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Energy and Exergy Analysis of the Solar Radiation Incident over Iraq

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Abstract. The solar radiation is renewable energy and great useful energy of in Iraq. This paper presents a study to compare the daily solar exergy, daily solar radiation, and daily solar that measured by Iraqi Agro-meteorological network in Baghdad. Then, a comparison between the solar energy and solar radiation in six cities in Iraq (Basra, Najaf, Baghdad, Anbar, Mosul, and Sulaymaniyah). The solar exergy estimated using the model of Nayak and Tiwari, while the solar radiation estimated using linear correlation which represented by (Angstrom correlation). The results showed that there is an agreement between daily solar radiation and daily solar which measured in Baghdad with mean error throughout the whole year from January to December (7.2%, 2.4%, 12.5%, 9.1%, 3.2%, 5.1%, 3.7%, 5.4%, 10.9%, 11.4%, 11.1%, and 3.7%), respectively. While, the daily solar exergy had very good agreement with the daily solar measured in Baghdad with mean error through the same 12- months (1.4%, 9.4%, 6.1%, 2.6%, 10.8%, 1.9%, 3.5%, 1.6%, 4.4%, 5.1%, 5%, and 2.7%), respectively. Also, higher daily solar radiation and daily solar exergy were in Basra, but the lowest was in Mosul. The daily solar exergy was (10.27, 10.09, 10, 10, 9.69, and 9.81 MJ/m^2) in Basra, Najaf, Baghdad, Anbar, Mosul and Sulaimaniya, respectively. While, the percentage difference between daily solar radiation and daily solar exergy was (7.09%, 7.04, 7%, 6.99%, 6.96%, and 6.85 %) in Basra, Najaf, Anbar, Baghdad, Mosul and Sulaimaniya, respectively.

1. Introduction

The sun is an atomic power, which is delivered control in kind of radiation at the wonderfully high rate of 3.8x10^{23}kW. An amazingly little division got by the earth surface; however, this little bit indicates a huge 1.8x1014 kW. Normally, around 60% of these sums pass through the atmosphere to reach the earth surface (1.1x1014 kW). The measure of energy disseminates over the whole surface of the earth. To convey this number nearer to home, consider that on the splendid radiant day each square meter of surface confronting the sun gets around 1 kW [1]. The source renewable energy is a key hotspot in the future, for Iraq as well as for the world. Baghdad is a major city that collection numerous enormous manufacturing plants, and it lies at the center of Iraq if depending on a solar energy source that fall at a huge amount in Baghdad lead to reduce the consumption of fossil energy, solar energy is green energy that not effect on environmental (Ozone layer and global warming) [2]. Sunlight based essentialness can accept a basic part with numerous central focuses. For instance, high wealth and grouped characteristics of yield imperativeness (electric and warm) that can be used in industry and structures with assortments of sun solar collectors. The execution of solar energy vitality essentialness foundations: photovoltaic, thermal or hybrid, flat or concentrating, fixed or movable, is usually analyzed on hourly, every day and month to month basis. This way requires related sun-fueled radiation data, which contains two sections: beam and diffuse [3]. There is a creating eagerness for different manageable power source resources, additionally, developing new resources as a result of the trickiness of oil costs. Some present imperativeness sources, for instance, oil subordinate or

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atomic power can be destructive to the human and environment. In this way, the sustainable power source especially the sun-powered vitality ends up noticeably a standout amongst the most essential vitality sources which can be considered to fulfill the expanding scene's vitality request. In solar energy vitality considers, evaluating the sunlight-based radiation information for a specific area is the initial phase in the appraisal of sun powered vitality accessibility [4]. The maximum work of energy that can be Exergy represents that can be taken away from a system until the properties were equilibrium with the surrounding [5]. Stephan K. 2005 [6] analyzed the exergy of solar radiation as an element of the sun's position and atmospheric condition. The entropy substance of approaching sun-powered radiation will be inspected by methods for a model environment. The results show that the reason for this entropy generation is a temperature befuddle between the incoming radiation temperature and the temperature of the surface of the device. The entropy production can be zero if the receiver surface closed to the average temperature of the incoming radiation. Also, the efficiencies of an ideal reversible solar energy are between 50% and 80% depending on surrounding conditions. Waleed I., et al 2009 [7] studied the net solar radiation on horizontal surface in three stations (Mosul, Baghdad and Nasiriyah) for period (1980-2002). The results showed that there is a matching between measured and estimated solar radiation in the three stations with error (11, 14, and 24) % in Baghdad, Nasiriyah, and Mosul, respectively. The summer season in Nasiriyah gave lower radiation than that in Baghdad. Abdullateef A. J., et al. 2012 [8] studied the behavior of solar radiation type (extraterrestrial, global, diffused, and beam) and compared them with those measured by metrological station. results have demonstrated that good agreement between calculated and measured radiations. Also, it is noted that Mosul city has the greater ranges of global radiation than Baghdad, and Nasiriya while Nasiriyah has greater extraterrestrial radiation than Mosul and Baghdad. The empirical model was presented by Faleh H. M. and Gheidaa S. 2014 [1] which depending on sunshine hours for investigation the solar radiation on the horizontal surface in (Baghdad, Rutba, and Nassiriyah). The results show a good agreement between the estimated and measured values. Also, solar radiation has a maximum value of Daily extra-terrestrial radiation and incoming daily global solar radiation for the selected locations in June and July, while the minimum was in January and December. Manuela N., et al 2017 [5] studied the exergy of solar based radiation in Italy by analyzed real radiation information and treated diffuse and direct radiation independently. The results showed that the total exergy factor was increase as the ratio of diffuse and direct solar radiation increase. The aim of this paper is to study the daily solar radiation in Baghdad (33.34° North latitude, 44.4° East longitude and 41 meters elevation above the sea level) in 2016. In addition, compare between the measured radiations in Iraqi Agro-meteorological network [9] and the daily solar exergy. Also, the paper has been compared between the daily solar radiation and daily solar exergy for six locations in Iraq (Basra, Najaf, Baghdad, Anbar, Mosul, and Sulaimaniya).

2. Case study

Iraqi Agro-meteorological network [9] was used to obtain the data for solar radiation. This data utilized to compare among experimental solar, theoretical solar and exergy radiations in Baghdad. Then, in addition to Baghdad, five locations in Iraq (Basra, Najaf, Anbar, Mosul, and Sulaimaniya) have been studied to compare them in terms of the theoretical solar, and exergy radiations. Meteonorm software used to select the wind speed and temperature. The information of six locations shown in Table 1.

Table 1. Six locations distributed in different regions in Iraq

Stations	Latitude (N)	Longitude (E)	Sea Level Altitude (m)
Basra	30.1	47.04	7
Najaf	31.5	44.3	19
Baghdad	33.3	44.2	30
Anbar	33.2	43	45
Sulaimaniya	35.5	45.4	450
Mosul	36.4	43.3	228

3. Mathematical model

The extraterrestrial solar radiation (H_o), is the solar radiation above the atmosphere and it's a function only of Latitude and independent of other location parameters. (H_o) can be calculated by the following equation [10, 11]:

$$H_o(J/m^2) = \{(24/\pi) \times I_{sc} \times [1 + 0.033 \cos\ (360 \times n/365)] \times (\cos\theta \times \cos\delta \times \cos\omega_s + (\pi/180) \times \sin\theta \times \sin\delta)\} \quad (1)$$

Where, I_{sc} is the solar constant which equal to 1367 W/m^2 [2], N is day of the year as show in table 2 [11], θ is latitude of the location, δ is solar declination angle and ω_s is the sunset hour angle. δ and ω_s can be expressed as [10,11]:

$$\delta = 23.45 \times \sin[(360/365) \times (N + 284)] \quad (2)$$

And

$$\omega_s = \cos^{-1}[-\tan\theta \times \tan\delta] \quad (3)$$

Table2. Representative Day of each month (N)

Month	N for i th day of the month
January	I
February	i+31
March	i+59
April	i+90
May	i+120
June	i+151
July	i+181
August	i+212
September	i+243
October	i+273
November	i+304
December	i+334

There are many methods to calculate tge global solar radiation. The equation of (Angström, 1924) and modified by (Prescott, 1940) is depended in this study [6,13]:

$$H_g = H_o[a + b \times (\bar{n}/N)] \quad (4)$$

Where H_g is the monthly average daily global radiation (MJ/m^2/day), a and b Empirical constant vary due to change in the air pollution and geographical parameters [12], and the value of a=0.3846 and b=0.3633 [13]. $\bar{n}$ "is the monthly average daily hours of bright sunshine" [12,13] and $\bar{N}$ "is the monthly average of the maximum possible daily hours of bright sunshine", it can be calculated as given below [12,13]

$$\bar{N} = (2 \times \omega_s)/15 \quad (5)$$

The monthly average daily diffuse radiation can be calculated as follows [13]:

$$H_d = H_g \times \left(1.354 - 4.02 \times {K_T}^2 + 5.53 \times {K_T}^3 - 3.108 \times {K_T}^3\right) \quad (6)$$

Where (K_T) called the "cleanness index ratio" is defined as the ratio of measured to calculated solar radiation. Finally, the beam radiation on horizontal surface was calculated [2]:

$$H_b = H_g - H_d \quad (7)$$

4. The solar exergy on the earth

The solar exergy was depended on the second law of thermodynamic, it is defining as the maximum energy output that can be extracted from a solar system in a given conditions [14]. To estimate the exergy solar radiation on the Earth, let us consider a machine set on the earth surface, as show in Figure1. The machine extracts the maximum work W_{max} obtainable from the energy source E_s, solar energy, and it delivers heat Q_0 to the environment at temperature T_0. Additionally, the machine transmits the energy by radiation E_e.

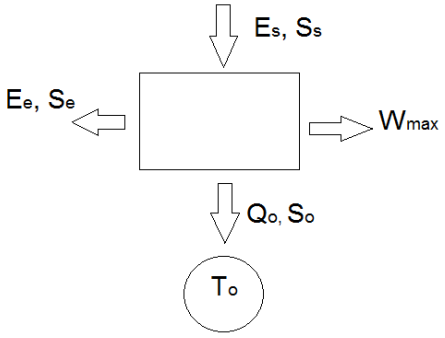


Figure 1. cyclic machine

The maximum work, $W_{max} = E_{xs}$, is the exergy of the solar energy E_s. The energy balance of the cyclic machine is $E_s - E_{xs} - Q_0 - E_e = 0$ and the entropy balance is $S_s - (Q_0/T_0) - S_e = 0$. This lead to the expression the exergy flux:

$$E_{xs} = (E_s - T_0 S_s) - (E_e - T_0 S_e) \quad (8)$$

If the machine considered as a black-body, and at the same temperature of the environment T_0, the second term in Eq. (8) becomes:

$$(E_e - T_0 S_e) = -\frac{1}{3}T_0^4 \quad (9)$$

According to the energy and entropy balance of the cyclic machine, the exergy solar radiation represented by Nayak and Tiwari [5, 15]:

$$E_{xs} = G * \left(1 - \frac{4}{3} * \left(\frac{T_a}{T_s}\right) + \frac{1}{3} * \left(\frac{T_a}{T_s}\right)^4\right) \quad (10)$$

Where G is the solar radiation incoming, T_a and T_s are the ambient and sun temperatures in Kelvin, respectively. The incoming solar radiation obtained from the relationship, the ambient temperature obtained from software Meteonorm [16], and the sun temperature is 6000 K [17].

5. Results and discussions

In this work, the extraterrestrial radiation, global solar radiation, diffuse solar radiation, beam solar radiation and the availability of solar radiation are estimated and compared with measured data of solar radiation that taken from Iraqi Agro-meteorological network [9] for the Republic of Iraq, Baghdad. Figures (2 to 13) show a comparison between measured solar radiation, direct solar radiation values that estimated using a linear mode (Angstrom model) and availability of solar radiation (solar exergy) that can be estimated by using equation (8). From these figures, an agreement can be seen between the estimated of direct solar energy and measured solar radiation through 12-months (January, February, March, April, May, June, July, August, September, October, November and December) in 2016. The average mean error that found for each month were 7.2%, 2.4%, 12.5%, 9.1%, 3.2%, 5.1%, 3.7%, 5.4%, 10.9%, 11.4%, 11.1%, 3.7%, respectively in addition, a very good agreement can be noted between the availability of solar energy and measured solar radiation through 12-months in the same year. The average mean error that found for each month were 1.4%, 9.4%, 6.1%, 2.6%, 10.8%, 1.9%, 3.5%, 1.6%, 4.4%, 5.1%, 5%, 2.7%, respectively. From the above result, it

can be concluded that the calculated the availability of solar energy (solar exergy) was very close to real measure value with a total average error for all months in the year was 4.58%.

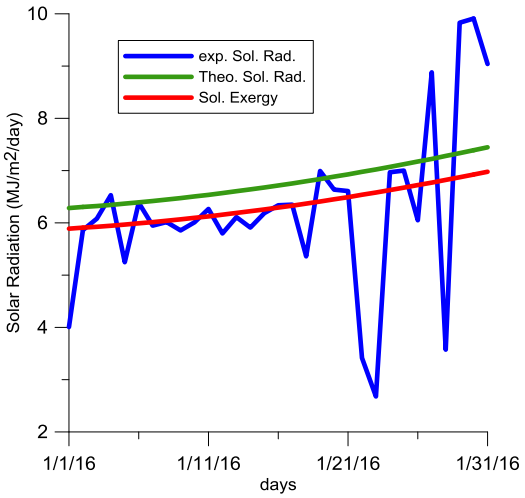


Figure 2. Solar radiation in January

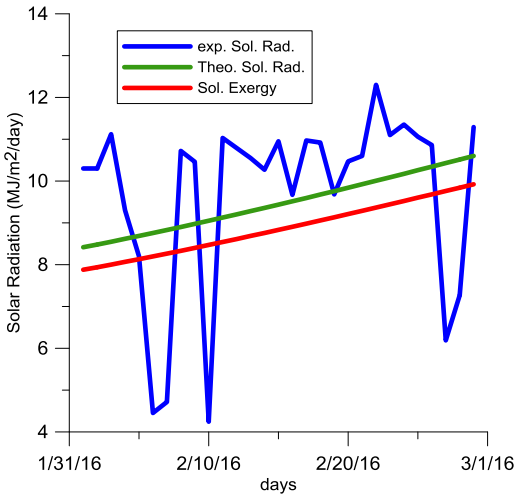


Figure 3. Solar radiation in February

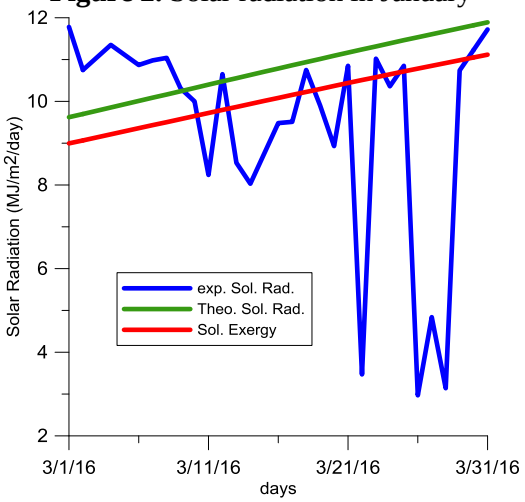


Figure 4. Solar radiation in March

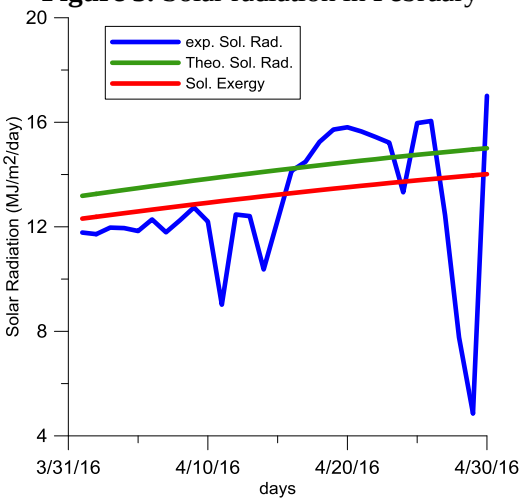


Figure 5. Solar radiation in April

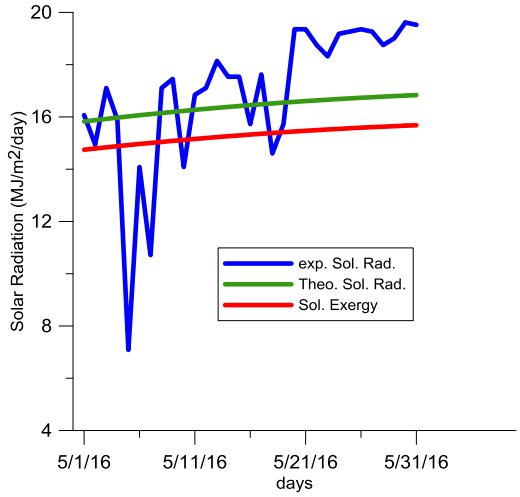


Figure 6. Solar radiation in May

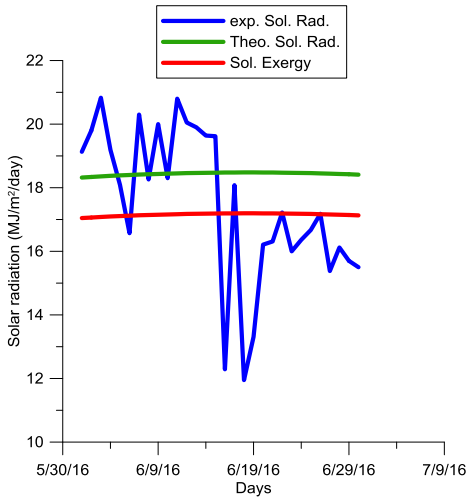


Figure 7. Solar radiation in June

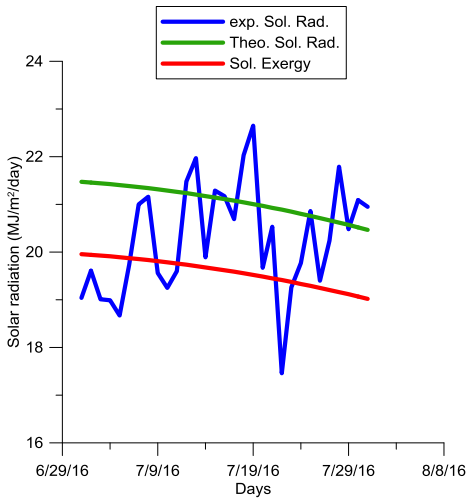


Figure 8. Solar radiation in July

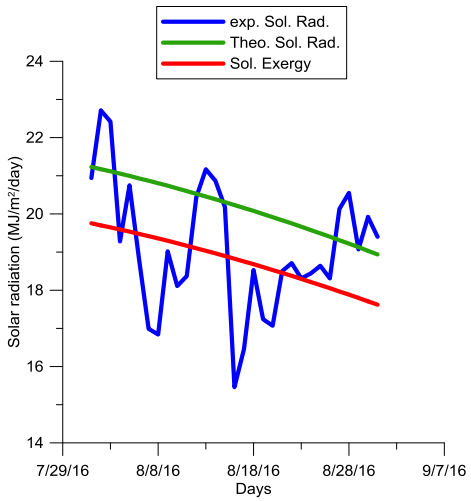


Figure 9. Solar radiation in August

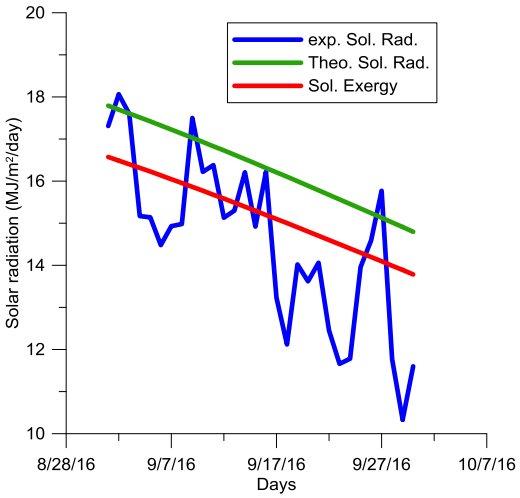


Figure 10. Solar radiation in September

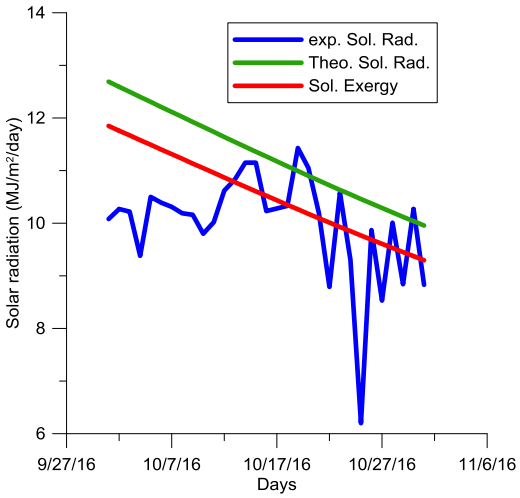


Figure 11. Solar radiation in October

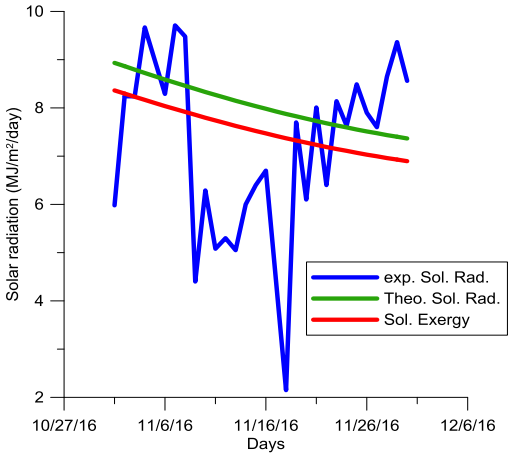


Figure 12. Solar radiation in November

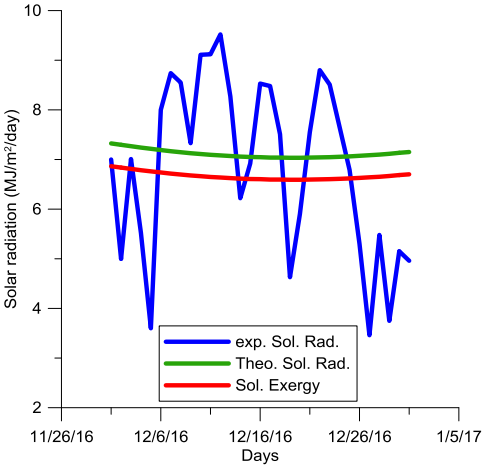


Figure 13. Solar radiation in December

Figure 14 shows the results of monthly measured solar radiation [10], estimation direct solar radiation and the availability of solar radiation. Moreover, the estimated direct solar radiation was larger than measured solar radiation. This difference is due to many factors, such as climate conditions, which implies rainfall distribution amounts, clear and cloudy, dusty, and fog sky, relative humidity, and air temperature. The maximum estimated and measured solar radiation was obtained in the summer season while the minimum was in winter. The main reasons for these differences are high cloud cover and humidity; high diffuse to direct radiation ratio, high air temperature during May to August, low relative humidity, and long day's length compared with other months. The availability in solar radiation is very close to the value of the measure solar radiation. Also, the maximum solar radiation was in summer (May, June, and July) while the minimum solar radiation was in winter (November and December, and January). The variation in solar radiation is a result of two reasons. The first reason is the orbit of the earth around the sun makes the earth close to the sun during the summer season and keeping the earth away from the sun during the winter season. The second one is due to the declination of earth rotation axis.

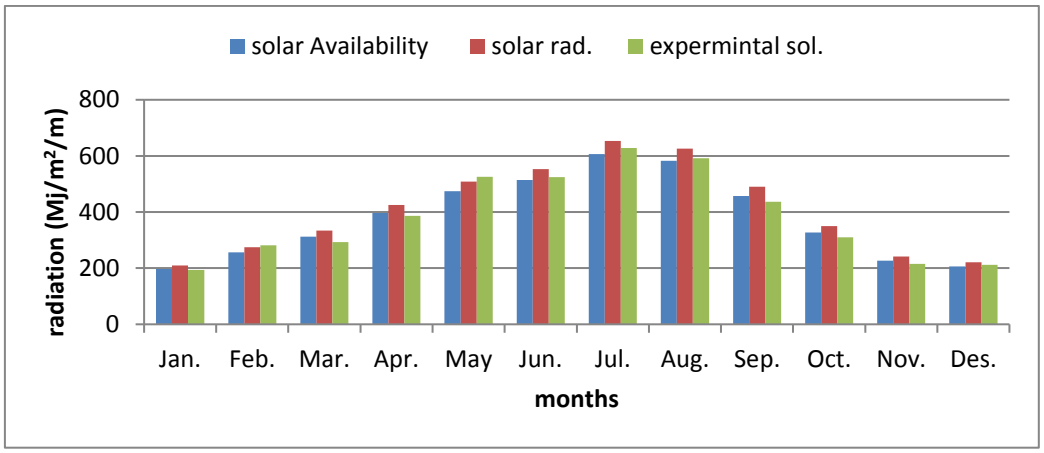


Figure 14. Comparison among theoretical, experimental and availability of Solar radiation through the year

Figure 15 shows the monthly experimental and theoretical losses in solar radiation during the year. The experimental losses are the difference between the estimated direct solar radiation and measured solar radiation. While the theoretical losses are the difference between the available solar radiation and measured solar radiation. It can be seen that maximum experimental losses in solar radiation occur at September (53.7 MJ/m^2) and the minimum experimental losses in solar radiation occur at February (1.7 MJ/m^2). While the maximum theoretical losses in solar radiation occur at July (46.1 MJ/m^2) and the minimum theoretical losses in solar radiation occur at January (13.1 MJ/m^2). The losses value in solar radiation depends on environmental conditions such as dust, humidity, cloud, smoke, the air temperature, etc.

Figure 16 shows the results of average daily solar radiation for six locations in Iraq. This figure indicates that the average daily solar radiation was great in Basra, Najaf, Baghdad, Anbar, Sulaimania, and Mosul. The results of average daily exergy solar radiation for six locations in Iraq were shown in Figure 17. It can be found that average daily exergy solar radiation was high in Basra, Najaf, Baghdad, Anbar, Sulaimaniya, and Mosul. The maximum average daily exergy solar radiation was in summer, while the minimum was in winter. Figures (16 and 17) show that the average daily exergy solar radiation is less than average daily solar radiation due to entropy generation in solar radiation due to irreversibility

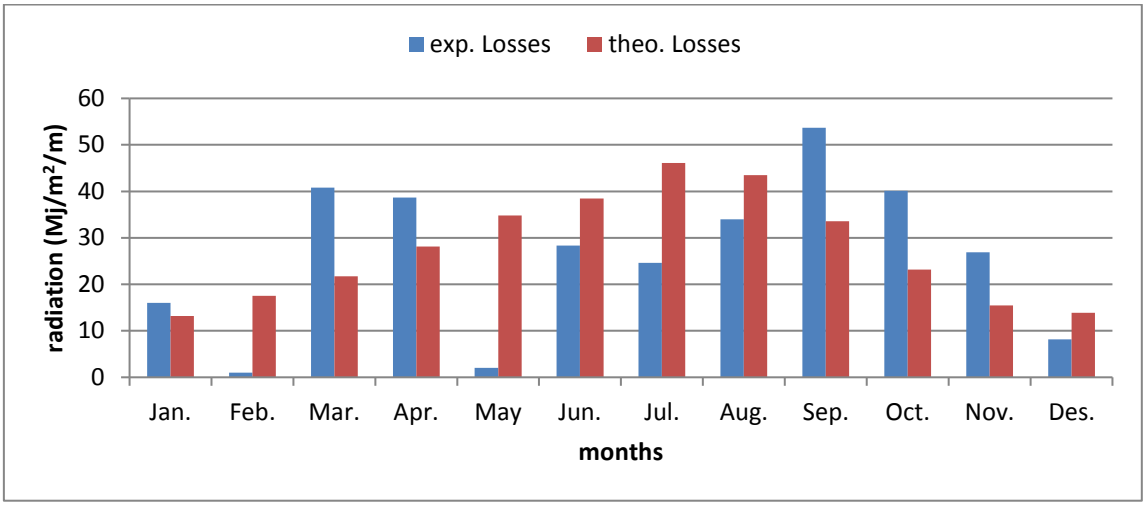


Figure 15. Experimental and theoretical losses in solar radiation through the year

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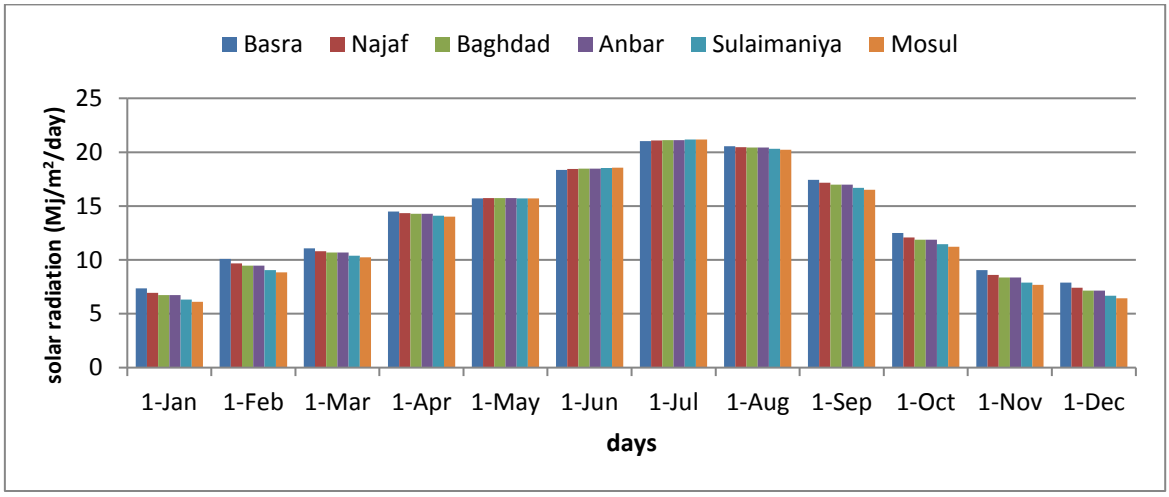


Figure 16. show the average daily solar radiation for six locations in Iraq

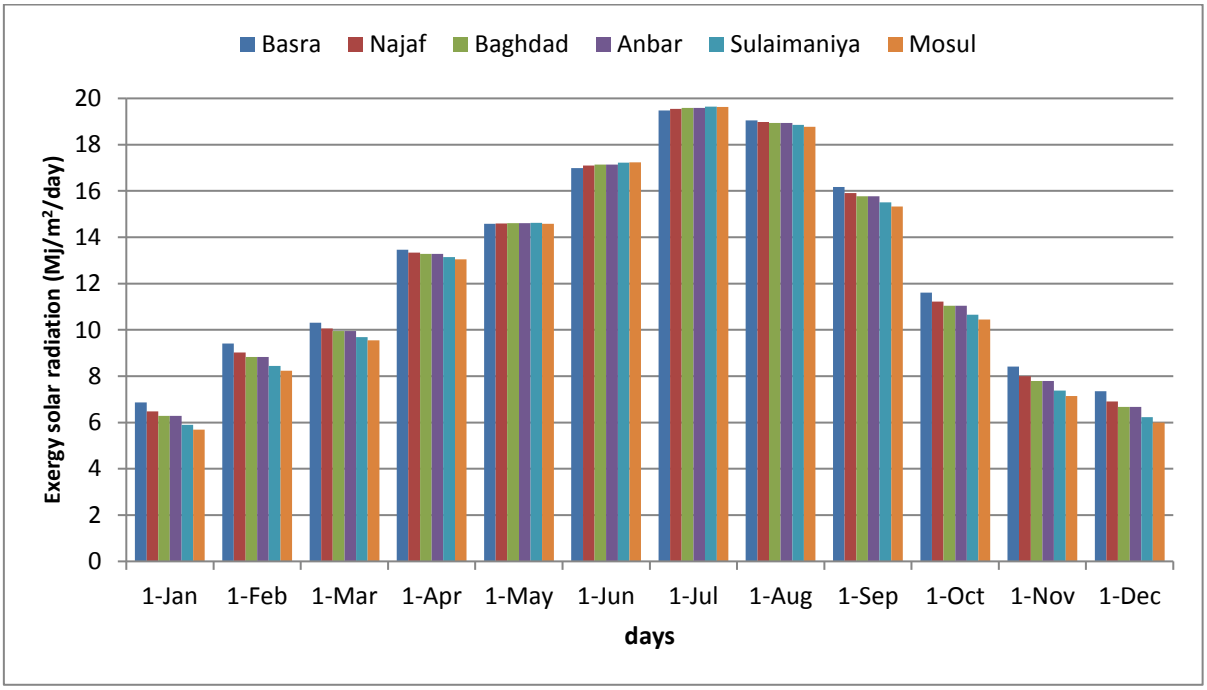


Figure 17. show the average daily exergy solar radiation for six locations in Iraq

Figure 18 shows the results of differences between average daily exergy solar radiation and average daily solar radiation for six locations in Iraq. The figure indicates that maximum and minimum differences occur in the six cities as follow. In Basra in July and January (1.548 and 0.498) MJ/m^2/day, respectively. In Najaf in July and January (1.54 and 0.464) MJ/m^2/day, respectively. In Baghdad in July and January (1.535 and 0.45) MJ/m^2/day, respectively. In Anbar in July and January (1.539 and 0.45) MJ/m^2/day, respectively. In Sulaimaniya in July and January (1.515 and 0.411) MJ/m^2/day, respectively. Finally, in Mosul in July and January (1.537and 0.405) MJ/m^2/day, respectively. The maximum differences occurred in Basra in July, which equal to 1.548 MJ/m^2/day, while the minimum differences occur in Mosul in January, which equal to 0.405 MJ/m^2/day. The results of losses percentage between average daily exergy solar radiation and average daily solar radiation for six locations in Iraq were shown in figure (19). It can be seen that the maximum and minimum differences occur in the six cities as follow. In Basra in July and January (7.36 and 6.76) %, respectively. In Najaf in July and January (7.3 and 6.73) %, respectively. In Baghdad in July and January (7.27 and 6.68) %, respectively. In Anbar in July and January (7.28 and 6.69) %, respectively. In Sulaimaniya in July and January (7.16 and 6.52) %, respectively. Lastly, in Mosul at July and January (7.26 and 6.65) %, respectively. Also it can be found that, the maximum differences occur in Basra in July which equal to 7.36 %, while the minimum differences occur in Sulaimaniya in January which equal to 6.52%.

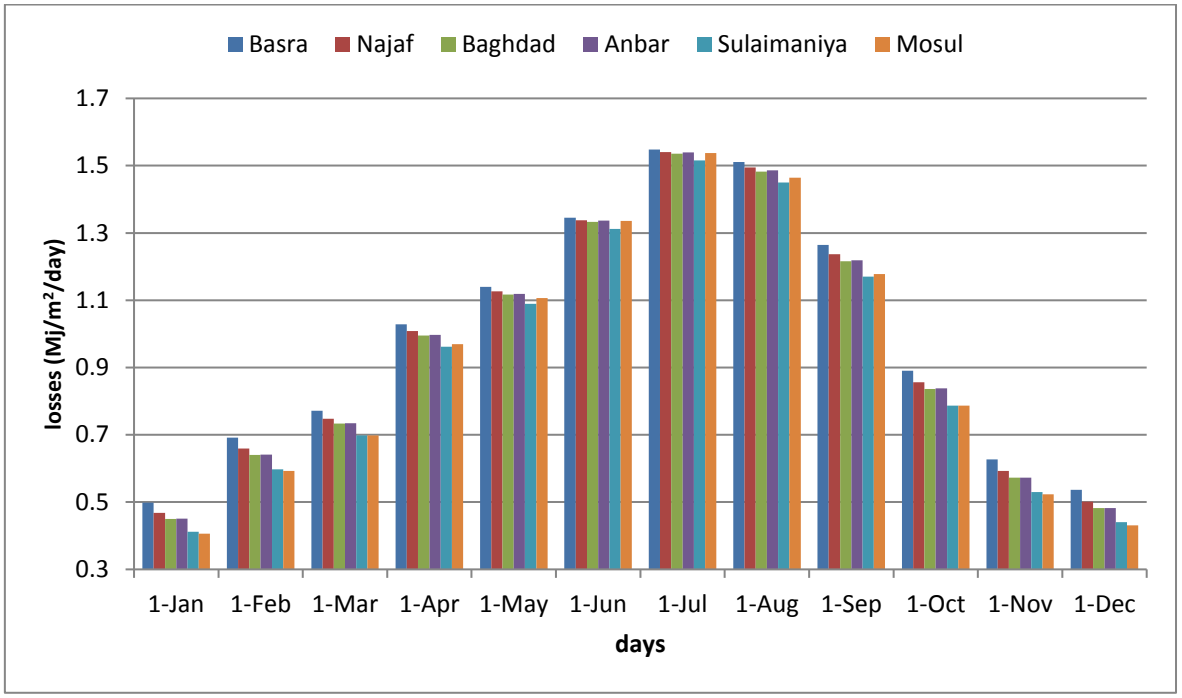


Figure 18. show the differences between average daily exergy solar radiation and average daily solar radiation for six locations in Iraq

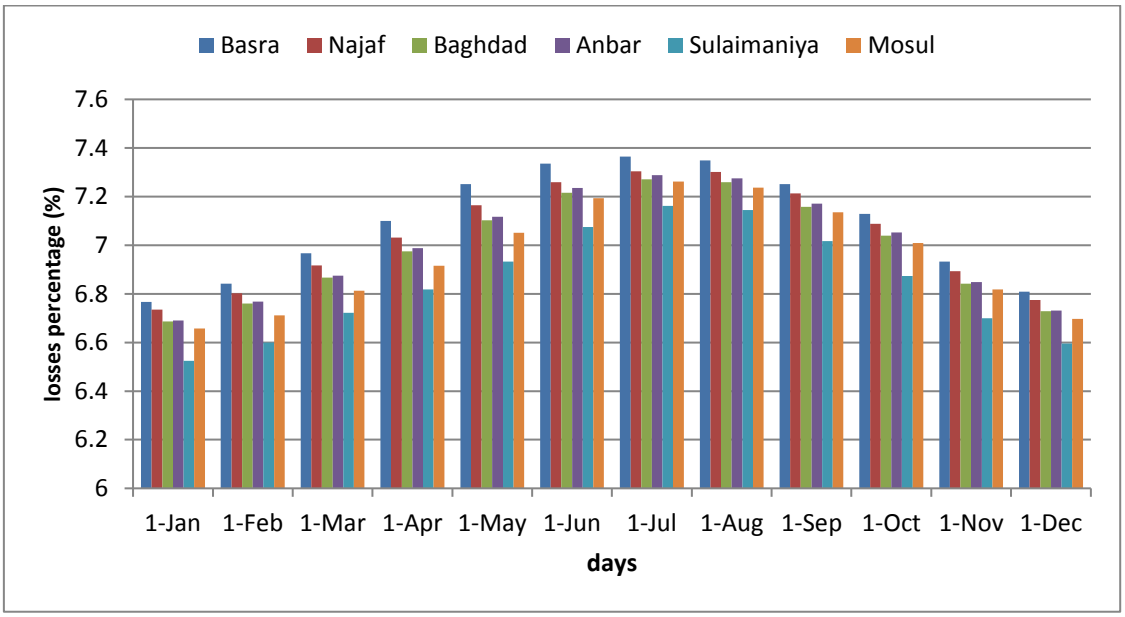


Figure 19. show the results losses percentage between average daily exergy solar radiation and average daily solar radiation for six locations in Iraq

6. Conclusion

In the present study, extraterrestrial radiation, global solar radiation, diffuse solar radiation, beam solar radiation and availability of solar radiation are estimated and compared with data of measured direct solar radiation taken from Iraqi Agro-meteorological network [10] for the Republic of Iraq, Baghdad city base on 12-months for 2016. The following findings and conclusions can be stated:

1- An agreement has been found between estimated and measured values of solar radiation. Where the average value of mean error for months of January, February, March, April, May, June, July, August, September, October, November, and December were 7.2%, 2.4%, 12.5%, 9.1%, 3.2%, 5.1%, 3.7%, 5.4%, 10.9%, 11.4%, 11.1%, and 3.7%, respectively.
2- A very good agreement has been found between availability and measured values of solar radiation. Where the average value of mean error for months of January, February, March, April, May, June, July, August, September, October, November, and December were 1.4%, 9.4%, 6.1%, 2.6%, 10.8%, 1.9%, 3.5%, 1.6%, 4.4%, 5.1%, 5%, and 2.7%, respectively.
3- The calculated availability of solar radiation, solar exergy, was very close to the real measure value of solar radiation with a total average error for all year of 4.58%.
4- The maximum solar radiation took place in a summer season, May, June, and July, while the minimum solar radiation took place in a winter season, November, December, and January.
5- The maximum estimated and measured solar radiation was happening in summer season while the minimum was happening in the winter season.
6- The maximum experimental losses in solar radiation occurred in September (53.7 MJ/m^2) while the minimum experimental losses in solar radiation occurred in February (1.7 MJ/m^2).
7- The maximum theoretical losses in solar radiation occurred in July (46.1 MJ/m^2) while the minimum theoretical losses in solar radiation occurred in January (13.1 MJ/m^2).
8- The value of solar radiation depended on environmental conditions such as dust, humidity, cloud, smoke, the air temperature, etc.
9- Higher daily solar radiation and daily solar exergy was found in Basra and the lowest in Mosul, the daily solar exergy was (10.27, 10.09, 10, 10, 9.69, and 9.81 MJ/m^2) for Basra, Najaf, Baghdad, Anbar, Mosul, and Sulaimaniya, respectively
10- The percentage differences between daily solar radiation and daily solar exergy were (7.09%, 7.04, 7%, 6.99%, 6.96%, and 6.85 %) for Basra, Najaf, Anbar, Baghdad, Mosul, and Sulaimaniya, respectively.

Nomenclature

a, b	Empirical constant (Regression constants)
G	Solar radiation incoming ($MJ/m^2/day$)
H_b	Beam radiation ($MJ/m^2/day$)
H_d	Diffuse radiation ($MJ/m^2/day$)
H_g	Global radiation ($MJ/m^2/day$)
H_o	The extraterrestrial solar radiation (J/m^2)
I_{sc}	Solar constant which equal 1367 W/m^2
$I_{sol.}$	Availability of the solar radiation ($MJ/m^2/day$)
N	Day of the year
$\overline{N}$	Maximum possible daily hours of bright sunshine
$\bar{n}$	Bright sunshine
T_a	Ambient temperature (K)
Ts	Sun temperature (K)
ω_s	Sunset hour angle (degree)
K_T	Clearance Parameter
δ	Solar declination angle (degree)
θ	Latitude of the location (degree)

Subscripts

a Ambient
b Beam
d Diffuse
g Global
o Extraterrestrial
s Sun
sc Solar constant

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