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Estimation of clear sky hourly global solar radiation in Iraq

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Abstract
The availability of hourly solar radiation data is very important for applications utilizing solar energy and for climate and environmental aspects. The aim of this work is to use a simple model for estimating hourly global solar radiation under clear sky condition in Iraq. Calculations were compared with measurements obtained from local station in Baghdad city and from Meteosat satellite data for different locations in Iraq. The statistical test methods of the mean bias error (MBE), root mean square error (RMSE) and t-test were used to evaluate the performance of the model. Results indicated that a fairly good agreement exists between calculated and measured values for all locations in Iraq. Since the model is independent of any meteorological variable, it would be of a practical use for rural areas where no meteorological data are available.
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Keywords: Hourly solar radiation; Clear sky; Measurements; Iraqi locations.

1. Introduction

Solar radiation data are important tools for many areas of research and applications in various engineering and scientific fields including for example climatology, agro meteorology, hydrology and solar energy converting system design. Many of these applications require knowledge about hourly global solar radiation. Unfortunately, the number of solar radiation observations sites in arid and semi-arid regions is very poor. Therefore many formulas and methods have been developed for estimating hourly, daily, and monthly solar radiation some of which are simple and others are quite sophisticated [1]. Among the pioneer work of analyzing hourly global solar radiation data are those carried out by Whiller [2] and Hottel and Whiller [3], Liu and Jordan [4], Orgaill and Holland [5], and Collares-Pareira and Rabel [6]. More recent research works on the estimation of hourly solar radiation have been conducted by many researches around the world. Al-Sadah et al., [7] and Singh et al., [8] correlated hourly solar radiation with sunshine hours. Ahmed and Tiwari [9] evaluated and compared several hourly solar radiation models. Gueymard [10] developed a method for estimating hourly solar radiation from daily solar radiation. Katiyar et al., [11] and Katiyar and Pandey [12] presented an analysis of hourly solar radiation data and developed a new regression constants for estimating the hourly solar radiation on a horizontal surface, which is based on the ASHRAE model [13]. Chandel and Aggaerwall [14] developed a model for estimating hourly solar radiation on horizontal and inclined surfaces on the basis of daily solar radiation. The aim of this research is to use a simple model to estimate hourly global solar radiation for clear sky in Iraq.

2. The model

Neglecting the reflection component, the hourly global solar radiation intensity on a horizontal surface, R_h in clear sky model is given by Meinel and Mainel [15] as,

$$\overline{R_h} = \overline{R_a} 0.7^{m^{0.678}} \tag{1}$$

where, $\overline{R_a}$ is the extraterrestrial irradiance on a horizontal surface given by Markvart and Kreider [16] as,

$$\overline{R_a} = R_{sc}\left[1 + 0.033\cos\frac{2\pi J}{365}\right]\sin\alpha \tag{2}$$

where, R_{sc} is the solar constant = 1.367 kJ/m^2.s, and m is the air mass ratio calculated for clear sky condition by Kreith and Kreider [17] as,

$$m = \left[1229 + (614\sin\alpha)^2\right]^{0.5} - 614\sin\alpha \tag{3}$$

where, α is the sun altitude angle obtained from [18],

$$\sin\alpha = (\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta) \tag{4}$$

ϕ is the geographical latitude, and δ is the solar declination angle defined by [18],

$$\delta = 23.5\sin\left[\frac{360}{365}(J + 284)\right] \tag{5}$$

where, J is the number of days of the year starting from January 1. The hour angle (ω) is an angular measure of time and is equivalent to 15 per hour with morning (+) and afternoon (-). It is measured from noon-based local solar time (ST) from the equation given by

$$\omega = 15(12 - ST) \tag{6}$$

The local solar time (*ST*) is calculated from the local standard time (*LT*) and the equation of time (*ET*) as follows:

$$ST = LT + \frac{ET}{60} + \frac{4}{60}(L_s - L_L) \tag{7}$$

where L_s is the standard meridian for the local time zone and L_L is longitude of the location in degrees. The equation of time is obtained from formulae given by Tasdemiroglu [19] as:

$$ET = 9.87\sin 2B - 7.53\cos B - 1.5\cos B \tag{8}$$

where

$$B = \frac{360(J - 81)}{365} \tag{9}$$

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3. Data sources and methodology

Data for four cities in Iraq, whose geographical co-ordinates are given below in Table 1, were used to evaluate the model.

Measurements of hourly global solar radiation for the year of 2010 for Baghdad city were obtained from Al-Mustansiriyah University Weather Station. Unfortunately, no in site measurements are available for the other locations in Iraq, therefore the databases HelioClim was used to obtain data for the other cities. The HelioClim database, which is derived from Meteosat Satellites data, can be accessed through the SoDa Service (meteorology- observations) and free hourly solar radiation data are only available for the year of 2005 [20].

A Fortran code was developed for the model and calculations of hourly global solar radiation were made for 2005 for the four cities and for 2010 for Baghdad city only. Comparisons between calculated and measured solar radiation values were carried out and results are discussed in the next section.

Table 1. Iraqi cities used in this study and their geographical parameters

City	Latitude (°N)	Longitude (°E)	Elevation (m)
Mosul	36.33	43.11	223
Baghdad	33.33	44.39	34
Rutba	33.03	40.28	618
Basra	30.49	47.81	2

The Mean Bias Error (MBE), the Root Mean Square Error (RMSE), and the t-statistics were used for the purpose of evaluating the results. These parameters are defined by the following expressions [11]:

$$MBE = \frac{1}{n}\sum_{i=1}^{n} d_i \tag{10}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n} d_i^{\,2}\right]^{1/2} \tag{11}$$

$$t = \left[\frac{(n-1)MBE^2}{RMSR^2 - MBE^2}\right] \tag{12}$$

4. Results and discussion

Figure 1 shows comparisons between calculated and measured hourly global solar radiation for the 15th day of each month for Baghdad city. It is seen that the trend of the calculated and measured values are similar for all months and there is an over estimation in the calculated values, particularly during the early hours of the day, for all months except for April when the calculated values of solar radiation are lower than the measured values during the afternoon hours. These discrepancies may be attributed to the simplicity of the model used in this work. Figure 2 shows the scatter plot of calculated and measured hourly global solar radiation for all hours during the days of year 2010 for Baghdad city. It is evident that majority of clusters of the data are close to the regression line.

Figures 3, 4, 5, and 6 show the scatter plots of calculated and measured global hourly solar radiation for the cities of Mosul, Baghdad, Rutba, and Basra respectively. The data are for the 1st and 15th day of each month for 2005. Measured valued were obtained from SoDa site. It is seen that the scatter data congregate very close to the regression line for all four cities. Table 2 gives a comparison of MBE, RSME, and t-test for the four cities. It seen that MBE is negative for all cities indicating that the model gives an underestimated values of global hourly solar radiation and this underestimation is lowest for Baghdad city. The t-test results suggest that the model performance is better for Baghdad than other cities.

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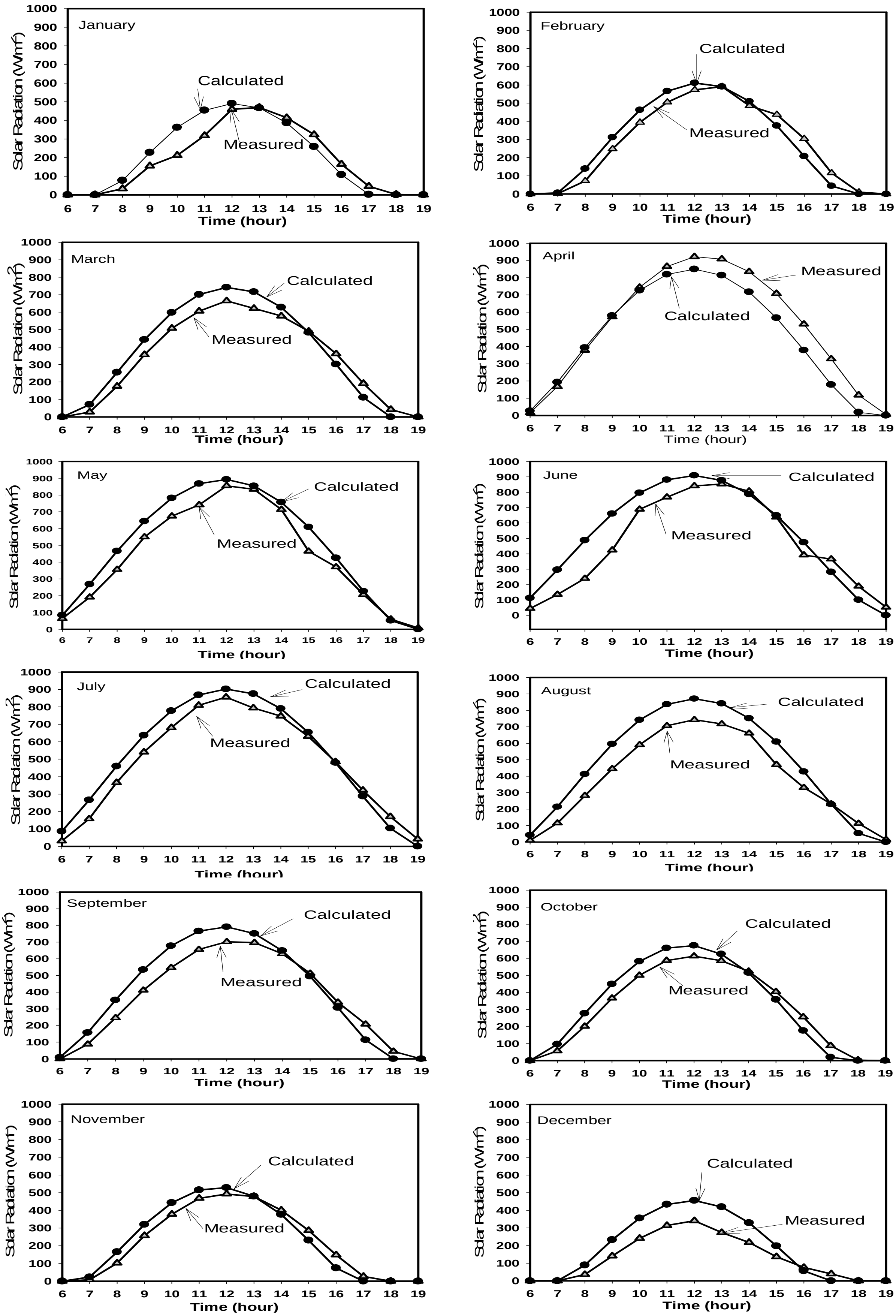

Figure 1. Comparison between calculated and measured hourly solar radiation at the 15th day of each month in 2010 for Baghdad city

Table 2. Comparison of MBE, RMSE, an t-test for the four cities

Station	MBE	RSME	t-test
Mosul	-85.12	96.77	29.87
Baghdad	-65.51	97.18	14.63
Rutba	-84.02	88.42	49.10
Basra	-67.47	72.92	39.72

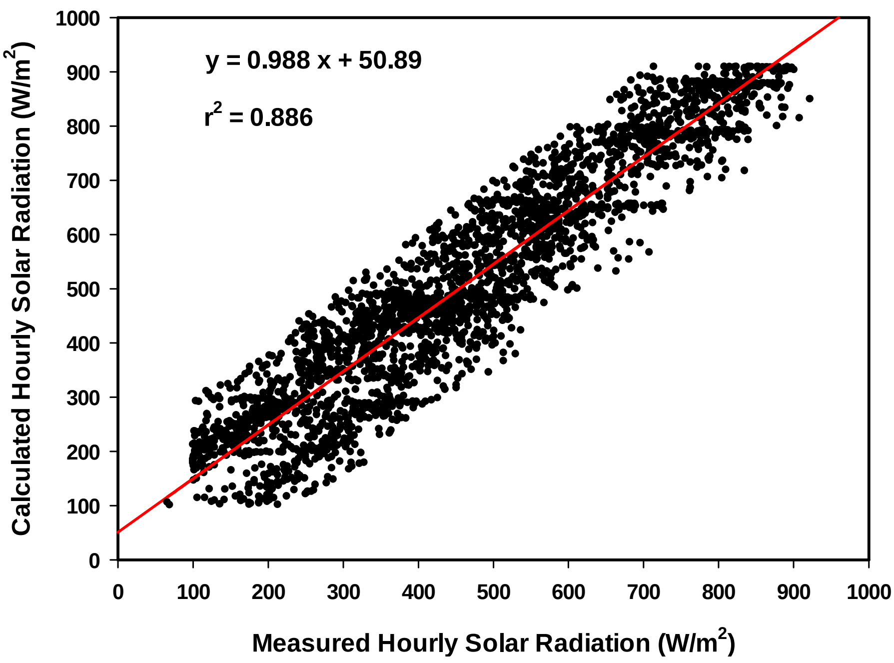

Figure 2. Comparison between calculated and measured hourly solar radiation for the year of 2010 for Baghdad city

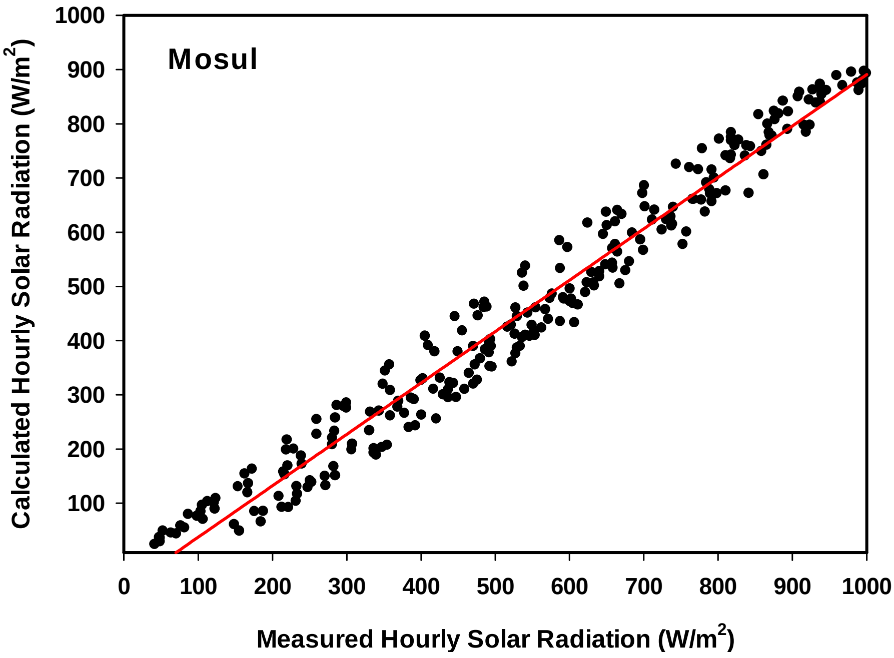

Figure 3. Comparison between calculated and SoDa measured hourly solar radiation for the year of 2005 for Mosul city

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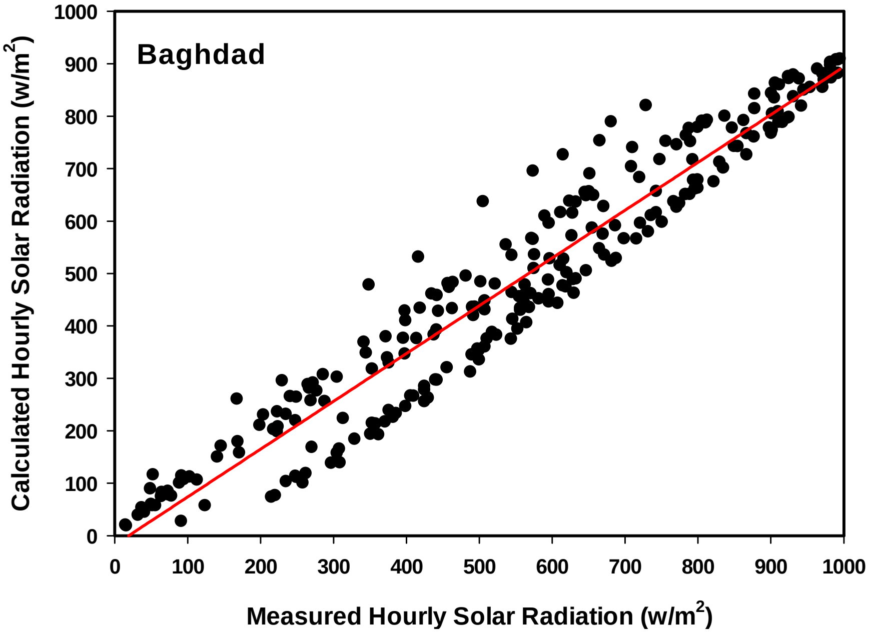

Figure 4. Comparison between calculated and SoDa measured hourly solar radiation for the year of 2005 for Baghdad city

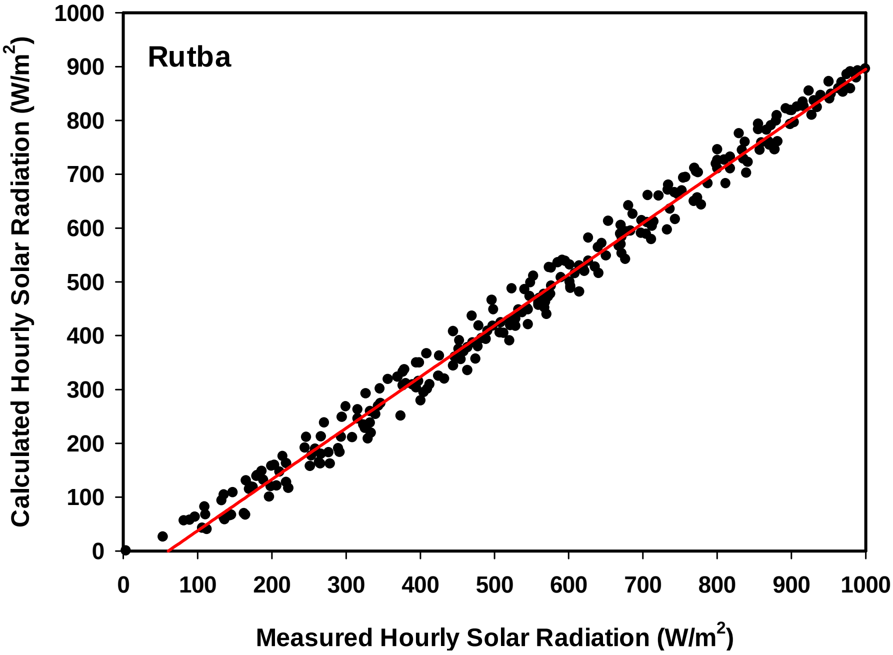

Figure 5. Comparison between calculated and SoDa measured hourly solar radiation for the year of 2005 for Rutba city

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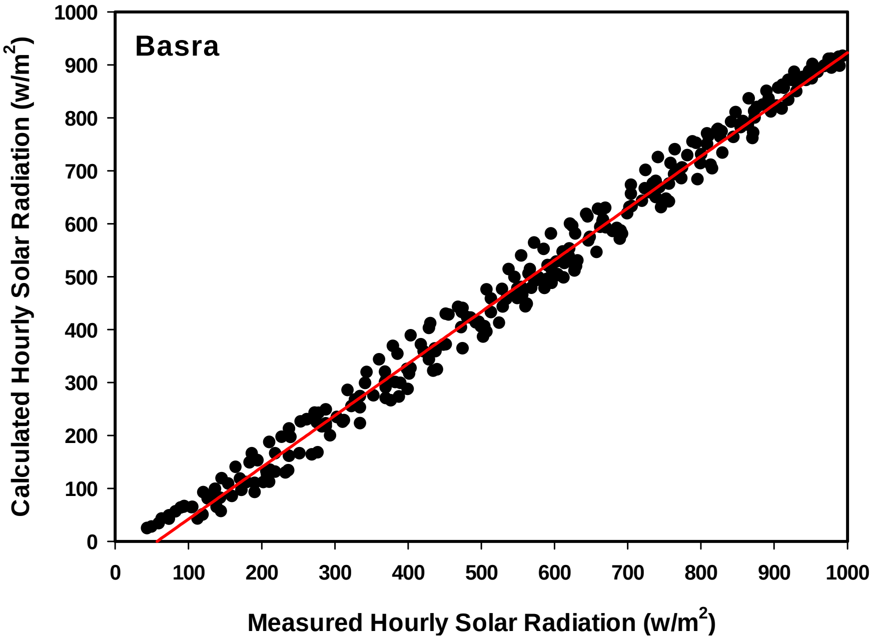

Figure 6. Comparison between calculated and SoDa measured hourly solar radiation for the year of 2005 for Basra city

5. Conclusion

In this work a simple model was employed to estimate hourly global solar radiation for clear sky in Iraq. Calculations were compared with direct measurements obtained from local station for Baghdad city and with data derived from Meteosat Satellites observations for Baghdad and other locations. Fairly good agreement between measured and calculated values suggests that the model can be employed for clear sky conditions in Iraq. Considering that the model is only depended on the air mass and solar elevation, it would be of practical use for estimating hourly solar radiation for locations where no meteorological measurements are available which the case in most rural areas in Iraq is.

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