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Estimation of Average of Global Solar Radiation Depending on Sunshine Duration Hours for Iraqi Metrological Stations

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Abstract
In this study, the global solar radiation for the locations of fourteen Iraqi metrological stations was studied and calculated. This was performed because most of the Iraqi stations lack solar radiation measuring devices. The equation postulated by Angström (1924) and modified by Prescott (1940) was utilized for the estimation of the solar radiation for the fourteen Iraqi metrological stations depending on sunshine duration measurements of these stations. Empirical constants of Angstrom-Prescott equation that are adopted by the Food and Agriculture Organization (FAO) were used for obtaining the results. The utilized data reported in this study were taken from the Republic of Iraq Meteorological Office (RIMO). The calculations and diagrams were carried out and the results were obtained by making advantage of Excel's program capabilities.

Keywords: solar radiation, sun duration, Angström-Prescott equation.

تقدير متوسط الإشعاع الشمسي العالمي حسب ساعات السطوع في محطات الانواء الجوية العراقية

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الخلاصة
في هذه الدراسة ، تمت دراسة وحساب الإشعاع الشمسي العالمي لم اقع محطات القياس العراقية الأربعة عشر. تم ذلك لأن معظم المحطات العراقية تفتقر إلى أجهزة قياس الإشعاع الشمسي. تم استخدام المعادلة المفترضة من قبل (Angström 1924) وتعديلها بواسطة (Prescott 1940) ، لتقدير الإشعاع الشمسي لمحطات القياس العراقية الأربعة عشر وفقًا لقياسات السطوع لهذه المحطات. ان الثوابت التجريبية لمعادلة أنجستروم–بريسكوت من منظمة الأغذية والزراعة (الفاو) قد استخدمت وتم الحصول على النتائج. أخذت البيانات المستخدمة الواردة في هذه الدراسة من دائرة الأرصاد الجوية لجمهورية العراق (RIMO). تم تنفيذ العمليات الحسابية والرسوم البيانية وتم الحصول على النتائج من خلال الاستفادة من امكانات برنامج Excel.

Introduction
In addition to energy security concerns, the environmental concerns about fossil fuels led to significant interest in using of renewable energy (RE). The sun affecting the Earth is providing renewable energies that are mostly inexhaustible. Renewable energy sources include solar, wind,

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ocean waves, and thermal sources, noting that the incoming energy from the sun in a visible radiation form of energy to the surface of the earth is known as solar radiation [1]. Solar energy is friendly to the environment and available almost everywhere on Earth, unlike fossil fuels that are available only in limited locations of the world. In addition to the above advantages, solar energy is available and is never subject to price changes related to the oil market. Solar radiation may be harnessed either as a solar or photoelectric radiation. [2]. The differences in the received solar radiation at a given place are caused bythe sequence of the day of the year, latitude, sea level (altitude) and climatic factors such as clouds, humidity and dust [3].In principle, most of these variables are well understood. Difficulty arises for not describing physical weather conditions in both spatially and temporally dimensions. Other difficulties are related to clouds as they are highly variable in both spatial and temporal dimensions and in spatial dimension. Clouds are impossible to be described even for a specific short time in a specific location [4]. Daily mean solar radiation data are necessary for the study and the design of solar energy control devices [5]. Sunshine duration is one of the most important parameters of meteorology measurement because it plays an active role to determine the data of solar radiation. Also, through its relationship with global solar radiation, relative humidity and other climatic variables, sun duration represents the most efficient parameter [6].

A huge source of energy is represented by solar energy, with about 170 trillion kw of being usually received to the Earth. Global solar radiation *H* with its components (i.e. diffuse H_d and direct H_r) are active parameters [7]. Angstrom-Prescott equation is utilized to calculate global solar radiation (H) on a horizontal surface by using the sun duration data [8]. The modified form of Angstrom equation is a simple model utilized for estimating the global radiation. In 1924, Angstrom was able to develop the first relationship between the sun duration and global solar radiation, the irradiation using a linear model. After that, Prescott developed the equation in a favorable form when he replaced the global solar radiation on a clear sky by extraterrestrial solar radiation, as follows:

$$H/H_o = A + B(n/N)\text{.........}(1)$$

Where *H* is the global solar radiation on horizontal surface in a day ($MJ.m^{-2}.d^{-1}$), n is the daily bright light duration (Hours per month), N is the maximum possible daily bright duration (Hours per month), [9]

$$N = \frac{2w}{15}\text{..........}(2)$$

A, and *B* are empirically constants. The FAO proposed two values for *A* and *B* as in the following:[10]

A= 0.25, *B*= 0.50

The following equation was used to calculate the monthly average daily extraterrestrial radiation on horizontal surfaces ($MJ.m^{-2}.d^{-1}$):

$$H_o = 37.6 \times E_o\left[\cos\phi\cos\delta\sin\omega + \frac{\pi w}{180}\sin\phi\sin\delta\right]\text{..........}(3)$$

Where E_o is the emendation of receiving solar radiation due to the changing distance in the path between the Sun and the Earth. It is given by the equation:

$$E_o = 1 + 0.033\cos\left(\frac{2\pi}{365}d\right)\text{.........}(4)$$

Where φ is the latitude, *d* is the Julian day number and δ is the declination angle given by the equation:

$$\delta = 0.4093\sin\left[360\left(\frac{2\pi}{365}d - 1.39\right)\right]\text{..........}(5)$$

Where *w* is the sunset hour angle given by the equation:

$$w = \cos^{-1}(-\tan\phi\tan\delta)\text{.........}(6)$$

Weather in Iraq

Iraq as a Middle Eastern country is one of the countries which are situated on a yellow belt of Earth that can receive the maximum light during the day and in different months in the year. Iraq climate is described as hot weather in summer and cold in winter. A typical meteorological data set is not available in Iraq, mainly due to the lack of sufficient raw data [11].

The RIMO data

The utilized RIMO data of the studied sunshine duration of the fourteen Iraqi metrological stations are illustrated by using an Excel program in Figure-1. The table describes the monthly average data of Iraqi metrological stations with their latitude, longitude and elevation.

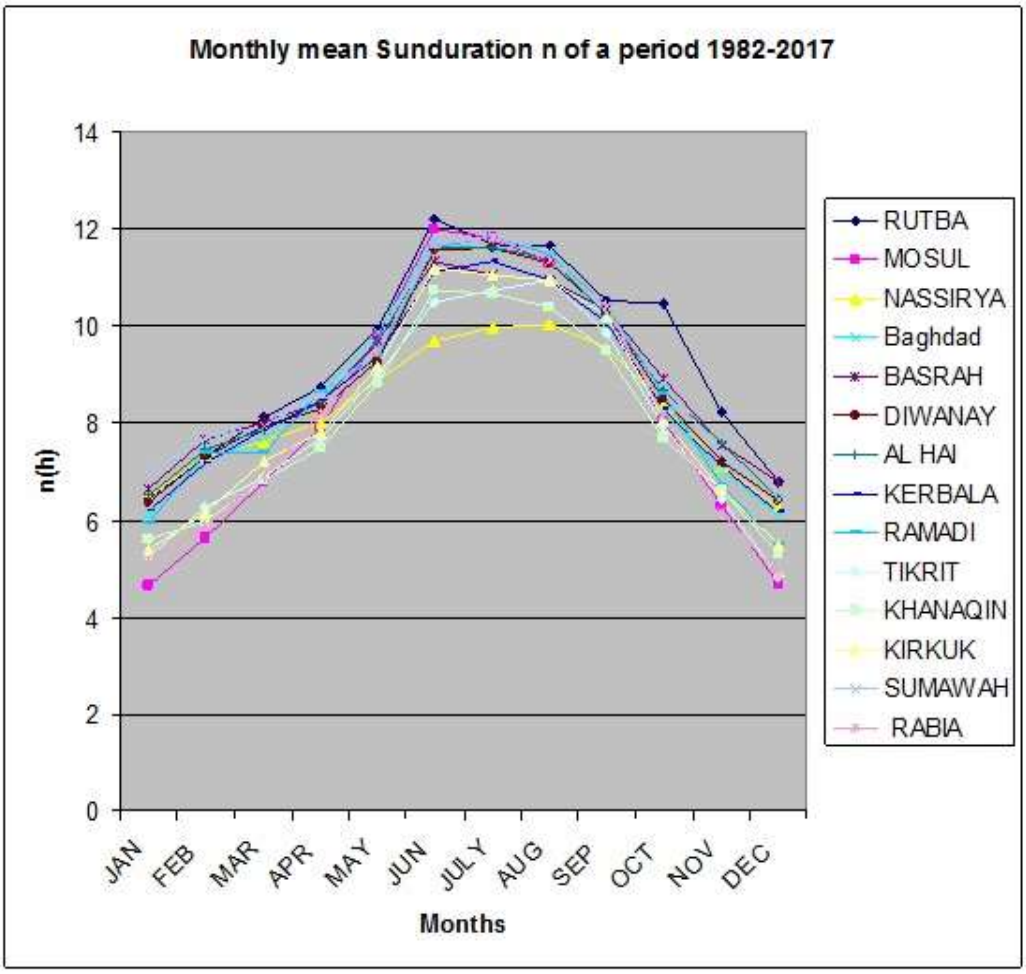

Figure 1-The mean monthly Sun duration data for the period of 1982 to 2017.

Table 1-The measured values of the monthly average daily sun duration of the studied stations recorded over the period 1982-2017

Station name	Station No	Long. E^o	Lat. N^0	Elevation (m)	Sun duration
Basrah-husain	689	47.47	30.31	2	8.923951
Nasrya	676	46.14	31.01	5	8.760606
Samawa	674	45.16	31.16	11.4	9.13935
Aldiwanya	672	44.57	31.57	20	9.018923
Hai	665	46.02	32.08	17	8.994462
Kerbela	656	44.03	32.34	29	8.81058
Rutba	642	40.17	33.02	630.8	8.995417
Baghdad	650	44.24	33.18	31.7	8.719084
Ramadi	645	43.19	33.27	48	8.7708043

Khanaqin	637	45.23	34.21	202	7.977162
Tikrit	633	43.42	34.34	107	7.708043
Kirkuk	621	44.24	35.28	331	8.230881
Mosul	608	43.09	36.19	223	8.088286
Rabiah	602	42.06	36.47	382	8.212987

Results and discussion

Angstrom equation is an important equation in the field of studying solar radiation. This equation was used after the calculation of the correction of the incoming solar radiation E_o , declination angle δ, sunset hour angle *w*, astronomical day length *N*, and extraterrestrial solar radiation H_o. The experimental constants a and b of the FAO were supplied to Angstrom equation.

In order to determine the values of global solar radiation for the fourteen stations, equation 1 was utilized after applying the following steps:

1. The correction of incoming solar radiation E_o was calculated for the 365 days of a year by using equation 3. Figure-2 illustrates the change in E_o values with the 365 days of a year.

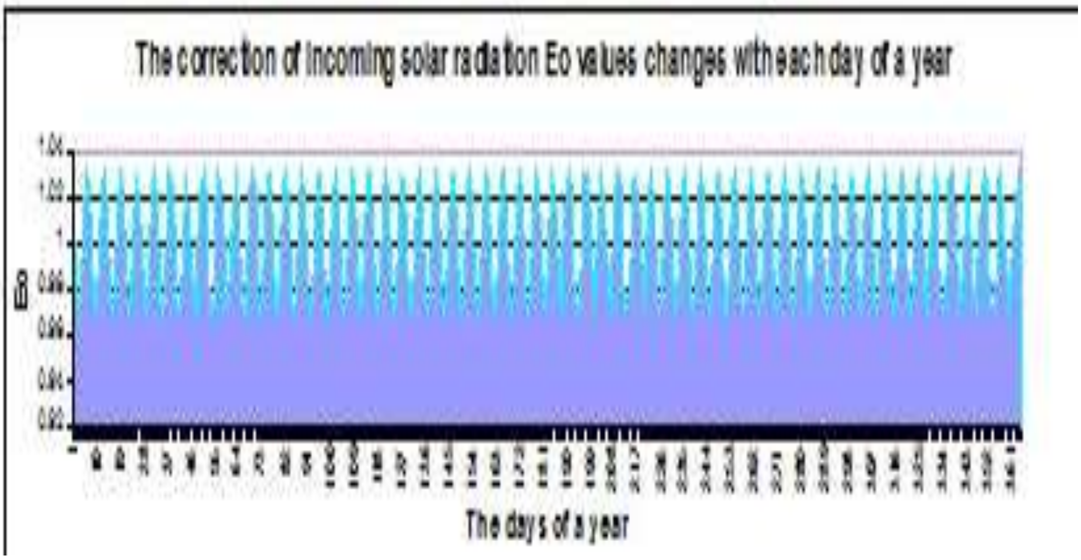

Figure 2-The change in E_o values with the 365 days of a year.

2. The declination angle δ was calculated for the 365 days of a year by using equation 4. Figure-3 illustrates the change in δ angle values with the 365 days of a year.

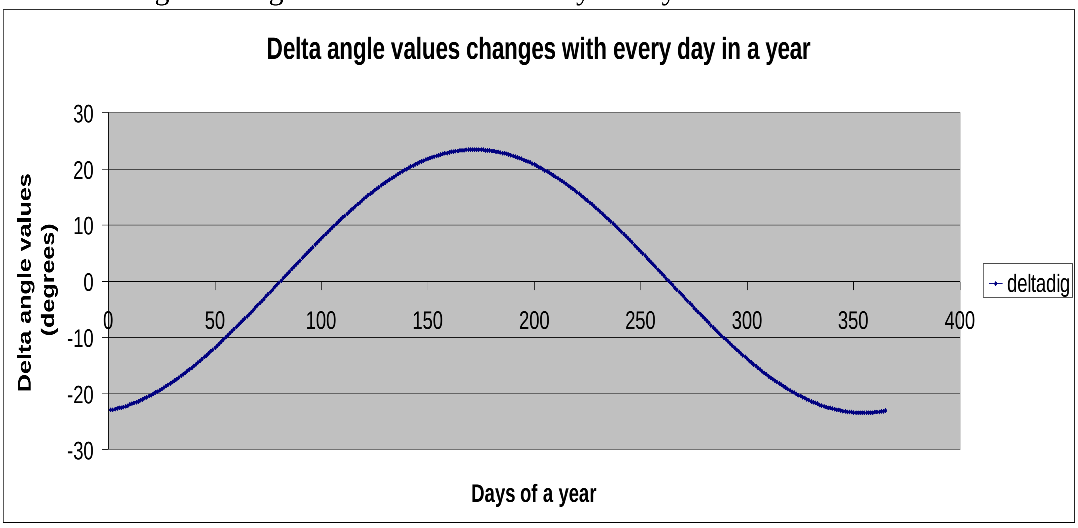

Figure 3-The change in δ angle values with the 365 days of a year

3. The sunset hour angle *w* was calculated for the 365 days of a year by using equation 5 depending on the location (latitude). Figure-4 demonstrates the change in *w* angle values with the 365 days of a year in each sun duration station.

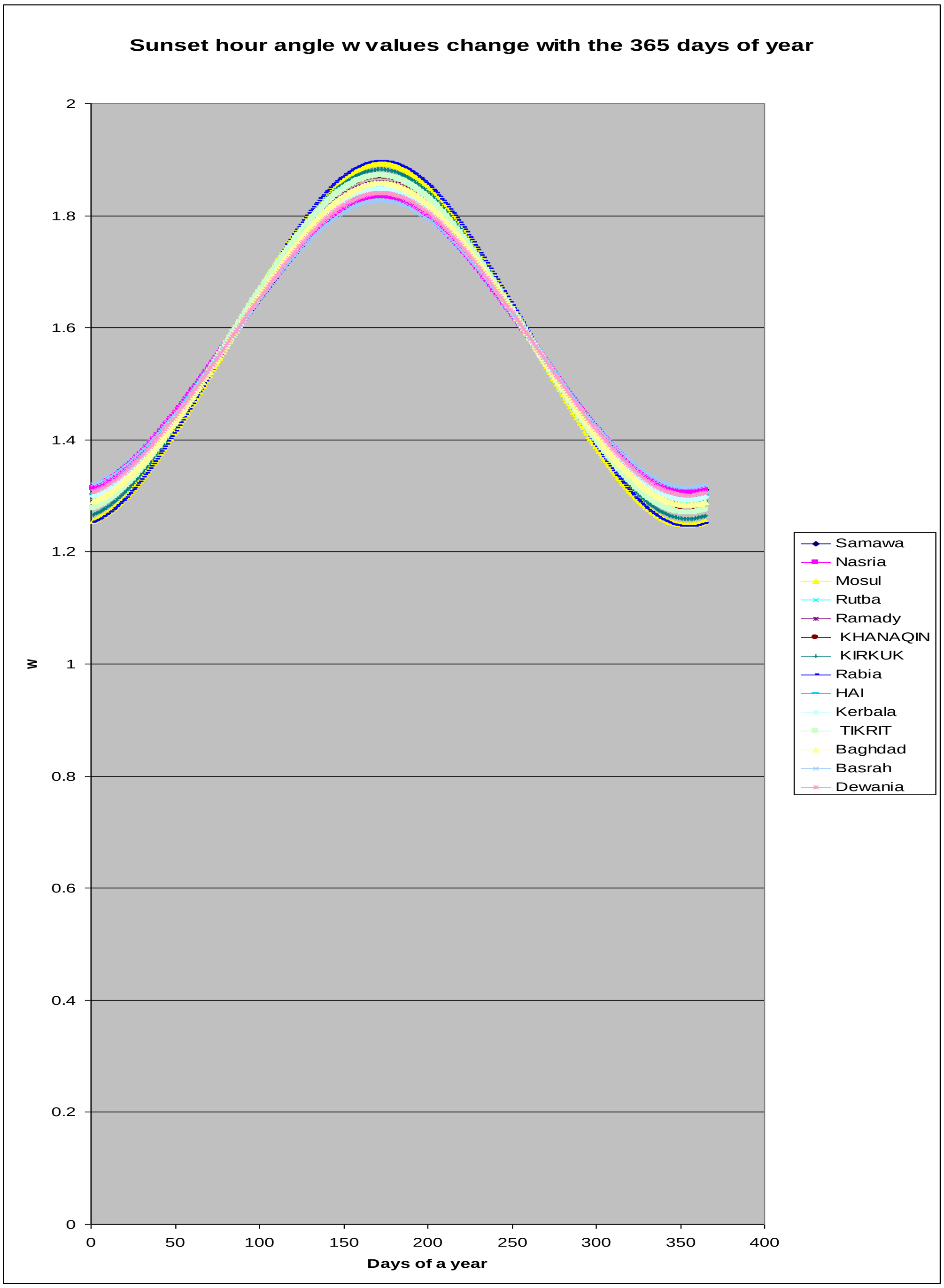

Figure 4-The change of *w* angle values with the 365 days of a year in each studied sun duration station.

4. Astronomical day length *N* (hours) for a horizontal surface for the 365 days of a year was calculated in each station by using equation 6. Figure-5 illustrates the change in *N* values (hours) with the 365 days of a year in each sun duration station.

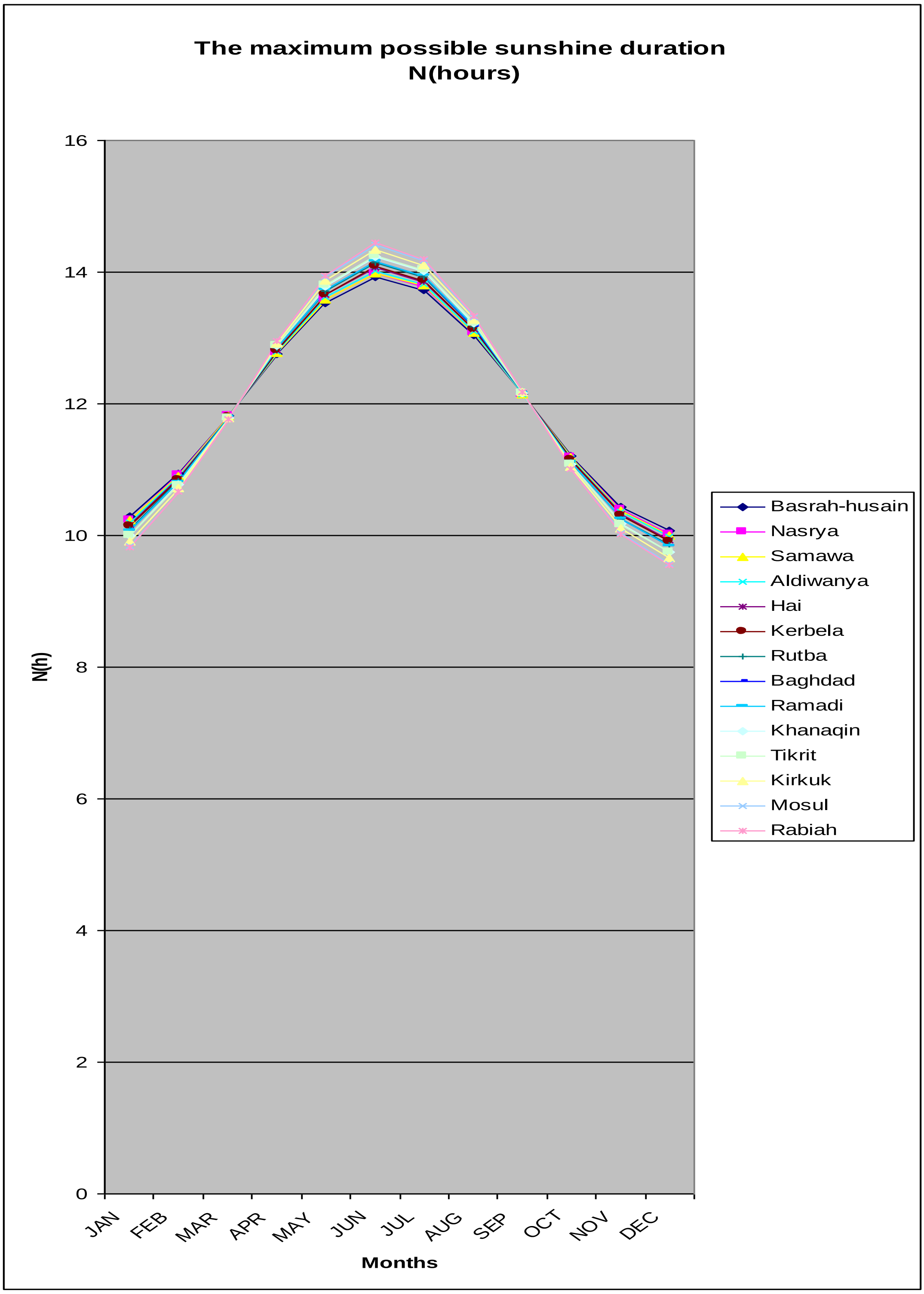

Figure 5-The change of astronomical day length N values (hours) with the 365 days of a year in each studied sun duration station

5. The calculated values of E_o, δ, w and N were applied in equation 2 to calculate the extraterrestrial solar radiation on a horizontal surface H_o for the 365 days of a year. Figure-6 shows the change in H_o values with the 365 days of a year in each sun duration station.

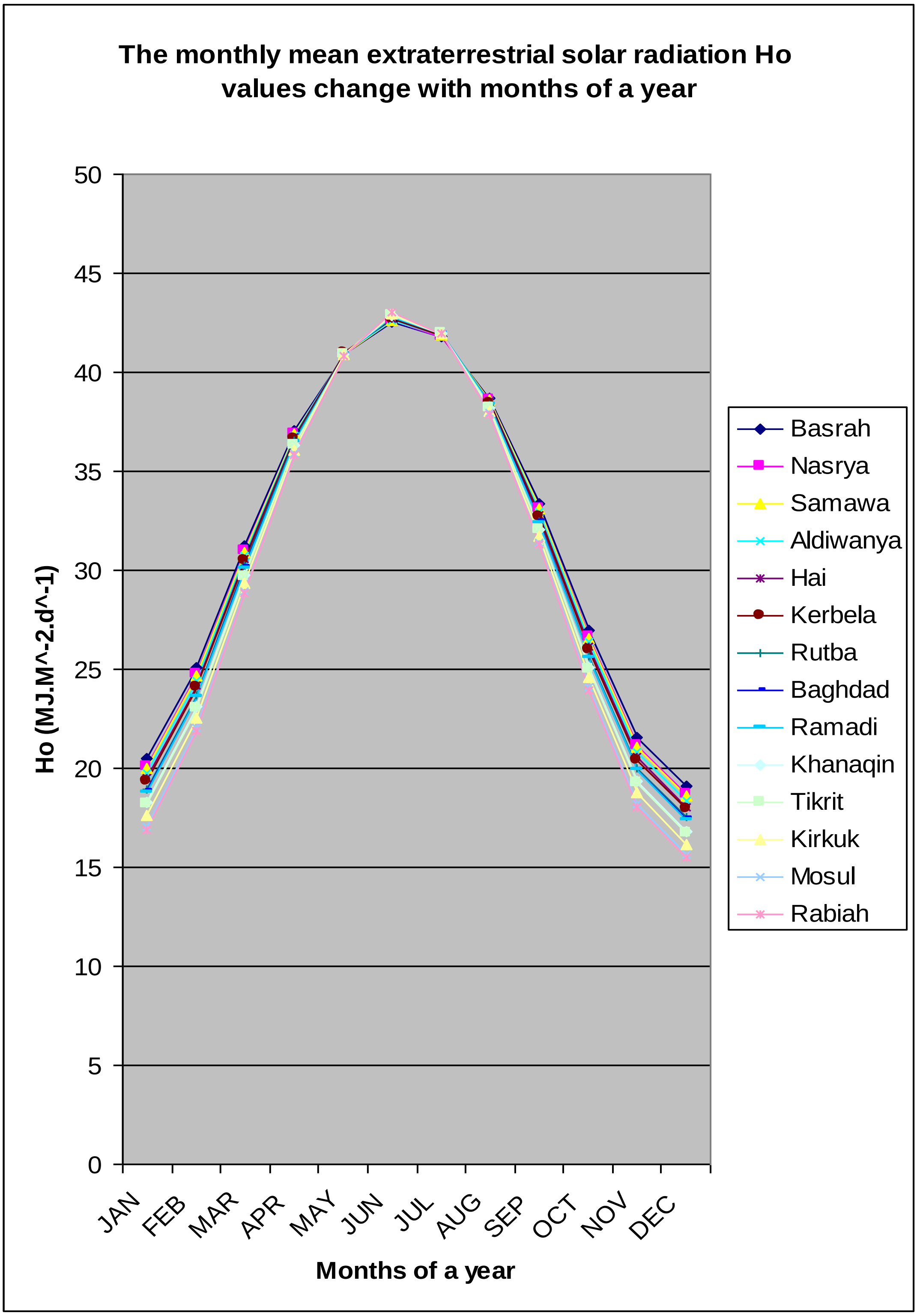

Figure 6-The change of the extraterrestrial solar radiation H_o for the 365 days of a year in each studied sun duration station

The results also show that the astronomical day length N and the extraterrestrial solar radiation H_o values decrease with the increase in the distance from the equator, as shown in Figures-(5 and 6).
The calculated values of monthly mean H_o and N were applied in equation 1 to determine the monthly mean values of global solar radiation H. Figure-7 shows the change in H values with the months of a year in the stations.

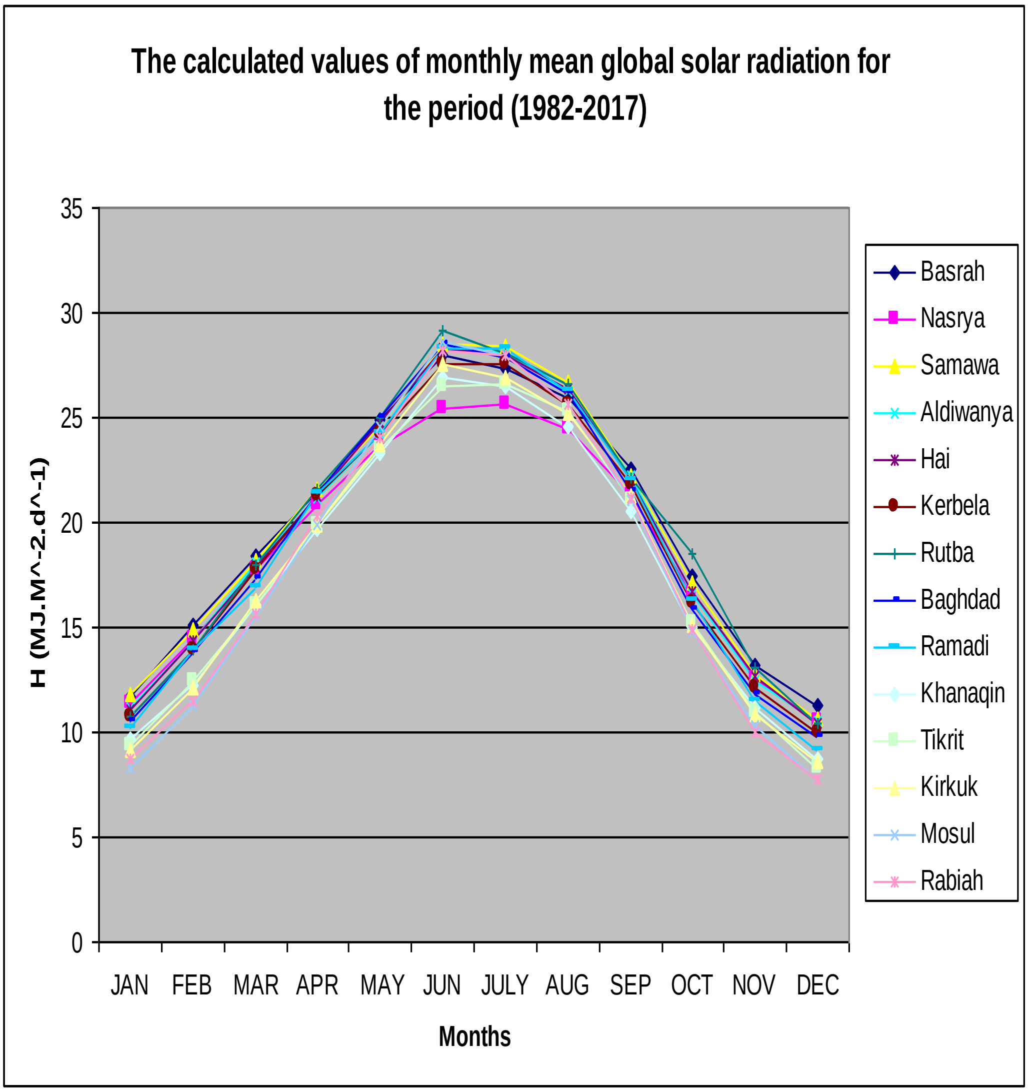

Figure 7-The change of the calculated monthly mean global solar radiation *H* for each studied sun duration station

The results obtained from this research generally indicate that the analysis of the geographical location is the most influential factor on global solar radiation values. Therefore, the values of solar radiation decreased with the increase in the distance from the equator, whereas the solar radiation values typically decreased with the increase in the latitude, as shown in Figure-7.

The calculated values of the monthly average daily of H_o and N were applied in equation 1 to determine the monthly average daily values of global solar radiation H., as illustrated in Table-2. Figure-8 shows the change in H values with stations distribution from south to north of Iraq.

Table 2-The calculated values of the monthly average daily of sun duration n, extraterrestrial solar radiation H_o, maximum possible sunshine duration N, and global solar radiation H in the fourteen meteorological stations studied for the period 1982-2017.

Station name	***n***	***N***	H_o	H
Basrah-husain	8.923951	11.99309	31.56458	19.63461
Nasrya	8.760606	11.99294	31.36285	19.29568
Samawa	9.13935	11.99291	31.31912	19.76335
Aldiwanya	9.018923	11.99282	31.19866	19.53078

Hai	8.994462	11.9927	31.04697	19.40427
Kerbela	8.81058	11.99264	30.96886	19.11809
Rutba	8.995417	11.99249	30.76208	19.22765
Baghdad	8.719084	11.99245	30.71292	18.84311
Ramadi	8.7708043	11.99243	30.68517	18.89227
Khanaqin	7.977162	11.99222	30.39173	17.70614
Tikrit	7.708043	11.99219	30.35063	17.34167
Kirkuk	8.230881	11.99196	30.04968	17.82497
Mosul	8.088286	11.9917	29.7522	17.47184
Rabiah	8.212987	11.99167	29.65948	17.57163

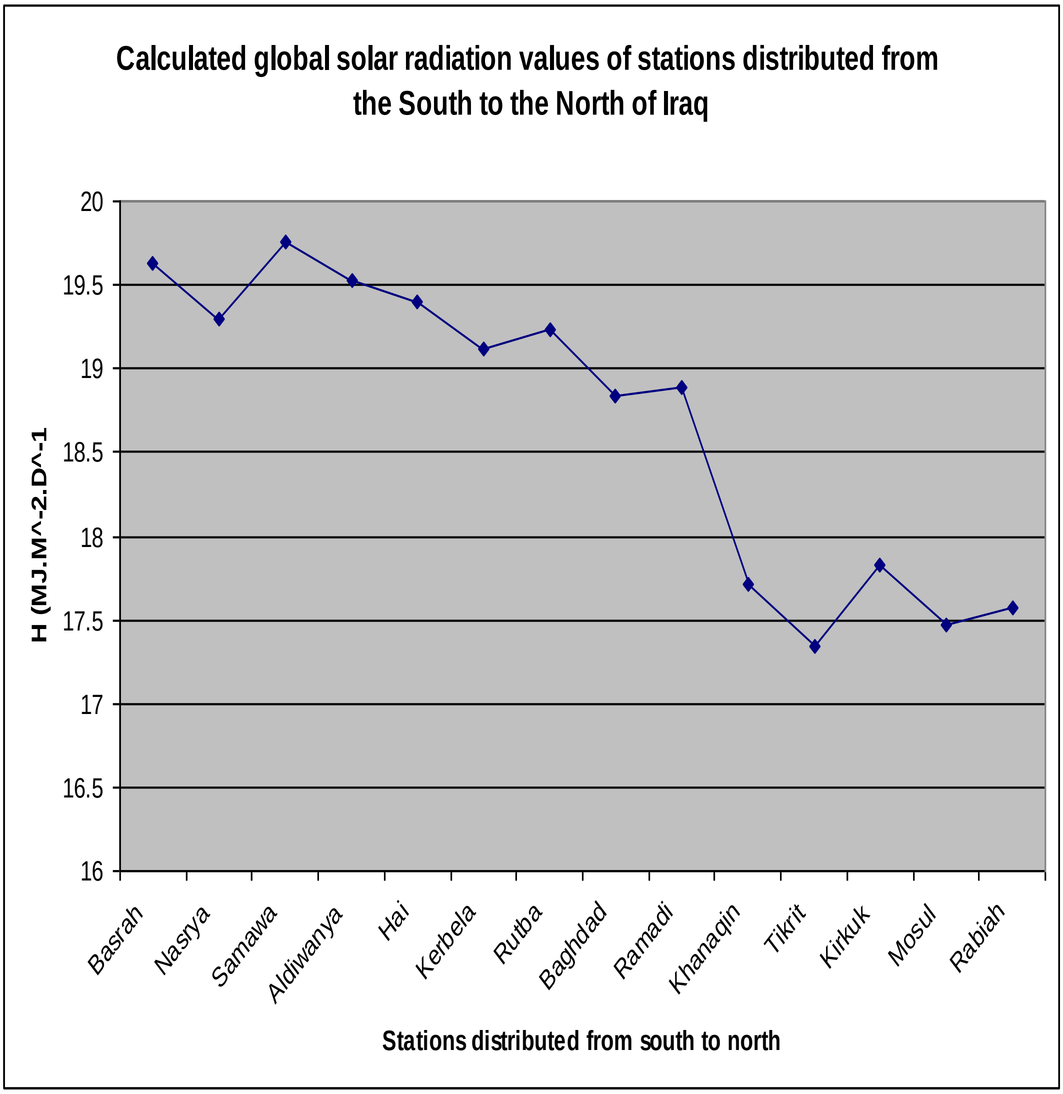

Figure 8-The change in *H* values with stations distribution from south to north of Iraq.

The values of the ratio of sun duration to the astronomical day length (n/N) in the included stations during the months of the year are shown in Figure-9.

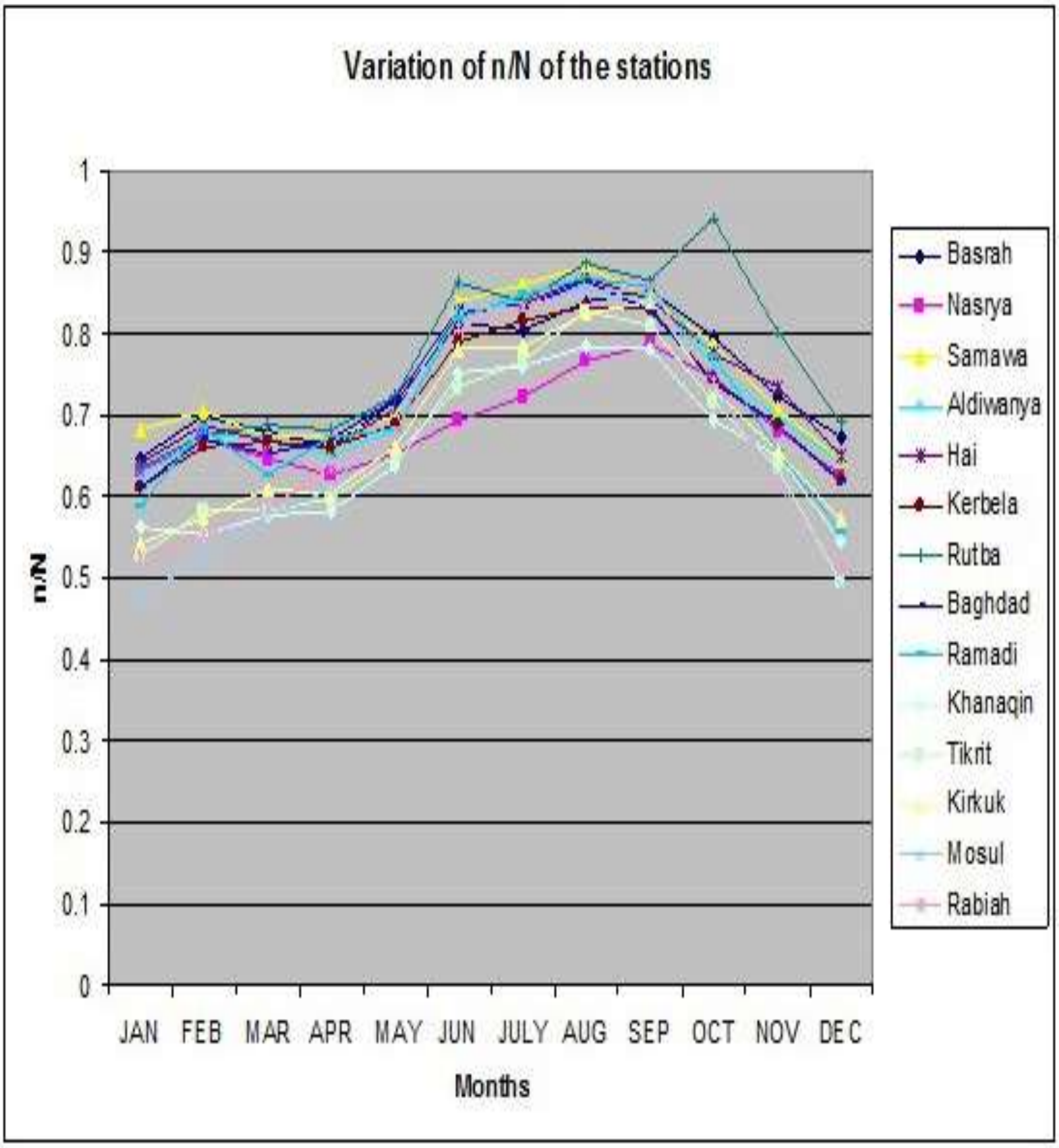

Figure 9-The change of n/N ratio during months of the year for each studied sun duration station.

Conclusions

This study showed that it is possible to calculate the values of extraterrestrial radiation (Ho) and global solar radiation (H) by means of the geographical location (latitude) and sunshine duration data, making the application of Angstrom equation possible. The values of the regression constants *A* and *B* of the FAO The values of the constants were dependent on the location of the station within the Iraqi land. In this study, the application of Angstrom equation provided a successful estimation of global solar radiation (H) for all the fourteen stations. This was deduced by the fact that the calculated values decreased gradually with the increase in the distance from the equator, which is consistent with what was expected. Figures-(6, 7), which are related to the changes in the monthly mean values of extraterrestrial solar radiation (Ho) and global solar radiation, show that the maximum value of Ho (about 43) and H (about 28) for the fourteen stations were recorded during the summer, especially in June and July, while the minimum values of Ho (about 15.1) and H (about 8) were observed during the winter, especially in January and December.

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