



## HARLIN model for prediction of solar radiation for Baghdad city, Iraq

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### Abstract

In this study a combination of two basics known methods used to daily prediction of solar insolation in Baghdad city, Iraq, for the first time, the harmonic and the classical linear regression analyses, thus it is called HARLIN model. The resulted prediction data compared with basics data for Baghdad city for two years (2010-2011), where the model showed a great success application in the accurate results, compared with the linear famous and well known model which is used the classical linear Angstrom equations with various formulations in many previous studies.

**Keywords:** harmonic analysis, linear regression, Angstrom equation, global radiation.

### الموديل التوافقي - الخطي لتقدير الاشعاع الشمسي لمدينة بغداد في العراق

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### الخلاصة

في هذا البحث سندررس موديل جديد ولأول مرة يطبق في العراق ولمدينة بغداد، حيث يدمج ما بين التحليل التوافقي الاساسي لمتسلسلة فورير والتحليل الكلاسيكي لمعادلات انكستروم الخطية ثم استنتاج معادلة تجمع ما بين الطريقتين لتقدير ودراسة الاشعاع الشمسي الكلي اليومي ولذلك سمي الموديل "التوافقي-الخطي". وقد تم مقارنة القيم المستنتجة مع القيم المقاسة لمدينة بغداد لسنتين 2010-2011، حيث اظهر الموديل نجاحا باهرا ودقة في النتائج مقارنة مع موديل الخطي المتعارف عليه والمتداول كثيراً الذي يستخدم المعادلات الخطية لانكستروم المشهورة وبمختلف صيغها في مختلف الدراسات السابقة.

### Introduction

Most solar energy applications such as the systems of solar energy simulation require at least, knowledge of day by day values of global solar energy insolation for horizontal surface. Thus, accurate estimation of daily values of global radiation data is essential for the design and estimation of long term solar energy conversion systems performance, such as a solar project, forecasting of meteorological, systems of solar heating, drying and architectural engineering design [1].

The importance of this work lies on the essential acknowledgement of needing global solar radiation data in the country were unfortunately especially recently not easily available, due to lack of Pyrometer stations around therefore it is, important to elaborate methods to estimate the solar radiation on the basis of more readily meteorological data such as estimate the daily global solar radiation using sunshine data.

There are many previous researches have used the empirical linear models which developed to estimate daily solar radiation as well as sunshine duration data using classical linear regression

ngstrom equations in the world and Iraq. In Turkey, Bakirci (2009) [2] provided a correlations to estimate daily global solar radiation together with bright sunshine hours and, Bulut and Buyukalaca model (2007) [3] predicted a simple model to generate daily global solar radiation and have compared with real data. In Iraq, Fayadh *et al.* models (2010) [4] provided empirical correlation using sunshine duration for Tikrit and Kirkuk and, over Haditha, Samara and Beji (2010) [5] Fayadh *et al.* evaluted the global solar radiation on horizontal surface. In (1993), Akrawi and Najar [6] studied the Harmonic analysis of global solar radiation for monthly values in Iraq. For clear weather solar radiation prediction using harmonic analysis method in (1998) by Al-Riahi *et al.* [7]. The mentioned models, linear method adopted alone and harmonic analysis method adopted only, but the way in which we have adopted in our research integrated both these methods in one model and apply for the first time in Iraq with high currency results compared with real data, this is the importance of this new technique.

In this research we used a combination of HARmonic and classical LINEar model or HARLIN model, and applied the harmonic analysis to solar radiation and sunshine duration hours data for more refined psuperior pertinent predication of solar radiation, combined together withand the linear regression analysis combined together, and therefore, it is referred to the HARLIN model. It separate first the periodicity from the daily averages of measured values and then apply the linear regression analysis and harmonic analysis of first order to the data to obtain better daily solar radiation prediction [8] and finally the comparison of records and prediction values is done..

**Materials and methods**

Daily Solar radiation and sunshine duration data recorded by Iraqi Meteorological Organization and Seismology for Baghdad city for two years 2010 and 2011.

**Harmonic analysis**

The periodic data are organized and simulated in a program as in Table-1, as daily records global solar radiation  $\bar{Y}_{ij}$  are arranged in 365 columns as  $i=1, 2, 3, \dots, 365$  and rows as  $j=1, 2, 3, \dots, n$ ,  $n$  referred to the number of years ( $n=2$  for two years as in this research), where the last row in Table (1) includes 365 daily averages  $\bar{Y}_i$ .

**Table 1-**Calculation of daily averages.

		Days				
<b>Years</b>		$Y_{1,1}$	$Y_{1,2}$	.....	$Y_{1,364}$	$Y_{1,365}$
		$Y_{2,1}$	$Y_{2,2}$	.....	$Y_{2,364}$	$Y_{2,365}$
		⋮	⋮	⋮	⋮	⋮
		$Y_{n-1,1}$	$Y_{n-1,2}$	.....	$Y_{n-1,364}$	$Y_{n-1,365}$
		$Y_{n,1}$	$Y_{n,2}$	.....	$Y_{n,364}$	$Y_{n,365}$
<b>Daily Averages</b>		$\bar{Y}_1$	$\bar{Y}_2$	.....	$\bar{Y}_{364}$	$\bar{Y}_{365}$

The expansion form of the basic equation used in harmonic analysis which composed of sine and cosine waves is:

$$Y_i = \bar{Y} + A \sin\left(2\pi \frac{i}{T}\right) + B \cos\left(2\pi \frac{i}{T}\right) \tag{1}$$

Where  $\bar{Y}$  : is the average for all daily averages. The arithmetic average  $\bar{Y}$  of all daily averages is given as follows:

$$\bar{Y} = \frac{1}{365} \sum_{i=1}^{365} \bar{Y}_i \tag{2}$$

T: is the basic period duration equal to 365 days.

A and B: are the coefficients of the amplitudes for harmonic components of sine and cosine curves, respectively, which can be calculated as:

$$\mathbf{A} = \frac{2}{T} \sum_{i=1}^T \bar{Y}_i \sin\left(2\pi \frac{i}{T}\right) \quad (3)$$

$$\mathbf{B} = \frac{2}{T} \sum_{i=1}^T \bar{Y}_i \cos\left(2\pi \frac{i}{T}\right) \quad (4)$$

The equations (1), (2) and (3) are computed using the daily averages  $\bar{Y}_i$  ( $i = 1, 2, 3, \dots, 365$ ), [6, 8].

### Angstrom equation

Angstrom (1924) presented the first correlation for estimating the monthly average of daily global radiation values. The original Angstrom type regression equation related monthly average of daily radiation of clear day radiation for a given location with the average fraction of sunshine duration hours [9]:

$$\frac{H}{H_0} = \mathbf{a} + \mathbf{b} \left(\frac{S}{S_0}\right) \quad (5)$$

where  $H$  is the monthly average of daily global radiation ( $\text{W/m}^2/\text{day}$ ),  $H_0$  is the monthly average for the given location of clear sky daily global radiation ( $\text{W/m}^2/\text{day}$ ),  $S$  is the monthly average of daily bright sunshine duration (hours),  $S_0$  is the monthly average maximum daily of bright sunshine duration (hours), finally  $\mathbf{a}$  and  $\mathbf{b}$  are empirical constants [10].

### Result and discussion

In Figure-1 the two sequences of basic data for HARLIN model, where it indicates the agreement between the harmonic analysis curve and daily averages for basic data (for two years).

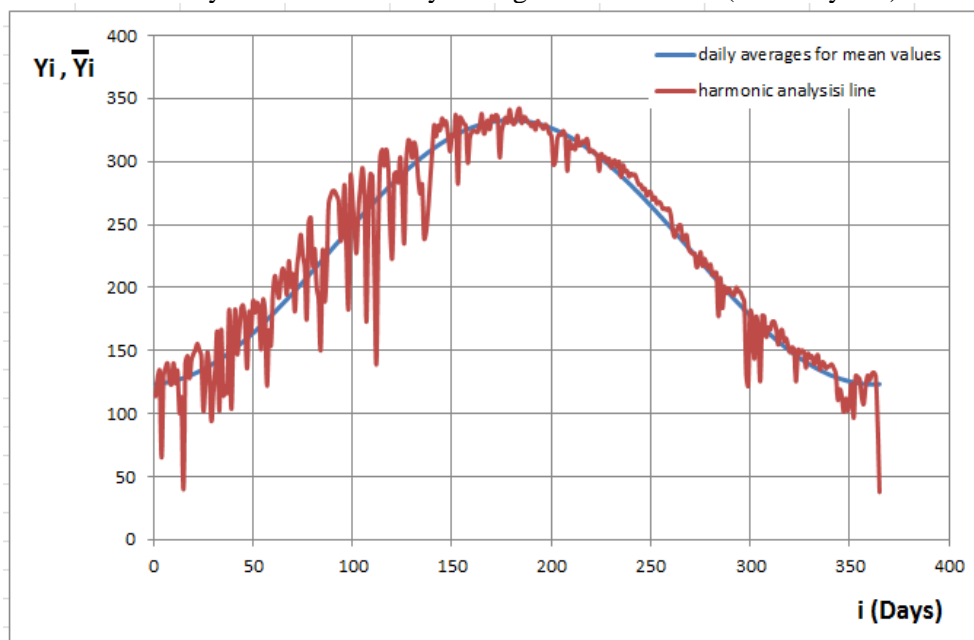


Figure 1-Harmonic analysis line and daily averages for global solar radiation.

According to harmonic analysis, the new progression is generate by subtracting the corresponding harmonic values ( $Y_i$ ) from the daily averages ( $\bar{Y}_i$ ) for sunshine duration and global solar radiation and their plots as show in Figure-2.

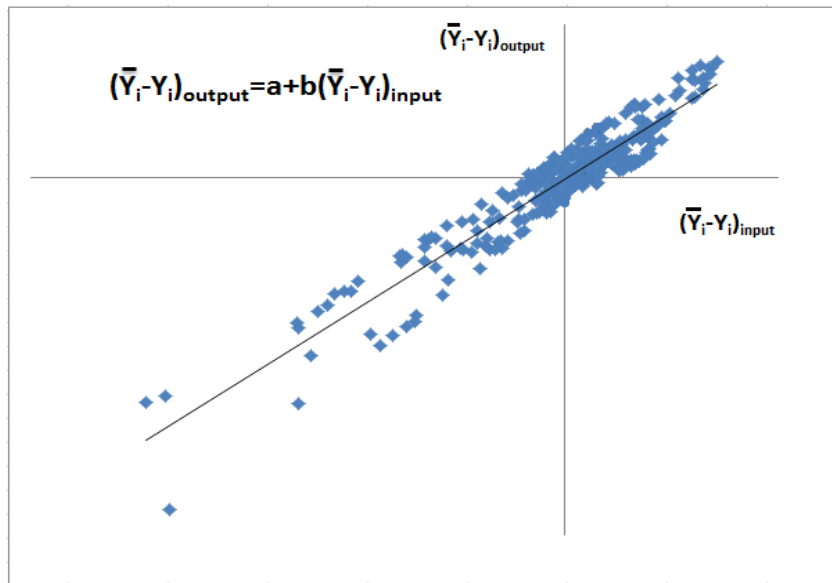


Figure 2- Linear regression analysis for different data.

In Figure- 2 the  $\bar{Y}_i$  and  $Y_i$  values are the solar radiation which is represented the output and sunshine duration which is represented the input so as to make the prediction with regard to the linear regression model parameters which is called the Angstrom equation.

Applying HRLIN model to calculate the predicted daily values, where  $Y_p$  the predicted daily value is can be written in terms of two components.  $Y_H$  as harmonic results represented by equation (1), and  $Y_L$  as linear regression results represented by equation as shown in Figure- 2, therefore the prediction expression can be written mathematically as [8];

$$Y_p = Y_H + Y_L \tag{6}$$

Figure-3 shows the same procedure is applied to global solar radiation and sunshine duration for Baghdad city, as well as shows the straight line and the empirical constants (a and b) of the prediction equation which give the possibility to solar radiation prediction according to Angstrom model [10].

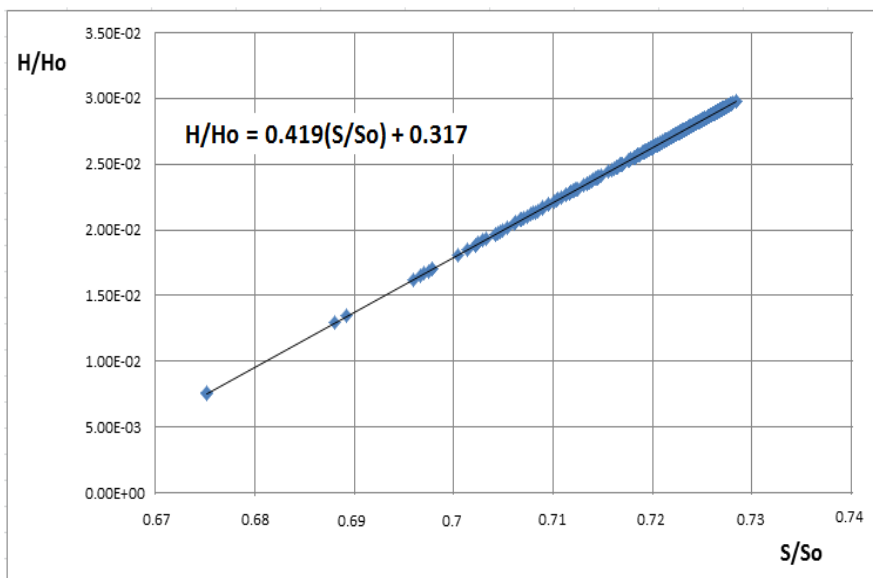


Figure 3- Angstrom equation for Baghdad city (2010-2011).

Figure-4 shows the harmonic analysis results of solar radiation and sunshine duration are plotted in these two figures respectively.

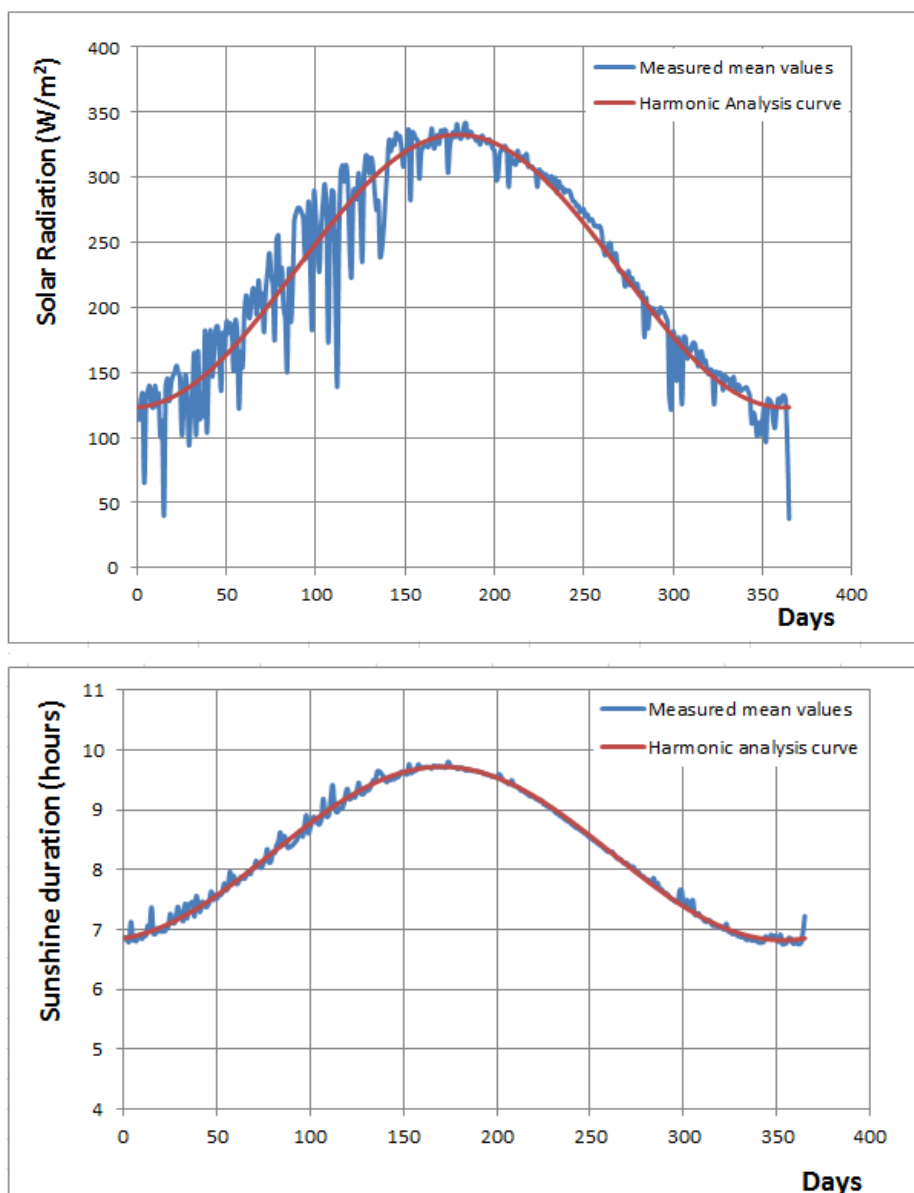


Figure 4- Harmonic analysis of HARLIN model for solar radiation and sunshine duration.

The coefficients A and B, in addition to  $\bar{Y}$  values in equation (1) are calculated and presented in Table -2 for both global solar radiation and sunshine duration.

Table 2- A and B coefficients and  $\bar{Y}$  values for Baghdad city for HARLINE model.

BAGHDAD CITY		
coefficient	Sunshine duration (hour)	Solar radiation (W/m <sup>2</sup> )
A	0.29648674	5.46126144
B	-1.41830174	-104.667743
$\bar{Y}$	8.27226595	228.070776

Angstrom as linear regression analysis for HARLIN model is generated by using differences of harmonic analysis values,  $Y_i$  from  $\bar{Y}_i$ . The results and the coefficients are shown in Figure-6.

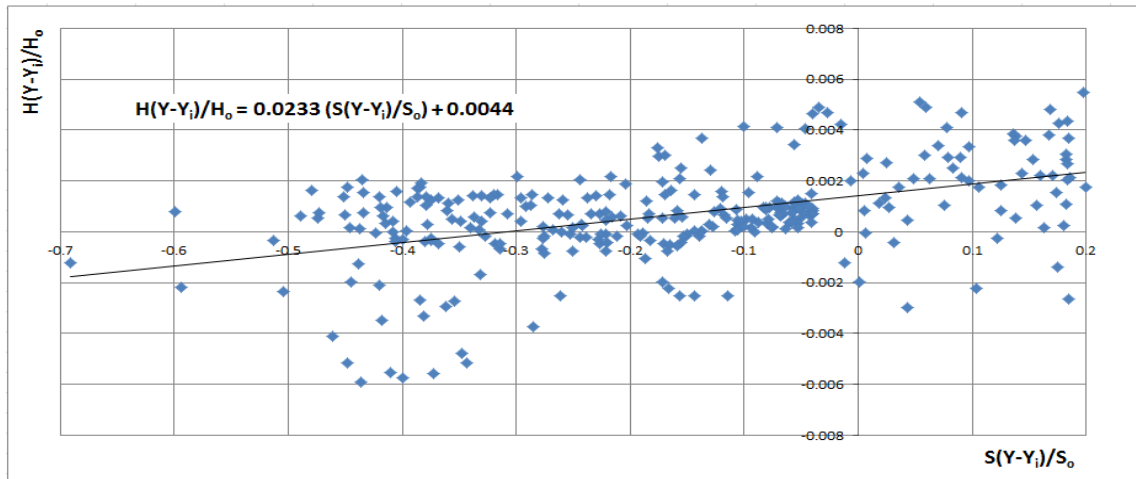


Figure 6- Baghdad 2010-2011 Angstrom equation for difference values.

Figure-7 and Figure-8 showing the linear relation between the estimation and measurements values for both HARLIN and Angstrom models.

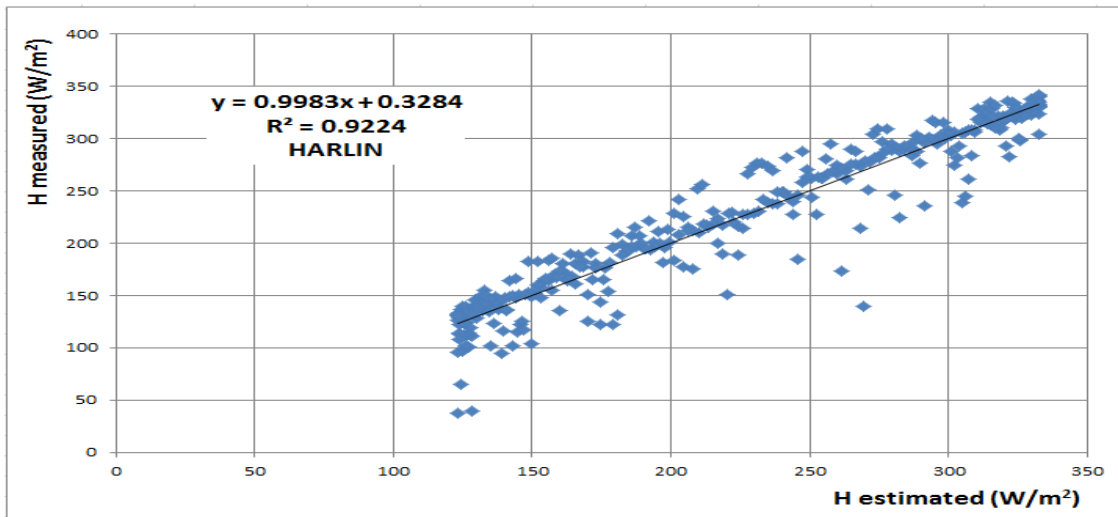


Figure 7- A comparison between Estimations-Measurements for HARLIN model for Baghdad 2010-2011.

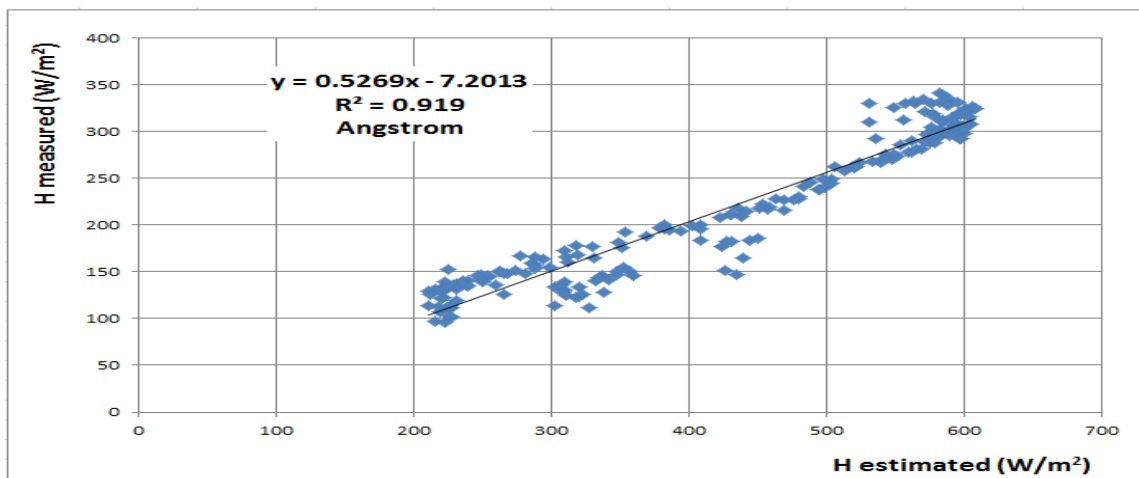


Figure 8- A comparison between Estimations-Measurements for Angstrom model for Baghdad 2010-2011.

### Comparisons

The prediction errors for HARLIN model compared to Angstrom equation are calculated by using Mean Absolute Error (MAE):

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^n |Y_i - Y_j| \quad (7)$$

Where  $Y_i$  is the actual (or measured) values in ( $\text{W}/\text{m}^2$ ).

$Y_j$  is the predicted values in ( $\text{W}/\text{m}^2$ ).

Herein,  $n = 365$  the number of total values [11].

The MAE for HARLIN model is 14.0806137 and for Angstrom model is 64.951589. As we see the error for HARLIN model lower than Angstrom model, this mean that HARLIN model more accuracy and successful in prediction the daily values.

### The determination coefficient, $R^2$

The determination coefficient,  $R^2$  as shown in Figure-7 and Figure-8 gives some information about the fineness of fit of a model, it is statistical measure to how well the estimated values approximates the measured values, whenever it closer to 1[1]. It is clear from above that HARLIN better than Angstrom.

### Conclusion

The objective of this work to evaluated HARLIN model for prediction daily solar radiation from given measured values and sunshine duration by using simple approach of combined harmonic analysis and classical linear regression model to produce the HARLIN model. The HARLIN model is simple, precise and dependable approach for solar radiation calculation which includes the harmonic structure on the average. It is more successful than the classical linear Angstrom model.

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