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A Comparative Study of the Available Measured Global Solar Radiation in Iraq

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ABSTRACT

In Iraq, solar radiation field measurements are available in limited locations such as some universities and research centers. In this article, the measured data of monthly average global solar radiation in Iraqi provinces and cities was compared with the available data in the literatures and studies over the internet especially Google Scholar, Research Gate and IASJ. The selected locations were Baghdad, Mosul, Tikrit, Rutba, Nasiriya, Kirkuk, Haditha, and Najaf. The measured data was compared with the corresponding available satellite data from NASA and Meteonorm software and root mean square error was calculated to investigate NASA and Meteonorm performance. The review results showed that the maximum GSR was in Haditha in July (8.3 kWhr/m^2), while the minimum GSR was in Mosul in December (1.68 kWhr/m^2). The measured monthly average data of Baghdad was about 5.20 kWhr/m^2. The data of satellites in some cities, such as Mosul, Rutba and Nasiriya, had a large deviation in summer, while the measured data nearly agree with the satellite data in the other months. The satellite data were not reliable and might not be suitable for the design consideration. The measured data of Baghdad, Kirkuk and Tikrit were acceptable since the mean deviation between measured and satellite data were less than 1 MJ/m^2.

1. INTRODUCTION

The estimation of the local solar irradiation is important for many practical problems such as the proper design of building energy cooling load, solar energy systems (thermal or photovoltaic), agriculture, irrigation evaporation rate, etc. The long-term data of monthly average global solar radiation (GSR) are essential for designing and sizing of systems. Therefore, many research papers and scientific articles focused on the presenting of GSR distribution and statistics either as maps based on the measured data on earth surface or from satellite imaging. In some studies, the amount of GSR was quantified by developing correlations or models based on a set of sky clearness index and weather data like sunshine duration ratio, mean temperature and relative humidity. Iraq is located at longitudes 38.45º-48.45º and latitudes 29.5º-37.22º. Iraq has a promising potential for solar irradiation to provide a large share of the energy demands. Up to now, the production of electricity in Iraq depends on fossil fuel which causes the well-known environmental problems. Iraq is featured with about 3316 hours per year of sunshine period in with 501 W/m^2 of average daily solar power intensity [1]. Abed et al. [2] comprehensively presented an overview for the status of energy and production of electricity from fossil fuel in Iraq. Also, the study reviewed briefly the estimation of solar radiation levels, the present and the future possible productivity by solar energy systems in terms of photovoltaics (PV), concentrated solar powers (CSP) and others renewable energies like wind energy. Global solar radiation that reaches the surface of earth is composed of two components, beam (direct) and diffuse. The relationship between clearness of the sky and the ratio of diffuse radiation component to the total solar radiation in some Iraqi cities were studied in the references [3-12]. Also, the available models correlate the global solar radiation with sunshine duration humidity, maximum and minimum temperature were investigated in the references [13-19].

Although this study reveals the poor of available measured data, it is a good and fast reference for the researchers or practitioners who look for a measured data since the expensive instruments or an official meteorological station are not capable.

2. MATERIALS METHOD

In this section a servey for the literatures is presented. The studies over the internet especially Google Scholar,

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Research Gate and IASJ were collected and the data of GSR were presented as tables and graphs in this review. Some papers of journals were not available on the internet not be considered in the present study.

Al-Riahi et al. [20] analyzed measurements of GSR, reflected radiation and net total radiation inside and outside a greenhouse in Fudhiliyah Agrometeorological Research Station of the Agricultural Application Department, Solar Energy Research Centre/Baghdad during the period from 1 January to 30 April 1987. Several correlations were presented to estimate the radiation of inside flux as a function of outside flux using linear regression. Al-Riahi et al. [21] analyzed thoroughly GSR and diffuse radiation data for a 30-month period between August 1984 and August 1987 at Fudhaliyah, Baghdad. Then, Al-Riahi et al. [6] analyzed a set of GSR data and the general atmospheric transparency for the period of 1971-1985 for three different climatological zones (Mosul, Baghdad and Nasiriyah). The measurements carried out by the Iraqi Meteorological Organization. Munir et al. [22] studied the performance of a pumping system installed in a remote residential complex belong to an irrigation company located 100 km north of Mosul. The authors just referred to the source of the data which is the Meteorological Authority in Iraq without mentioning the collecting period.

A set of data was used in two studies by Abdul-Wahid et al. [14, 23]. The data of solar radiation was collected by the Iraqi Meteorological Office in sixteen locations around of Iraq in thirty years (1961-1991). Abdul-Wahid et al. [14] calculated the daily sum of the solar radiation using meteorological data and utilized the data to validate the theoretical model. Abdul-Wahid et al. [23] used the data accompanied with clearness index data to calculate the daily average diffuse fraction using four mathematical models.

Al-Salihi et al. [24] employed GSR measurements on the horizontal surface in Baghdad to carry out mathematical models. The statistical tests showed that the proposed models presented a good predicting ability of global solar radiation in Baghdad. In that paper, the global solar radiation and sunshine duration data were supplied by Energy and Environmental Research Center and a radiometric station was established at Baghdad in Al-Jadiriyah location during the period from January 1996 to December 1998. Al-Salihi et al. [25] developed a multi linear correlation to estimate GSR based on a meteorological data. The data collected by Iraqi Meteorological Office over five years for 2004-2008 in three locations, Baghdad, Mosul and Rutba. The model had been tested and compared with the practical measurements. The same data used later by Ali [26] who suggested the model which estimated the daily averaged global solar radiation. Al-Dulaimy and Al-Shahery [15] used a model that estimates GSR based on clearness index and sunshine duration data for a period of more than 17 years in Haditha, Beji, and Samara. Ali [27] developed a simple correlation to predict GSR in different Iraqi locations (Kirkuk, Baghdad and Nasiriyah) for five years interval (1981-1985) measured by the Iraqi Meteorological and Seismological Organization. The same data used later by Sultan et al. [28] to specify the optimal monthly, seasonally and yearly tilt angles of the solar collectors.

Al-Dulaimy and Al-Shahery [16] presented the analysis of the solar radiation. The sunshine duration was collected in Tikrit, Tuz-Khurmato, and Kirkuk in the period of 1977-2000 by Iraq Meteorological State Agency. Al-Dulaimy and Mohammed [18] presented a correlation of measured data for the solar radiation on a horizontal surface at the ambient temperature and humidity and the data was measured in the period from January to December 2011. The measuring station was located on the roof-top of the Mechanical Department, Faculty of Engineering, and University of Tikrit. Al-Naimi et al. [19] implemented meteorological data, provided by the Iraq Meteorological Organization and Seismology in Baghdad, for the period of 1971-2000 to develop an artificial neural network model. The obtained data was investigated the accuracy of the model from 2008 to 2011. Hachim et al. [30] collected wind and GSR data in the building of Engineering Technical College, Najaf over a period of one year from April 2015 to March 2016.

In some studies, the measured GSR was presented as data of monthly average clearness index which was the ratio of GSR to the monthly average daily extraterrestrial solar radiation (ESR). ESR is a function of declination angle (average day of the month), sunset hour angle and latitude. To calculate the values of ESR in MJ/m^2, a presented table by Duffie and Beckman [31] had been used where ESR was presented for each month from -90° to 90° with 5° steps.

Majeed [32] used multi-linear polynomial form of the Angstrom-Prescott model to estimate GSR for Rutba over five years (2004-2008). The calculated data were compared with the measured clearness index values that taken from the Iraqi meteorological organization and seismology. Kadouri [17] used meteorological parameters measurements supplied from the meteorological station of the University of Babylon/College of Science /Department of Physics, during from June 1st 2009 to June 1st 2010. Kadouri [17] developed eight models to predict the value of GSR and compared the results with the observed values. Saeed and Qadir [33] selected six locations at Kurdistan region to analyze GSR data collected during three years (2001 -2003). The stations were established by the Ministry of Agriculture, the co-operation of Food and Agriculture Organization of the United Nations, in 2001. The study presented maps for monthly average ratio of global to extraterrestrial solar radiation for the whole of Kurdistan region.

Al-Ghezi [29] developed a mathematical linear correlation of Angstrom to estimate the daily average total solar radiation on a horizontal surface in Baghdad using same data which was used by Ali [27]. The used data of Al-Ghezi was in the period of 1961-2016.

Some authors worked on presenting maps of GSR. Mohammed et al. [34] who provided maps for all Iraq which are plotted using numerical surface technique programs based on the hourly measured of solar radiation intensity for eight provinces (Mosul, Sulaimaniya, Baghdad, Ana, Hait, Rutba, Imara and Nasiriyah) in 1973 and 1974 the hourly radiation intensity in J/cm^2. Ahmad et al. [35] developed correlations for the estimation of solar radiation in Baghdad, Basrah and Mosul based on the recorded weather data of 4 to 16 years. Then, the correlation utilized to calculate the solar radiation in 24 locations in the different regions of the representative meteorological stations. The results were used to prepare solar radiation maps cover all Iraq. Al-Naser et al. [36] worked on the atlas contained a three sets of maps which presented an annual means of sunshine duration, global solar radiation and diffuse solar radiation. Climatic solar radiation data had been collected from meteorological centers in 280 stations spread all over the Arabian countries (five centers in Iraq) for over 10 years in the most cases. Table 1 summarizes the literature studies where longitude and latitude for each location is mentioned.

TABLE 1. Summary of the monthly averaged GSR data from the oldest published studies to the newest

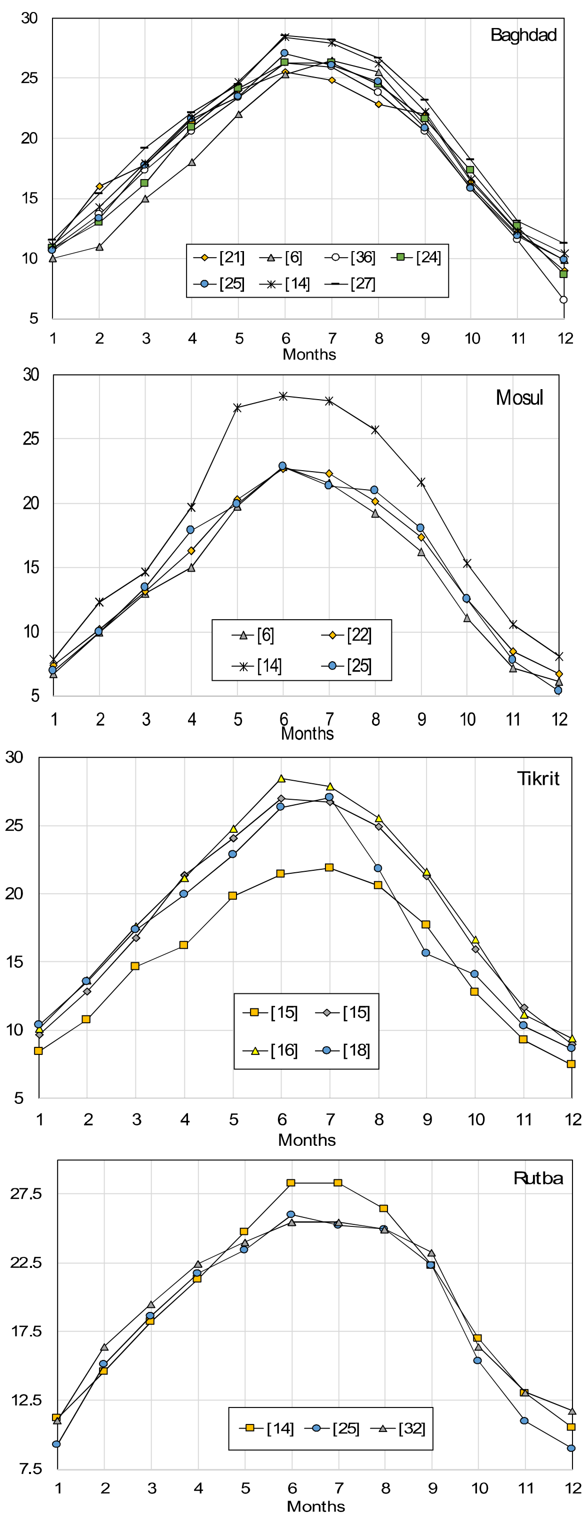
Reference	Location (province)	Latitude	Longitude	Collection data period
Al-Riahi et al. [20]	Baghdad	33.14	44.14	1st Jan. - 30th Apr., 1987
Al-Riahi et al. [21]	Baghdad	33.14	44.14	1984 - 1987
Al-Riahi et al. [6]	Mosul	36.14	43.09	1971-1985
	Baghdad	33.02	40.14	
	Nasiriyah	31.05	46.14	
Al-Naser et al. [36]	Baghdad	33	44	1993-2003
Munir et al. [22]	Mosul	36.14	42.14	Not specified
Al-Salihi et al. [25] and Ali [26]	Baghdad	33.22	44.23	2004-2008
	Rutba (Anbar)	33.03	40.28	
	Mosul	36.35	43.15	
Al-Salihi et al. [24]	Baghdad	33.22	44.23	January 1996-December 1998
Abdul-Wahid et al. [14] and Abdul-Wahid et al. [23]	Al-Basrah	30.31	47.78	1961-1991
	Al-Nasiriyah	31.01	46.16	
	Samawa	31.16	45.28	
	Al-Amara	31.50	47.10	
	Al-Diwaniya	31.57	44.90	
	Al-Najaf	31.57	44.33	
	Al-Hai (Kut)	32.08	46.04	
	Kerbala	32.34	44.01	
	Rutbah (Anbar)	33.02	43.15	
	Baghdad	33.31	44.36	
	Haditha-Anbar	34.08	42.26	
	Khanaqin (Diala)	34.21	45.38	
	Kirkuk	35.28	44.38	
	Al-Sulaimaniya	35.32	45.43	
	Mosul	36.19	42.14	
	Zakho (Duhok)	37.08	42.67	
Al-Dulaimy and Al-Shahery [15]	Haditha (Anbar)	34.09	42.26	17 years (without specifying the years)
	Samara (Tikrit)	34.11	43.52	
	Beji (Tikrit)	34.55	43.29	
Ali [27] Sultan et al. [28] Al-Ghezi [29]	Kirkuk	35.30	44. 21	1981-1985
	Baghdad	33.22	44.23	or
	Nasiriyah	31.01	46.16	1961-2016
Al-Dulaimy and Al-Shahery [16]	Tikrit,	34.35	43.37	1977-2000
	Tuz Khurmato (Tikrit)	34.88	44.64	
	Kirkuk	35.30	44.21	
Al-Dulaimy and Mohammed [18]	Tikrit	34.66	43.46	2013
Majeed [32]	Rutba (Anbar)	30.03	40.28	2013
Kadouri [17]	Babylon	32.23	44.24	1st June 2009-1st June 2010
et al. [19] Al-Naimi	Baghdad	33.22	44.23	1971-2000
Hachim et al. [30]	Najaf	31	44.33	April 2015-March 2016

3. RESULTS AND DISCUSSION

This section compares the available measured data with each other for different locations in Iraq. after that, a comparison between measured data and satellite is presented and discussed.

3.1. Data analysis and comparison

The mentioned locations in Table 1 with more than one data are plotted in Fig. 1 for the sake of comparison. These locations are in Baghdad, Mosul, Tikrit, Rutba, Nasiriya, Kirkuk, Haditha and Najaf which are distributed all over the country.



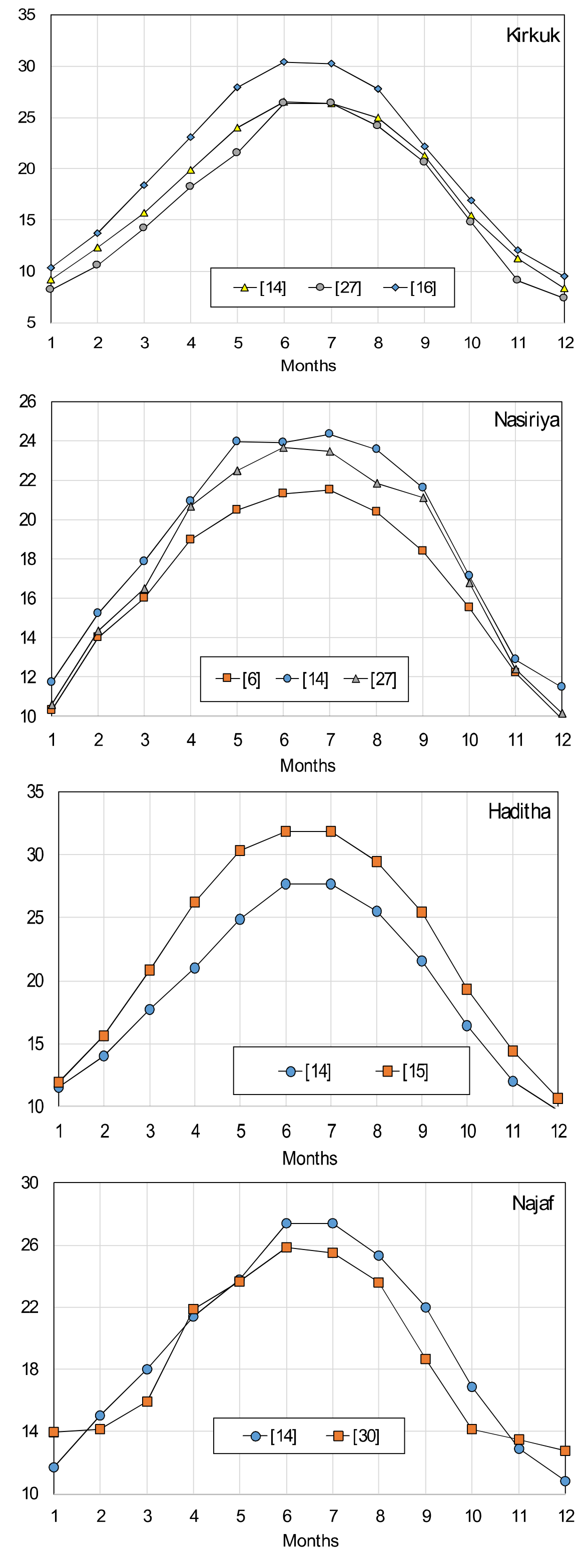


Figure 1. Monthly averaged daily global solar radiation [MJ/m^2-day] in Baghdad, Mosul, Tikrit, Rutba, Nasiriya, Kirkuk, Haditha and Najaf

Baghdad is the capital of Iraq and located in its middle region. Most of the studies focus on Baghdad because of the large number of universities, ministries and research centers. Seven measured GSR data are found in literature and noticeably coincides in January, September, October and November as shown in Fig.1. In summer, GSR is slightly varies from 25 to 28 MJ/m^2 (6.9 to 7.8 kWhr/m^2) and the mean value is 18.71 MJ/m^2 (5.1 kWhr/m^2). 1 kWhr/m^2 means one hour of time where the solar insolation is 1000 W/m^2.

Mosul is the second largest city in Iraq and the data of four studies are plotted in Fig. 1. The study of Abdul-Wahid et al. [14] showed a noticeable deviation in April-October, compared to the other data. Therefore, this data is not considered in Table 2. The GSR of Mosul is recorded about 14.54 MJ/m^2 (4.04 kWhr/m^2) which is the lowest GSR value among the selected location of this review. The minimum value of GSR is 6.07 MJ/m^2 (1.68 kWhr/m^2) in December.

The data of Al-Dulaimy and Al-Shahery study [15] for Samaraa city in Tikrit province, the yellow square markers, is much lower than other studies for most the months and this data is neglected for taking the average in Table 2. The measured GSR of Nasiriya is lower than the expected value in summer months. Where the results showed that it is even less than Kirkuk data in summer. Because of Nasiriya is in south of Iraq were the sky is clearer and it is expected to have higher GSR than Kirkuk in the north of Iraq.

Al-Dulaimy and Al-Shahery [16] data is neglected in Kirkuk for March - August because the results in Fig. 1 are revealed that it is higher than the study of Ali [27] and Abdul-Wahid et al. [14].

Haditha, Najaf and Rutba have the highest GSR values because they are located at the west region characterized with a desert nature and less sky turbidity. The data of Abdul-Wahid et al. [14] is neglected in Rutba for June-August was because it is much higher than other data. The mean value of Haditha is about 20.74 MJ/m^2 (5.76 kWhr/m^2) which is the largest measured value. Also, the maximum GSR value is 29.78 MJ/m^2 (8.3 kWhr/m^2) in Haditha, in July.

TABLE 2. Averaged Measured of GSR data in MJ/m^2-day for the selected studies

	Mosul	Kirkuk	Tikrit	Rutba	Haditha	Najaf	Nasiriya	Baghdad
January	7.03	9.23	10.05	10.52	11.71	12.83	10.88	10.83
February	10.06	12.20	13.35	15.40	14.82	14.56	14.52	13.81
March	13.19	14.96	17.23	18.78	19.30	16.97	16.79	17.30
April	16.38	19.05	20.83	21.82	23.63	21.64	20.21	20.87
May	19.99	22.77	23.90	24.08	27.60	23.72	22.31	23.73
June	22.80	26.41	27.28	25.74	29.77	26.63	22.94	26.76
July	21.76	26.40	27.23	25.36	29.78	26.44	23.09	26.52
August	20.13	24.56	24.07	24.95	27.47	24.44	21.92	24.86
September	17.19	21.36	19.51	22.62	23.52	20.33	20.37	21.62
October	12.05	15.70	15.56	16.27	17.89	15.51	16.48	16.59
November	7.81	10.76	11.05	12.36	13.23	13.19	12.51	12.23
December	6.07	8.41	8.99	10.41	10.15	11.79	10.51	9.36
Average [MJ/m^2-day]	14.54	17.65	18.25	19.03	20.74	19.00	17.71	18.71
Average [kWhr/m^2-day]	4.04	4.90	5.07	5.28	5.76	5.28	4.92	5.20

3.2. Comparison to the satellite data

Geostationary meteorological satellites operate since about 1980. These satellites can produce maps of estimated global insolation across a continent. Fundamentally, instruments on the satellite can separately measure the radiation from the sun and reflection from the ground and the difference is a radiation that is reaching to the surface of earth [37]. The data of satellites are available in websites, NASA, Meteonorm, SolarGIS, etc.

NASA provides an average of 22-year period (July 1983-June 2005) for each month in a latitudes grid of 1°x1° over the world (where 1° is 111 km) [38]. Each monthly averaged value is evaluated as the numerical average of 3-hourly values for the month.

NASA estimates that the root mean square error (RMSE) on monthly values is around 13-16%, and the absolute mean bias error (AMBE) lays -2 ±0.7%.

Meteonorm is a meteorological database containing climatological data for solar engineering applications at every location on the globe. The Meteonorm software database contains 8,325 weather stations worldwide, but not even one station is in Iraq. Therefore, the supplied data from Meteonorm is completely satellite data for the period of 1985-2002. The RMSE error of interpolating monthly radiation values is about 7% [39].

The calculated average of the studied data for every location are shown in Table 2. These averaged measured values are plotted in Fig. 2 against the data of the satellite from NASA website and Meteonorm (Meteonorm data is supplied by PVsyst photovoltaic systems simulation software).

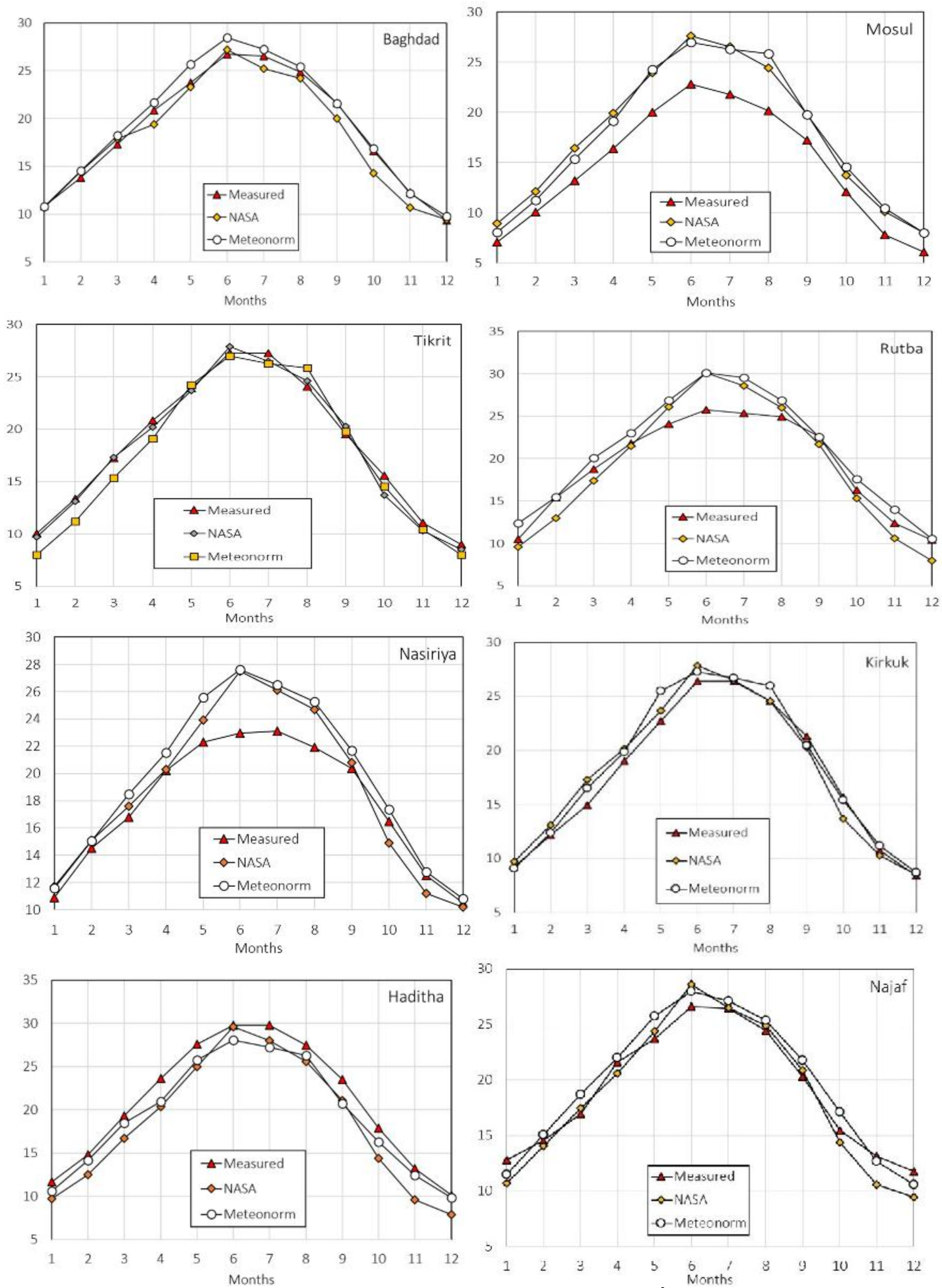


Figure 2. Measured and satellite monthly averaged daily global solar radiation [MJ/m^2-day] in Baghdad, Mosul, Tikrit, Rutba, Nasiriya, Kirkuk, Haditha, and Najaf

According to the Fig. 2, it can be observed that the satellite data noticeably coincides for each location and month. The measured data is much lower than satellite data in Mosul, Rutba and Nasiriyah.

AMBE and RMSE are used for comparing the measured data with the satellite data and can be calculated as follows:

$$AMBE = \frac{1}{12}\sum_{i=1}^{12}(m_i - s_i) \quad (1)$$

$$RMSE = \left(\frac{1}{12}\sum_{i=1}^{12}(m_i - s_i)^2\right)^{\frac{1}{2}} \quad (2)$$

Where m_i and s_i are the measured and satellite monthly averaged values, respectively.

Table 3 shows the AMBE values. Mosul shows a relatively large deviation of about 3.07 MJ/m^2 and 2.94 MJ/m^2 for NASA and Meteonorm, respectively. NASA data for Tikrit is very close to the measured data of Baghdad. The RMSE values for NASA data of Mosul is the largest about 326.56% while for Tikrit, NASA showed 74.8%. The largest and lowest RMS of Meteonorm are 324.4% (in Mosul) and 90.27% (in Baghdad), respectively. Mosul and Kirkuk have nearly the same RMS in the different satellite sources but there is a different behavior in the other locations. Generally, the average data of NASA and Meteonorm are very close to each other with 179.4% and 176% respectively.

TABLE 3. Absolute mean bias error and root mean square error (%)

	Mosul	Kirkuk	Tikrit	Rutba	Haditha	Najaf	Nasiriya	Baghdad	Average
AMBE									
NASA	3.07	0.92	0.6	1.81	2.36	1.16	1.49	0.94	1.54
Meteonorm	2.94	0.84	1.17	1.73	1.5	1.15	1.8	0.68	1.47
RMSE									
NASA	326.56	116.58	74.80	212.13	251.97	141.91	196.35	114.78	179.4
Meteonorm	324.38	111.41	135.90	221.39	169.40	125.71	229.54	90.27	176.0

TABLE 4. Average of measured and satellite data in MJ/m^2-day in the selected locations

	Mosul	Kirkuk	Tikrit	Rutba	Haditha	Najaf	Nasiriya	Baghdad
January	7.98	9.33	9.87	10.83	10.68	11.68	11.39	10.77
February	11.12	12.57	13.22	14.62	13.83	14.59	14.89	14.28
March	15.88	16.65	17.26	18.75	18.16	17.72	17.63	17.8
April	19.5	20.14	20.04	22.12	21.67	21.42	20.68	20.65
May	24.07	24.57	23.94	25.69	26.12	24.63	23.93	24.24
June	27.28	27.65	27.39	30.09	29.15	27.74	27.56	27.47
July	26.38	26.96	26.66	29.07	28.33	26.7	26.3	26.33
August	25.12	25.4	24.84	26.09	26.45	24.91	24.98	24.82
September	18.92	20.72	19.86	22.29	21.78	21.01	20.95	21.07
October	13.44	14.94	14.61	16.38	16.2	15.68	16.25	15.91
November	9.45	10.75	10.59	12.32	11.75	12.17	12.16	11.69
December	7.36	8.54	8.49	9.65	9.29	10.64	10.5	9.51
Average [MJ/m^2-day]	17.21	18.19	18.06	19.83	19.45	19.07	18.94	18.71
Average [kWhr/m^2-day]	4.78	5.05	5.02	5.51	5.40	5.30	5.26	5.20

There is no rule to choose a local weather station (pyranometer device) data or a satellite data. If the weather station has the well-maintained good quality calibrated instruments, it will provide the most accurate data for the solar insolation. They represent the field actual measurements, which are the relevant parameters for the solar energy systems. Unfortunately, weather stations are not always available in any specified project site and the period may be short or incomplete. Currently, satellites have become a trusted source for the solar irradiation data, especially in the simulation software of the solar energy systems. However, this approach has some uncertainties in aerosol values, cloud layers, etc. It is always recommended combining multiple of earth surface and satellite data to achieve the lowest uncertainty for resource assessment. Table 4 presents averages of measured and satellite data (NASA and Meteonorm) for the eight locations.

7. CONCLUSIONS

The aim of this study was to find an average of the field measurement of global solar radiation in Iraq. Eight locations were found arbitrarily which had over one data set in the previous literatures. It was useful and interesting to compare these average values by the available data of satellite in NASA and Meteonorm sources. The results showed that the maximum GSR was in Haditha in July (8.3 $kWhr/m^2$) and the minimum GSR was in Mosul in December (1.68 $kWhr/m^2$). The measured monthly average was about 5.20 $kWhr/m^2$ in Baghdad. The data of satellite in some cities like Mosul, Rutba and Nasiriya showed a large deviation in summer and the measured data nearly coincide with the satellite data in the other months. The satellite data were not reliable and might not be suitable for design consideration in Mosul, Haditha and Nasiriya. The measured data were acceptable in Baghdad, Kirkuk and Tikrit, since the mean deviation between the measured and satellite data was less than 1 MJ/m^2.

8. ACKNOWLEDGEMENT

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