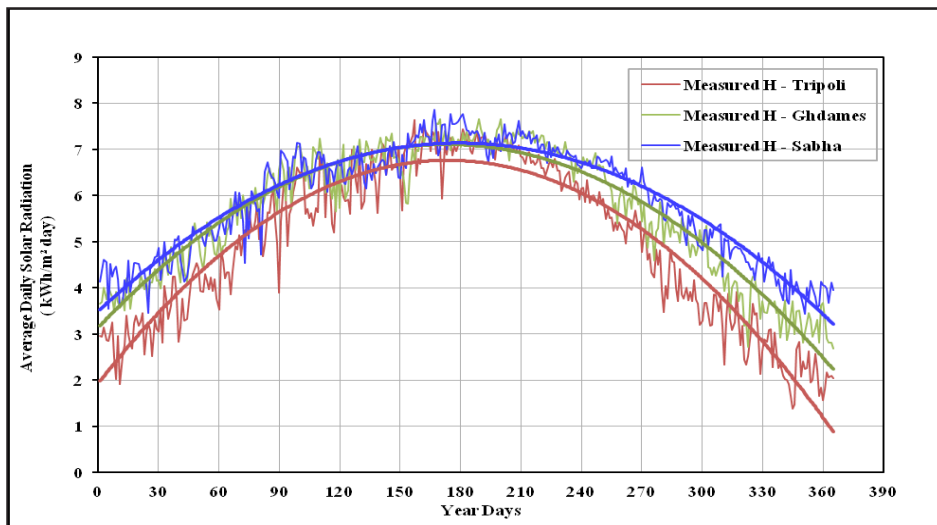


Figure (1). Global daily solar radiation for three different stations in Libya

2. METHODOLOGY

Solar radiation incident on buildings or collection surfaces is to be attained in order to perform thermal analyses. In general, only measurements of the total horizontal (global) radiation are available. As most surfaces of interest are inclined, it is necessary to estimate the radiation on a tilted surface from measurements of global radiation. Estimation procedures usually require the beam and diffuse components of global radiation. The beam and diffuse components of global radiation can be estimated from empirical relationships. Existing relationships correlate

the fraction of the global radiation which is beam or diffuse to an index of atmospheric clarity. Correlations of this type have been developed for use with hourly, daily, and monthly-average values of global radiation. Furthermore, radiation data are the best source of information for estimating average incident radiation [11]. Data on average days of sunshine or average percentage of possible sunshine days are obtained from different Libyan stations based on available instruments. Fortunately, authors from the current literature had modified the existing method to express extraterrestrial radiation on a horizontal surface rather than on clear day radiation as:

$$\frac{\bar{H}}{H_o} = a + b \frac{\bar{n}}{N} \dots\dots\dots (1)$$

Where H_o is the extraterrestrial radiation for the location that is averaged over the time period in equation. And a and b are constants depending on location. The ratio $\frac{\bar{H}}{H_o}$ is termed the monthly average clearness index and will be used frequently in later sections and chapter. Values of H_o , \bar{N} can be calculated from the following equations [11]:

$$H_o = \frac{24 \times 3600 G_{sc}}{\pi} \left(1 + 0.033 \cos \frac{360n}{365}\right) \times \left(\cos \phi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180} \sin \phi \sin \delta\right) \dots\dots\dots (2)$$

$$\bar{N} = \frac{2}{15} \omega_s \dots\dots\dots (3)$$

Where ω_s and δ are calculated by:

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta) \dots\dots\dots (4)$$

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) \dots\dots\dots (5)$$

Taking into consideration the determination of H_o , an artificial month of daily and hourly values of solar radiation requires an artificial daily total radiation H for each day of the month, and then applying a clear day model to obtain hourly values. First, it is of significance to compute a monthly average clearness index \bar{K}_T for each month of the year, which is defined as [11]:

$$\bar{K}_T = \frac{\bar{H}}{H_o} \dots\dots\dots (6)$$

The monthly average clearness index \bar{K}_T is defined as the ratio between monthly average daily radiation on a horizontal surface and monthly average daily extraterrestrial radiation, which is computed for each location as a function of its latitude. Then, the frequency of occurrence of days with a variant of the clearness index K_T and the cumulative frequency of occurrence of those days [11].

We can also define a daily clearness index K_T as the ratio of a particular day's radiation to the extraterrestrial radiation for that day. In equation form [11].

$$K_T = \frac{H}{H_o} \dots\dots\dots (7)$$

An hourly clearness index k_T can also be defined [11]:

$$k_T = \frac{I}{I_o} \dots\dots\dots (8)$$

It is also of interest to calculate the extraterrestrial radiation on a horizontal surface for an hour period as [11]:

$$I_o = \frac{12 \times 3600}{\pi} G_{sc} \left(1 + 0.033 \cos \frac{360t}{365}\right) \times \left[\cos \phi \cos \delta (\sin \omega_2 - \sin \omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin \phi \sin \delta\right] \dots\dots (9)$$

However, the above mentioned monthly, daily and hourly clearance index will be employed to identify the diffuse components of monthly, daily and hourly radiation according to the governing equations presented in the following sub- sections:

• **Diffuse components of monthly radiation:**

The average monthly diffuse radiation \bar{H}_d for the selected locations can be obtained from correlations [11], as function of the monthly average clearness index, \bar{K}_T . The correlation from Erbs is then used to define the monthly total diffuse fraction H_d .

- **For sunrise hour angle**

$$\omega_s \leq 81.4^\circ \text{ e } 0.3 \leq \bar{K}_T \leq 0.8$$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \dots\dots (10)$$

For $\omega_s > 81.4^\circ \text{ e } 0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \dots\dots (11)$$

• **Diffuse components of daily radiation:**

The daily diffuse radiation H_d for the selected locations can be obtained from correlations [12], as function of the daily clearness index, K_T . The correlation from Erbs is then used to define the daily total diffuse fraction H_d .

For $\omega_s < 81.4^\circ$

$$\frac{H_d}{H} = \begin{cases} 1.0 - 0.2727K_T + 2.4495K_T^2 - 11.9514K_T^3 + 9.3879K_T^4 & \text{per } K_T < 0.715 \\ 0.143 & K_T \geq 0.715 \end{cases} \dots\dots\dots (12)$$

For $\omega_s \geq 81.4^\circ$

$$\frac{H_d}{H} = \begin{cases} 1.0 - 0.2832K_T - 2.5557K_T^2 + 0.8448K_T^3 & \text{per } K_T < 0.722 \\ 0.175 & \text{per } K_T \geq 0.722 \end{cases} \dots\dots\dots (13)$$

• **Diffuse components of hourly radiation:**

Similarly, the correlations used for the determination of hourly diffuse radiation are suggested by Origill and Holland as the following:

$$\frac{I_d}{I} = \begin{cases} 1.0 - 0.09k_T & \text{per } k_T \leq 0.22 \\ 0.9511 - 0.1604k_T + 4.3388k_T^2 - 16.638k_T^3 + 12.336k_T^4 & \text{per } k_T \leq 0.8 \\ 0.165 & \text{per } k_T > 0.8 \end{cases} \dots\dots\dots (14)$$

Nevertheless, the above mentioned hourly clearance index (k_t) is of importance to be evaluated from Eq.8 which requires the hourly solar radiation. The latter concept has been identified according to the following equations [12]:

$$r_t = \frac{I}{H} \dots\dots\dots (15)$$

r_t is defined as the ratio of hourly total to daily total radiation, as a function of day length and the hour in equation.

It is possible to calculate 's r_t values from the equation below based on the work of Collares-Pereira and Rabl in 1979. [12].

$$r_t = \frac{\pi}{24} (a + b \cos \omega) \left(\frac{\cos \omega - \cos \omega_s}{\sin \omega_s - \frac{\pi \omega_s}{180} \cos \omega_s} \right) \dots\dots (16)$$

The coefficients a and b are given by:

$$a = 0.409 + 0.5016 \sin(\omega_s - 60) \dots\dots\dots (17)$$

$$b = 0.6609 - 0.4767 \sin(\omega_s - 60) \dots\dots\dots (18)$$

The H are from measurements of total solar radiation on a horizontal surface, that is, the commonly available pyranometer measurements. Values of \bar{H}_o , H_o and I_o can be calculated by using equations 2 and 9.

3. RESULTS AND DISCUSSION

In this section, the resulting monthly, daily and hourly beam and diffuse solar radiation will be discussed and further investigated.

Figure 2 shows a comparison between the resulting averaged monthly diffuse fraction (H_d/H) versus the monthly clearance index (K_T), according to the suggested correlations of Liu & Jordan, Stanhel, Erbs and Choudhury et al. The figure also represents a comparison between the above mentioned work of various authors against measured data of averaged monthly of daily radiation based on 3 different locations Sabha, Ghadams and Tripoli and will be subsequently denoted in this study as a, b and c, respectively. In general, the diffuse fraction (H_d/H) plays a predominant role in the determination of global radiation associated with both beam and direct radiations which is presented clearly on Figure 3a,3b,3c. As can be seen from Figure 2a,b, this fraction of (H_d/H) lies in between 0.2-0.4 (Sabha and Ghadamis) which indicates that the direct radiation will be high whereas in Tripoli the (H_d/H) was found to be in the range between 0.3-0.5 which gives an indication of a low direct radiation. Furthermore, the clearance index (K_T) is also of interest in knowing whether the day is clear or not. From previous studies, it was recommended that the K_T should be in the range between 0.3 to

0.8, hence approaching 0.8 ensures greater direct radiation. This is found clearly in Ghadamis and Sebha which are in the range of 0.6 to 0.7, while in Tripoli is between 0.4-0.6.

Figure 3 is divided into 3 sub-figures as a, b and c also, which denote Sebha, Ghadamis and Tripoli. The figure depicts the averaged monthly global radiation which includes the direct and diffuse radiations associated with the (H_d/H) based on the three different places. For instance in Sebha and Ghadamis, the direct radiation records up to 75% of the global particularly in the summer season, while in Tripoli it reaches up to 50% in the same season. The calculation of daily diffuse fraction (H_d/H) against the daily clearance index (K_T) has been achieved in a similar way to that one of the averaged monthly diffuse fraction as presented in Figure 4a,b,c. Figure 4, again, is separated into three figures for the three different locations. The resulting daily diffuse fractions reported for the three places are apparently found to be compared well with the other mentioned authors' work. Similarly, Figure 5 is also subjected to three sub-figures as a, b and c to represent the three mentioned locations. Accordingly, Figure 5a, b, c explains the daily global solar radiations in relation to the direct and diffuse radiations. Moreover, for more detailed knowledge, it is highly recommended to refer to the work that was already attempted by F. Ahwide et al [13].

Last but not least, the hourly beam and diffuse components of radiation $(\frac{I_d}{I})$ are also attempted in this study. Figure 6 and Figure 7 also consist of the three different locations that are denoted as a, b and c. In Figure 6, the ratio of $(\frac{I_d}{I})$ as a function of hourly clearance index (K_T) is represented over the three targeted locations. However, it is of significance to clarify that the hourly clearance index (K_T) is a good indication to understanding the usefulness of the hourly diffuse fraction. Therefore, having a greater hourly clearance index up to 0.8 would ensure a lower hourly diffuse fraction which gives more direct solar radiation. Apparently, Ghadamis and Sebha are reported to assign a large hourly clearance index, which is in the band between 0.35 and 0.8, meanwhile the more data are found in this region.

On the other hand, Tripoli has a lower hourly clearance index up to 0.2 which indicates a greater hourly diffuse fractions with a less direct solar radiation. Nevertheless, the green region in Figure 7a and b (Ghadamis and Sebha) shows a greater direct solar radiation, whilst a lower magnitude is reported in Tripoli as presented in Figure 7c.

4. CONCLUSIONS

After having a fairly thorough investigations based on the available daily solar radiation data over a period of 8 years (1982-1989), based in three different latitude angles in Libya as reported (Sebha, Ghadamis and Tripoli), the following concluding remarks are accomplished:

- The study has already attempted to take the benefit of the existing daily solar radiation data, hence to compute the hourly solar radiation and the averaged monthly daily radiation.
- The study has already achieved the determination of global solar radiation in accordance with the direct and diffuse radiation, over the three different regions.
- The study has already identified the monthly, daily and hourly fraction diffuse radiation as well as their related clearance indexes, in the three locations. Interestingly, these main findings are obtained within the range of other authors' attempts particularly the daily diffuse fraction; even though the data are relatively different.
- The study has concluded that the high magnitude of direct solar radiation in the off-coast region (Sebha and Ghadamis) is beneficial from the economic prospective, especially if the country has an obvious intention to establish the well-known CSP plants. However, in Tripoli as the direct solar radiation is found to be relatively of a less magnitude, thus it does operate for the so-called PV systems.
- According to what have been stated above, it is highly recommended to ensure obtaining more data, for instance, solar radiation data of 10 mins. This will surely encourage more studies to take place in such a developed country.

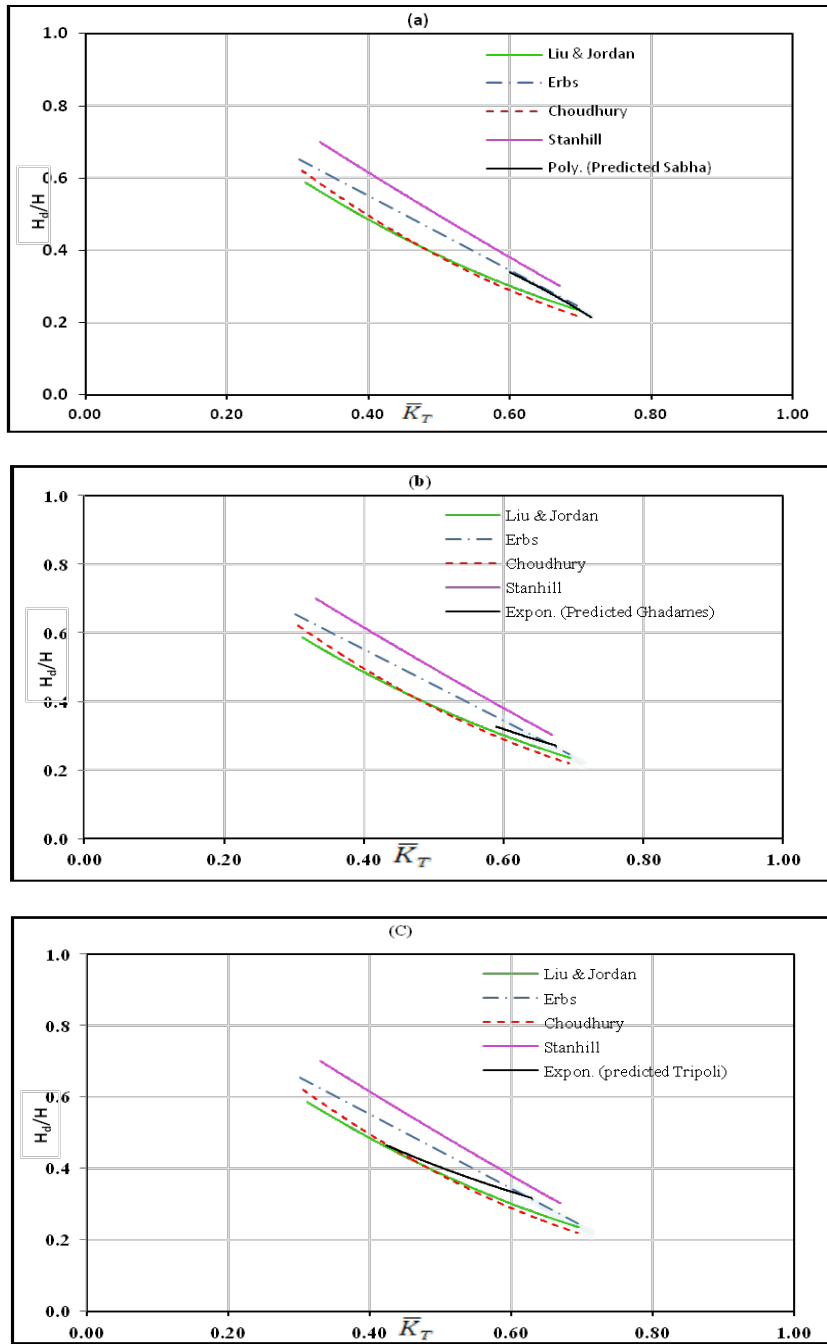


Figure (2). Correlation of average monthly diffuse fractions with average monthly clearness index

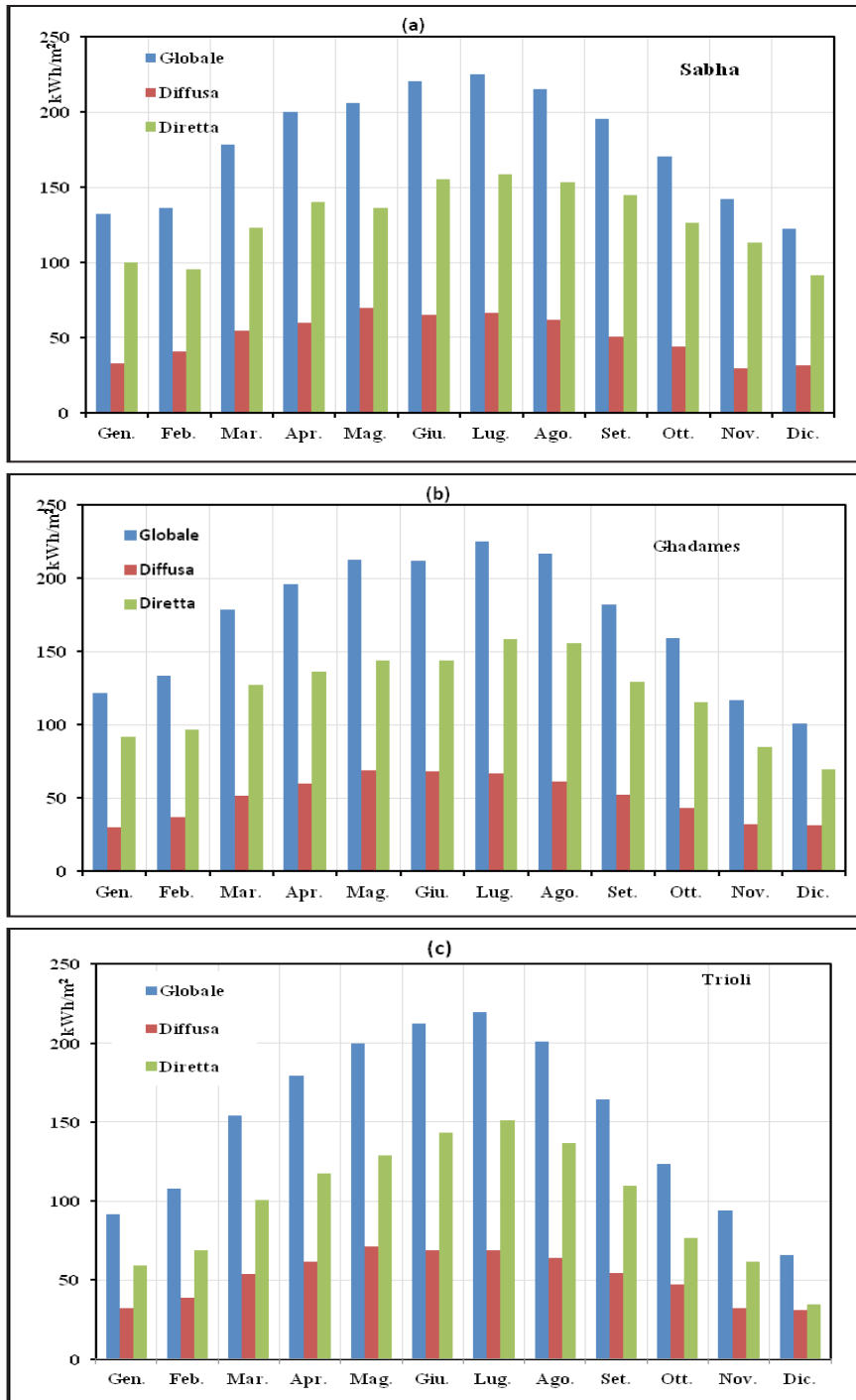


Figure (3). Beam and diffuse components of total monthly radiation

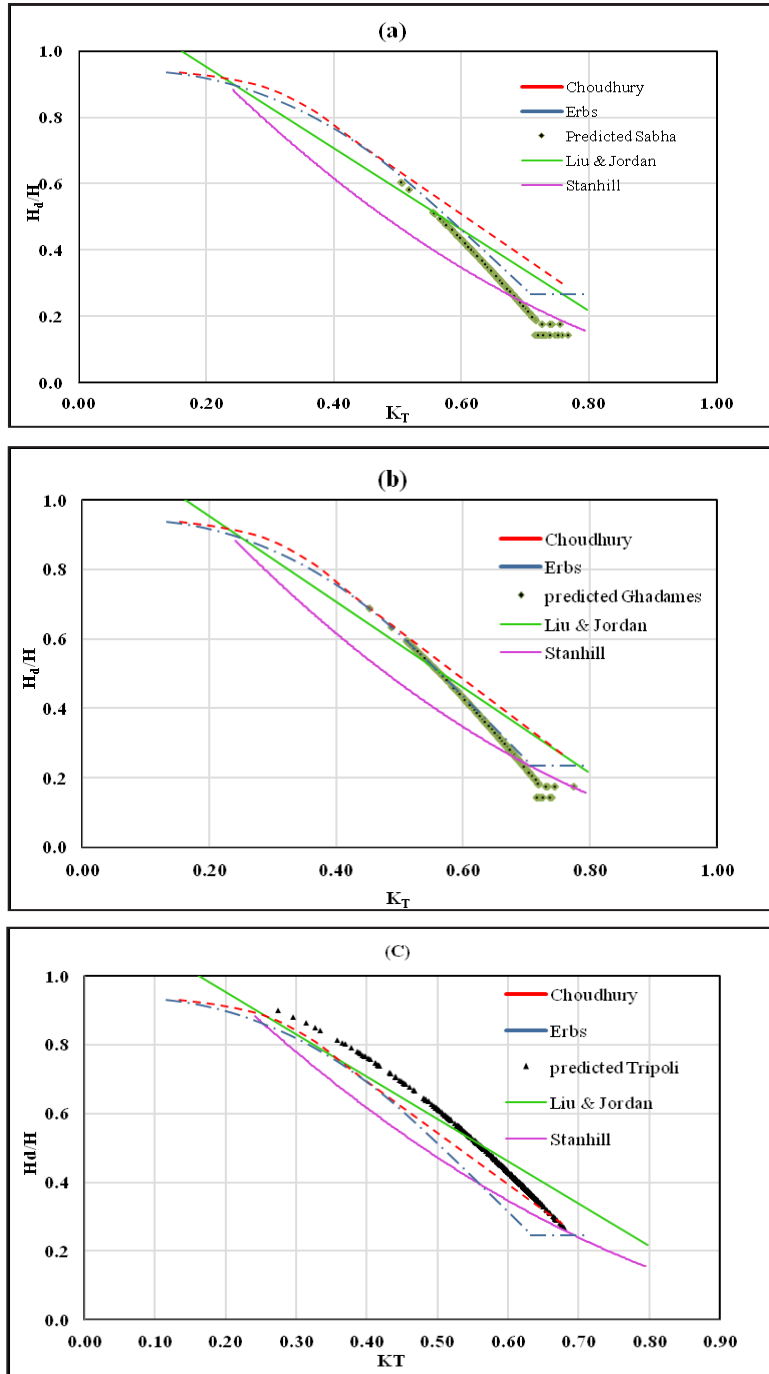


Figure (4). Correlation of daily total diffuse fractions with daily clearness index

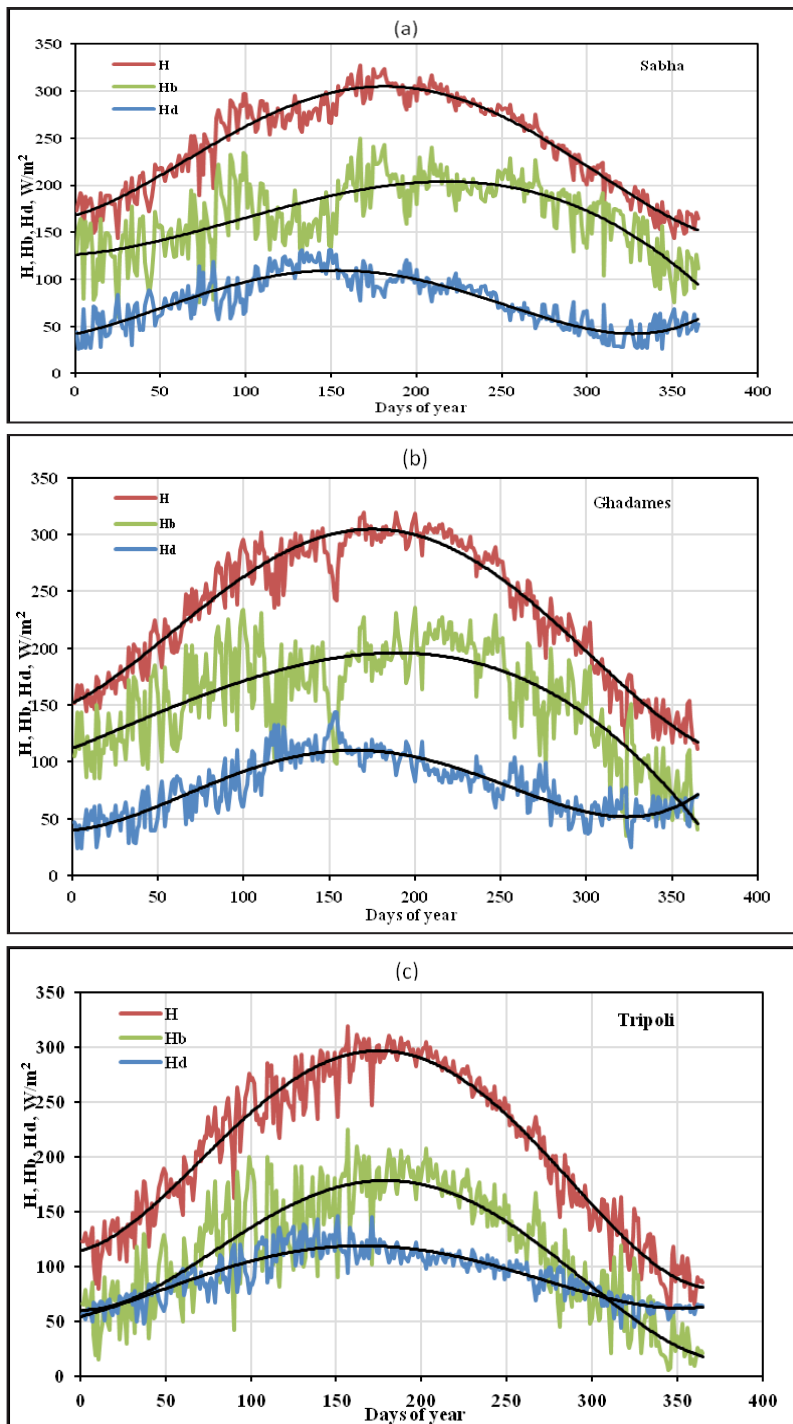


Figure (5). Beam and diffuse components of total daily solar radiation

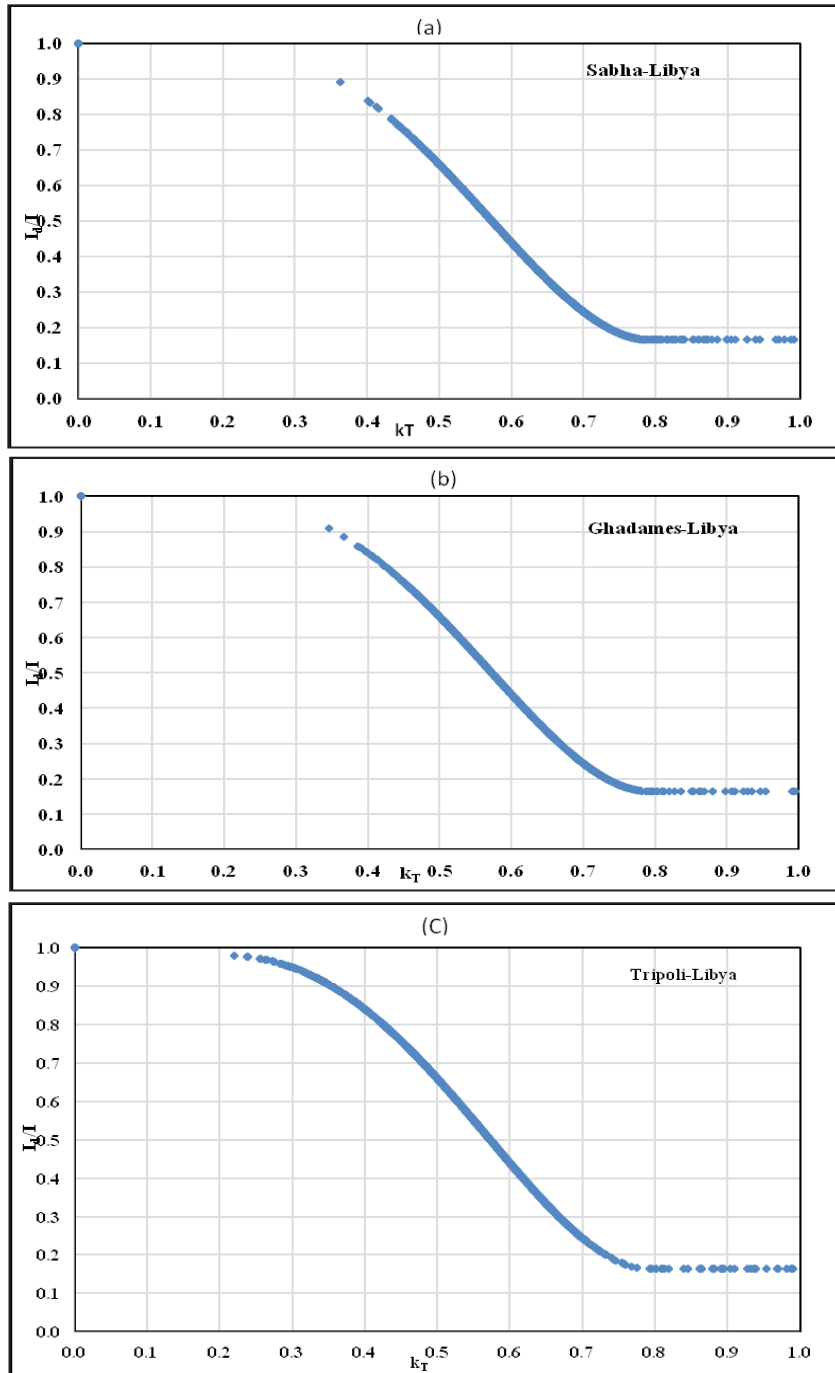


Figure (6). The ratio of hourly total diffuse fraction as a function of hourly clearness index

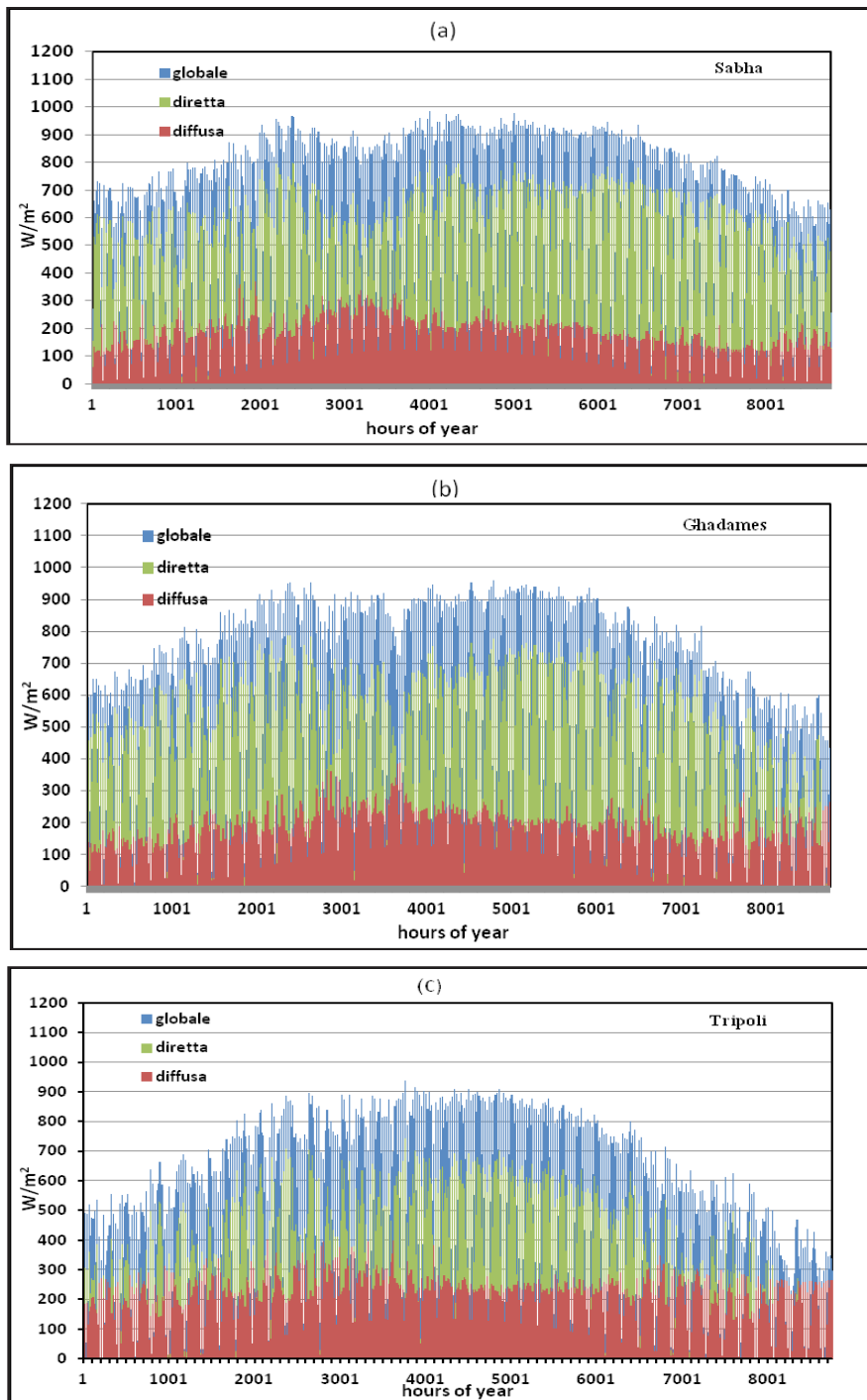


Figure (7). Beam and diffuse components of total hourly solar radiation

5. NOMENCLATURE

\bar{H}	the monthly average of daily global solar radiation on a horizontal surface (kWh/m ²).
\bar{H}_o	the monthly average of daily extraterrestrial radiation on a horizontal surface (kWh/m ²).
H	the daily global solar radiation on a horizontal surface (kWh/m ²).
H _o	the extraterrestrial solar radiation on a horizontal surface on an average day of each month (kWh/m ²).
\bar{N}	the mean daily number of hours of daylight in a given month between sunrise and sunset.
\bar{n}	the average monthly daily number of hours of observed bright sunshine.
a & b	empirical constants depending on location.
G _{sc}	the solar constant.
ω_s	the sunset hour angle.
δ	the declination angle.
φ	the latitude angle.
n	the day of year.
\bar{K}_T	the average monthly clearness index.
I	the hourly global solar radiation on a horizontal surface (kWh/m ²).
I _o	the extraterrestrial solar radiation on a horizontal surface for an hour period (kWh/m ²).
ω_1 & ω_2	the hour angles, where ω_2 is the larger.
\bar{H}_d	the average monthly diffuse radiation.
H _d	the daily diffuse radiation.
I _d	the hourly diffuse radiation
r _t	the ratio of hourly total to daily total radiation as a function of day length and the hour in question
$\frac{\bar{H}_d}{\bar{H}}$	the average monthly total diffuse fraction.
$\frac{H_d}{H}$	the daily total diffuse fraction.

$\frac{I_d}{I}$	the hourly total diffuse fraction.
ω	the hour angle in degrees for the time in question.
CSP	the concentrating solar power plants
PV	the photovoltaic systems.

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