

GIS-BASED ANALYSIS OF THE SOLAR RADIATION MAPPING AND POTENTIAL ASSESSMENT FOR THE NORTH IRAQ-KURDISTAN REGION

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Abstract

Insight of the spatial distribution of solar radiation and assessing its potential is essential for well-informed planning, investment, and utilization of solar energy in the Kurdistan region of Iraq. Using Geographic Information System techniques is considered highly effective for mapping solar radiation. In this research, solar data from meteorological stations and satellite-derived models were analyzed and compared through the PVGIS-5 geo-temporal irradiation database and the measured data from 29 stations to create solar radiation maps. These maps provide valuable insights into the areas with high solar energy potential and identify suitable areas for solar energy projects for power generation and heating applications. The results revealed significant spatial variations in solar radiation across the Iraqi Kurdistan Region. The solar radiation map identified zones with high solar potential, such as southern and western regions, while identifying zones with lower solar energy availability, such as mountainous or forested areas. The results indicate that the spatial variability of the daily solar radiation ranges from 4.4 to 5.4 kWh/m². The daily irradiation in the context of global horizontal irradiation (GHI), direct normal irradiation (DNI), and global irradiation optimum angle (GIOA) ranged from 4.4 to 5.6, 4.9 to 5.8 and from 4.7 to 6.2 kWh/m², respectively. The annual irradiation in the context of GHI and GIOA range from 1850 to 2250 kWh/m² and from 1750 to 2350 kWh/m², respectively. These findings serve as a valuable database and provide essential guidance for decision-makers, energy planners, and investors to identify suitable locations for solar energy projects and improve renewable energy production.

Keywords: Direct normal irradiation, GIS, Global horizontal irradiation, Global irradiation optimum angle, PVGIS, Solar radiation mapping.

1. Introduction

With the growth in energy demand worldwide, renewable energy sources provide clean energy and an alternative to fossil fuels. Solar thermal and photovoltaic technologies are the two most active solar energy technologies. Photovoltaic technology, which uses semiconductors to convert sunlight directly into electrical energy, has been a popular choice in recent years. Solar energy is converted into thermal energy for use in homes and/or commercial applications such as drying, heating, cooling, cooking, and power generation, which is growing fast in terms of research and industrial utilization. However, reliable solar data for planning for any solar project, whether PV-based power generation or solar thermal, is an essential pillar for the project's success. Because solar radiation data is the source of the greatest error in calculating solar energy system output, numerous studies in various regions of the world have been made available by countries to assist researchers, investors, and designers in predicting the outputs of solar projects more precisely. Not deviating from the global trend, the Kurdistan-Iraq authorities plan to utilize solar energy for power generation and other industrial applications in the region. There are numerous funds to support the research and development of solar energy in universities and research centers in the region. This work is evidence of the trend toward solar energy utilization.

The potential of solar technologies is considerably large, although their utilization is nearly non-existent in Iraq. There is some literature on renewable energy in general and solar energy in particular potential in Iraq. The reported outlook of renewable energy potential in Iraq by Al-Kayiem and Mohammad [1] found that the global solar radiation in Iraq ranges from 2000 to 2500 kWh/m² as an annual daily average. They concluded the possibility of two approaches for utilizing concentrated solar power (CSP) in Iraq. First, to integrate the CSP and support existing thermal power plants, and second, the possibility of implementing CSP as standalone plants. Also, they recommended proposals that the Iraqi government can adopt to support the use of renewable energy resources in general and solar energy in particular.

Muslim [2] reviewed the problems and barriers to deploying solar photovoltaic power generation in Iraq. In addition, based on an Iraqi GIS map, they analyzed the problems of implementing solar PV panels and electricity generation. They determined that the average daily solar radiation is around 5-5.5 kWh/m². Al-Riahi et al. [3] studied and explored climatological zones in Mosul, Baghdad, and Nasiriyah districts between years of 1971 and 1985. The results visually over a period of successive days with radiation less than 5 MJ/m²·day and 10 MJ/m²·day. More studies showed the status, challenges, policies, and prospects of solar energy in the Middle East region, Farahat et al. [4] during their reporting on the performance of an isotropic and an anisotropic model on solar energy potential on surfaces with various inclinations in Saudi Arabia.

Since the 1980s, gridded data sets of surface irradiance have been recorded with hourly and higher temporal resolutions (15-30 minutes) and spatial resolutions down to a few kilometers Polo et al. [5]. The main drawback of satellite data is that it does not directly record ground-level radiation. As a result, models are required and utilized to calculate solar radiation.

Urraca et al. [6] reported the quality of solar model changes with location and data volume (terabytes) and the sources of uncertainty in estimating annual global

solar irradiation. Therefore, having access to dependable and accurate solar radiation data is critical for completing any renewable energy project based on solar irradiance. While Alwadei et al. [7] reported a comparison of solar radiation in the Arabian Peninsula using Satellite Data, the Radiative Transfer Model, and the Machine Learning Integration Approach. In a study by Al-Khazzar and Khaled [8] the data comparison of monthly average global solar radiation between the measured data and data by NASA satellite for certain cities in Iraq has been investigated. The study was conducted in the cities of Baghdad, Mosul, Tikrit, Rutba, Nasiriya, Kirkuk, Haditha, and Najaf. The results were contrasted with NASA satellite data.

Other researchers have used the online PVGIS web application. PVGIS has been involved in estimating solar radiation from satellite data for many years, both independently by Amillo et al. [9] and then in collaboration with institutions such as Deutscher Wetterdienst [10, 11]. Then, a satellite-based climatology of surface solar irradiance was studied for different solar components and normalized irradiance. The data collection is supplemented with detailed documentation of Mueller et al.'s methods and validation tests [12].

However, geostationary-satellite images (GIS) are a powerful data processing tool that provides useful and necessary information for the optimal management of resources and facilities [13]. Mapping PV power plants is still challenging on a continental scale, which is limited by the computing resources and accuracy in complex environments Zhang et al. [14]. When real data based on site measurements is unavailable, prediction models are the adopted methods to plan solar projects. Models based on GSI are the most comprehensive technique to estimate and find the accurate value of solar irradiance [6, 15]. The current work is directed at developing solar data in the Kurdistan-Iraq region based on the GSI technique.

In line with the authorities of the Kurdistan Region of Iraq to utilize solar energy, this research aims to develop a solar map for the northern part of Iraq to support and provide a reference for installing photovoltaic and solar heating systems in the region. Furthermore, clear, and correct information on the available solar resources is crucial for feasibility analyses, power plant design, and bankability ideas at all levels. The region will highlight its solar energy potential by adopting reliable solar mapping while laying the groundwork for establishing a statewide network for precise solar radiation monitoring. The solar map development method is based on GIS data in the region, which have been extracted from archives of 78 locations distributed in four governorates in the Kurdistan region in the northern part of Iraq.

2. Methodology and Solar Data Processing

2.1. Region of study

The study area is in the upper part of Iraq, spanning between latitude and longitude of $32^{\circ} 80'$ to $37^{\circ} 20'$ N and $41^{\circ} 10'$ to $46^{\circ} 20'$ E, respectively. The total area of the selected region is approximately 75,800 km². The region has a diverse physical environment; the elevation ranges from less than 250 m in the wide plains to more than 3600 m near the Iraq-Turkish and Iraq-Iranian border. The region abuts Turkey in the north, Iran in the northeast, Diyala and Tikrit provinces in the south, and

Syria in the northwest. Figure 1 shows the employed stations within Duhok, Erbil, Kirkuk, Halabja, and Sulaymaniyah Provinces.

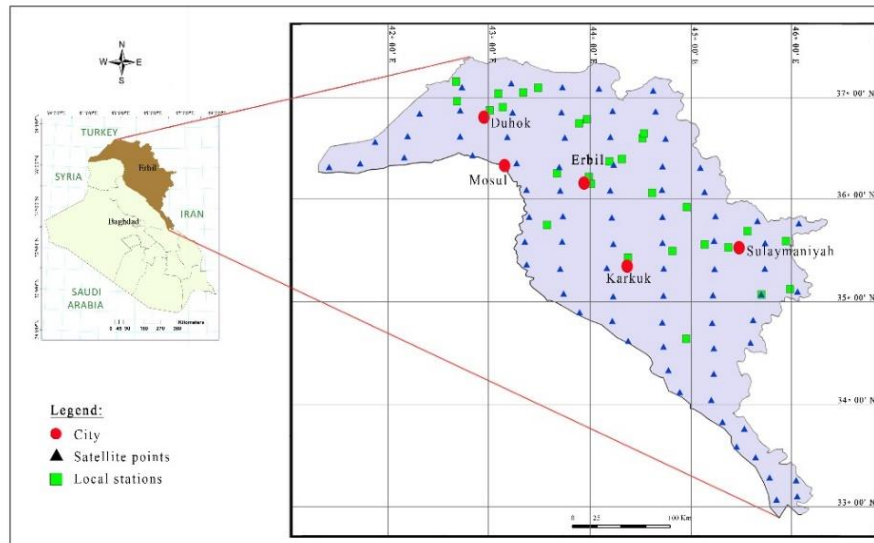


Fig. 1. Location of the stations and selected points over the study area.

2.2. Solar radiation calculation

Original data comes from data recorded by meteorological stations included in the Iraqi Kurdistan region and consists of 29 stations located in the selected area, as shown in Fig. 1. The data encompasses average daily sunshine duration and geographical coordinates. Solar radiation is measured in specialized agrometeorological stations with radiometers. These instruments require careful calibration and maintenance. The total incoming short-wave radiation can, in most cases, be estimated from measured sunshine duration according to the following empirical relationship, Eq. 1. In this study, solar radiation (R_s) was calculated with the Ångström method, which relates solar radiation to extraterrestrial radiation and relative sunshine duration [16]:

$$R_s = \left(a_s + b_s \frac{n}{N} \right) R_a \quad (1)$$

where, R_s daily solar or short-wave radiation [MJ/m^2], n actual sunshine duration daily [hour], N maximum possible duration of sunshine or daylight hours [hour], n/N relative sunshine duration, R_a daily extraterrestrial radiation [MJ/m^2], a_s regression constant, expressing the fraction of extraterrestrial radiation reaching the Earth on overcast days ($n = 0$), as $+b_s$ fraction of extraterrestrial radiation reaching the Earth on clear days ($n = N$).

The required parameters for calculating solar radiation were prepared for all stations. Table 1 shows an example of a database prepared for the Erbil station. The calculated daily R_s was in MJ/m^2 ; to convert unit to kWh/m^2 , the value of R_s was multiplied by 1/3.6.

Table 1. Monthly required parameter values for calculating daily solar radiation for Erbil station.

Month	<i>n</i> (hours)	<i>N</i> (hours)	<i>n</i> / <i>N</i>	<i>R_a</i> (kWh/m ²)	<i>R_s</i>
January	4.7	9.78	0.481	4.8	2.4
February	5.7	10.69	0.533	6.2	3.2
March	6.8	11.70	0.581	8.0	4.3
April	7.7	12.91	0.596	9.9	5.4
May	9.1	13.92	0.654	11.1	6.4
June	11.4	14.42	0.791	11.6	7.5
July	11.4	14.22	0.802	11.3	7.4
August	10.9	13.41	0.813	10.4	6.8
September	9.9	12.20	0.811	8.7	5.7
October	7.8	11.09	0.703	6.8	4.1
November	6.1	10.08	0.605	5.2	2.9
December	4.7	9.58	0.491	4.4	2.2

2.3. PVGIS data analysis

In the next step, the irradiation satellite recorded data for 78 points included in the study area are prepared. The total study area was more than 75800 square kilometers, which was divided into equal squares and a point was selected from each square according to a homogeneous grid pattern as described in Fig. 1.

The algorithms used for the satellite-based solar radiation data present in PVGIS have been developed within the Satellite Application Facility on Climate Monitoring (CM SAF) collaboration. Nevertheless, satellite-based solar radiation data's accuracy is generally very good. For this reason, most of the solar radiation used in PVGIS is based on satellite algorithms [17]. SARA, one of the Photovoltaic Geographical Information System versions, is available hourly with a spatial resolution of 0.05° (5.6 km). This data is based on observations from the Meteosat Visible Infrared Imager (MVIRI) and the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instruments carried by EUMETSAT's geostationary Meteosat satellites. Three types of data are used from the PVGIS-5 geo-temporal irradiation database taken for the period of 2005 to 2016. The data was set as global horizontal irradiation (GHI), direct normal irradiation (DNI), and global irradiation optimum angle (GIOA) for processing in the ArcGIS application.

GHI is defined as the total amount of shortwave terrestrial irradiance received by a surface horizontal to the ground [18]. On the other hand, R_s is the energy released by the sun that propagates in all directions via electromagnetic waves. R_s is the proportion of the almost rectilinear solar radiation, which reaches the earth's surface from an angle of 0.25° to the center of the sun and reaches a normal area, which is oriented perpendicularly to the direction of the radiation [19]. The solar surface emits it. GIOA value is the monthly sum of the solar energy that hits one square of a plane facing the equator's direction at the inclination angle that gives the highest annual irradiation, measured in kWh/m². A quality control process has been applied to check and validate extreme values. This was done by selecting the best observation years or the years with complete data sets. This means the data was checked and filtered to remove spurious values before processing. After preparing the irradiation dataset, the ArcGIS software version 10.2, using the Kriging interpolation method was applied to map the spatial variability of the solar radiation (three components) over the region.

3. Results and Discussion

Table 2 illustrates the results of calculated solar radiation, R_s based on the records of extraterrestrial radiation for meteorological stations. The average daily R_s ranged from as high as 5.5 kWh/m² to as low as 4.4 kWh/m². The Kirkuk site offered the highest value, and the Zakho site exhibited the least. While the average daily extraterrestrial radiation for Kirkuk and Zakho is 8.93 and 7.96 kWh/m². The results showed that the solar radiation trends increased north to south over the study area.

Table 2. Results of calculation for average daily R_a and R_s based on the available data sets from 2005-2016.

Station	Latitude, N	Longitude, E	Ave. Daily	Ave. Daily
			R_a	R_s
(kWh/m ²)				
Akre	36.75117	43.89554	8.23	4.7
Amadia	37.09173	43.48769	8.13	4.6
Ankawa	36.23813	43.99126	8.24	4.7
Batel	36.96247	42.68088	8.29	4.8
Bazian	35.59147	45.14094	8.22	4.7
Chamchamal	35.52921	44.82173	8.19	4.7
Chwarta	35.71967	45.56623	8.18	4.7
Darbandikhan	35.11137	45.70512	8.39	4.9
Duhok	36.87509	43.00578	8.26	4.8
Dukan	35.94956	44.96210	8.31	4.8
Erbil	36.17239	44.01438	8.25	4.8
Halabja	35.16550	45.98961	8.32	4.8
Kirkuk	35.46558	44.38039	8.93	5.5
Khabat	36.27235	43.67333	8.27	4.8
Kifri	34.68867	44.95802	8.84	5.4
Koya	36.08470	44.62108	8.39	4.9
Makhmoor	35.77811	43.57616	8.36	4.9
Mangesh	37.03542	43.09148	8.12	4.6
Musol	36.33500	43.11889	8.57	5.1
Penjwen	35.62387	45.94915	8.30	4.8
Rwanduz	36.60854	44.52387	8.37	4.9
Pirmam	36.38593	44.19615	8.30	4.8
Sarsink	37.04638	43.33869	8.03	4.5
Shaqalawa	36.40984	44.32018	8.21	4.7
Sharia	36.78889	43.97298	8.35	4.9
Soran	36.65470	44.53781	8.31	4.8
Sulaymaniyah	35.56298	45.37699	8.24	4.7
Zakho	37.15046	42.67268	7.96	4.4
Zaweta	36.90466	43.13592	8.24	4.7

Figure 2 shows the total annual solar radiation recorded in the 4 cities of Kirkuk, Sulaymaniyah, Erbil, and Duhok. As discussed earlier, the highest value was recorded in Kirkuk but the lowest in Sulaymaniyah. While Figs. 3 and 4 show the monthly average daily R_s and GHI for all 4 cities, the monthly average daily solar radiation for each city increases from the lowest level in January until it peaks in June and decreases in the winter months. The results show a clear image of the solar radiation map for the region. The three cities of Duhok, Erbil, and Sulaymaniyah have almost the same level of solar radiation during the year, with small differences. The opportunities for using solar energy systems in the 4 cities are

high, especially in the field of renewable energy, such as generating electricity and heating systems.

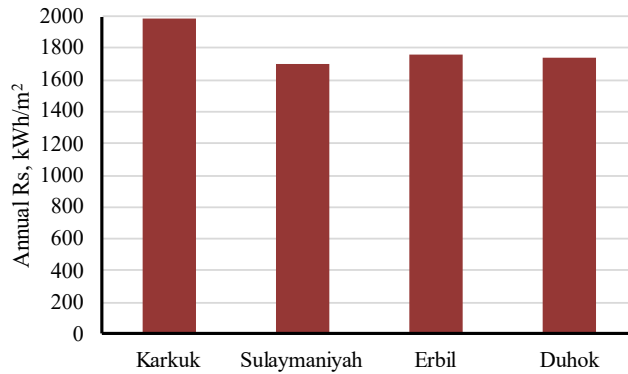


Fig. 2. Calculated annual solar radiation (R_s in kWh/m²) for four cities in the study area from 2005 to 2016.

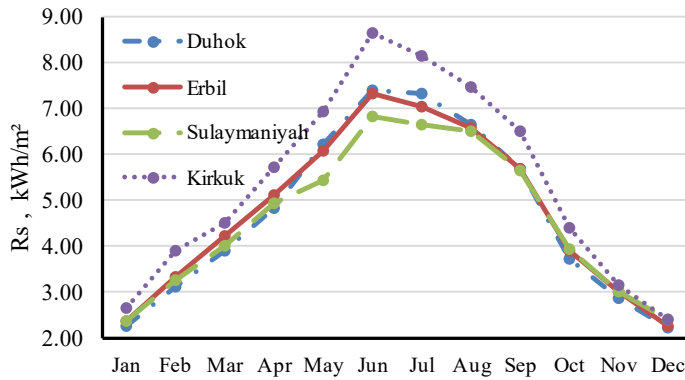


Fig. 3. Monthly average daily solar radiation (R_s in kWh/m²) for four cities in the study area from 2005 to 2016.

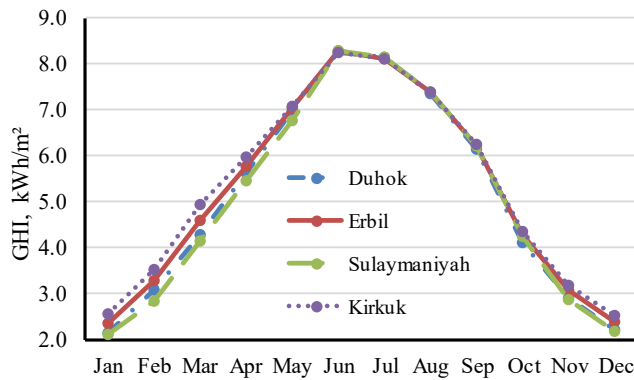


Fig. 4. Monthly average daily global horizontal irradiation (GHI in kWh/m²) for four cities in the study area from 2005 to 2016.

To investigate the spatial distribution of daily and annual irradiation, the satellite data based on (GHI, DNI, and GIOA) are used and allocated based on the GIS software to create the solar map, as shown in Figs. 5, 6, and 7. The results show an increasing pattern for irradiation from north to south, which is related to a decrease in the latitude in the same direction. This trend is also following the GHI, DNI, and GIOA patterns.

Solar mapping of GHI in Fig. 5 shows that the spatial distribution of Global horizontal irradiation is highly affected by latitude. The average daily and annual GHI trend increased from north to south. The average daily GHI ranges from as low as 4.5 kWh/m² at the 37°-38° latitude band to as high as 5.5 kWh/m² at the 33°-34° latitude band and those of the remaining points fell between these two extremes. Figure 5 also indicates that the average annual GHI ranges from as low as 1650 at the 37°-38° latitude band to as high as 2050 kWh/m² at the 33°-34° latitude band. The annual irradiation in the context of GHI and GIOA ranged from 1850 to 2250 kWh/m² and 1750 to 2350 kWh/m², in Figs. 6 and 7, respectively.

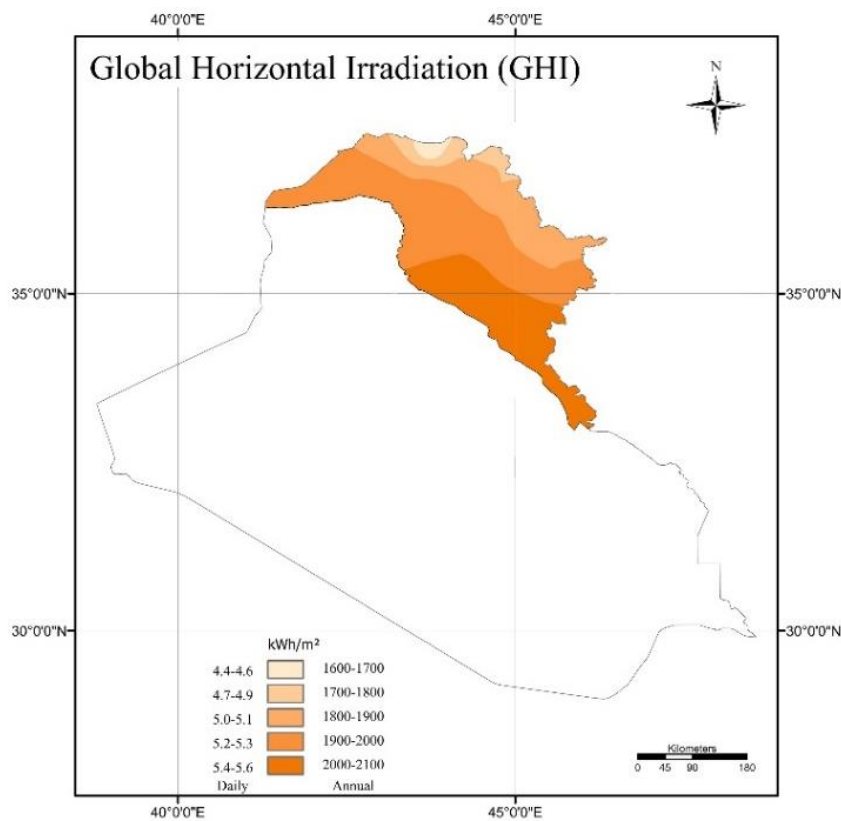


Fig. 5. Spatial distribution of global horizontal irradiation (GHI in kWh/m²) in the study area.

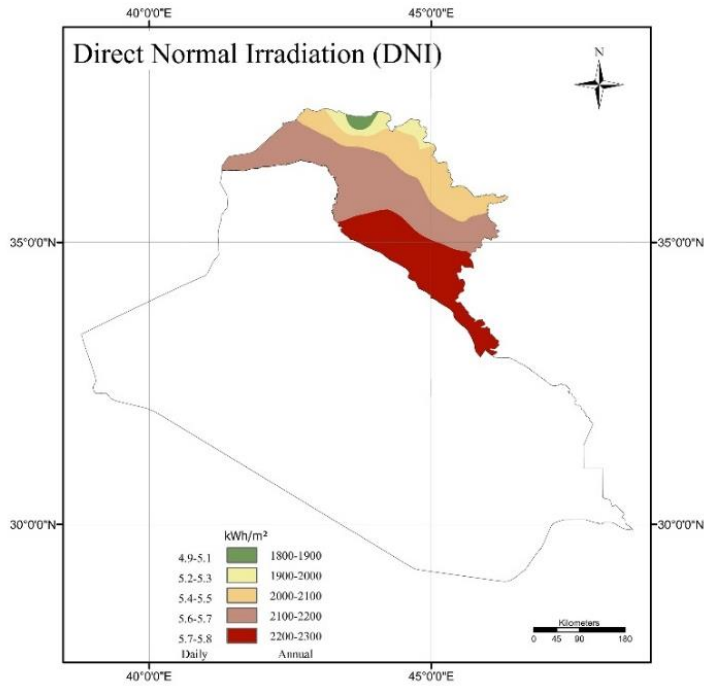


Fig. 6. Spatial distribution of direct normal irradiation (DNI in kWh/m²) in the study area.

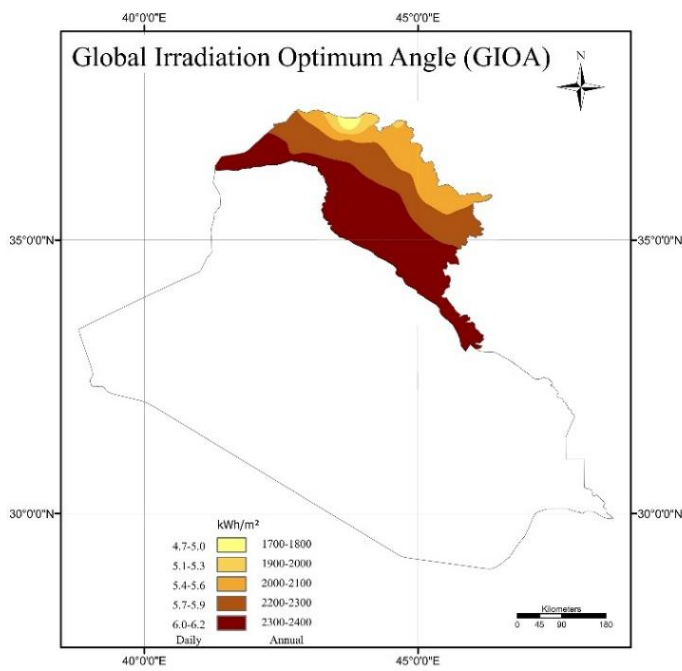


Fig. 7. Spatial distribution of global irradiation optimum angle (GIOA in kWh/m²) in the study area.

Furthermore, to give strong validation for this study based on the results from calculations with the Ångström equation and satellite data, the average values of solar radiation related to latitude bands from 34°-35°, 35°-36°, 36°-37°, and 37°-38° were compared between local stations and the corresponding selected points. The correlation between R_s and GHI in all latitude bands equals 0.91, Fig. 8.

It is noticed that GHI-satellite data yield results that are close to those from the Ångström formula. It means that the annual calculated R_s exhibited the strongest correlation with irradiation in the context of GHI followed by latitude. There is observed a change in the value of annual GHI from 1850 kWh/m² to 1753 kWh/m² via the Ångström formula (approximately 5% greater), while this change for DNI and GIOA is approximately 14% greater. However, the mean GHI in Kurdistan - Iraq is generally lower than the receded mean GHI in entire Iraq.

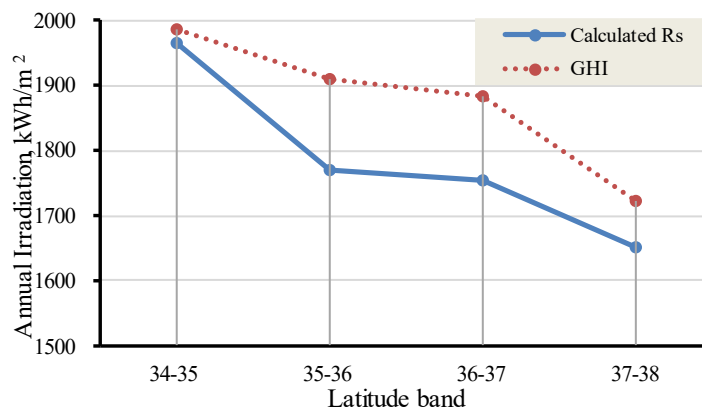


Fig. 8. Comparison of the average annual solar irradiation values between solar radiation (R_s) and global horizontal irradiation (GHI) in different latitude bands from 2005 to 2016.

4. Conclusions

To get more details about solar energy utilization, this study aimed to draw a solar map and provide a guideline for the global solar radiation in the north of Iraq, especially the Kurdistan Region of Iraq. Using satellite and calculated solar radiation values, the results demonstrated comprehensive data for Duhok, Erbil, Sulaymaniyah, and Kirkuk. Both data were verified and checked by comparing the satellite and the ground based on the locations and the GIS software. The main results showed that the average daily global horizontal irradiance (GHI) ranges from 4.5 to 5.5 kWh/m², which is considered a starting point and platform for researchers in this field to make more studies and investigate the potential of using solar energy systems in different fields of heating, cooling, production of electricity, and other applications.

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Daya Availability:

The datasets generated during and/or analysed during the current study are available in the PVGIS Photovoltaic Geographical Information System repository, [PERSISTENT WEB LINK TO DATASETS]: https://joint-research-centre.ec.europa.eu/pvgis-photovoltaic-geographical-information-system_en

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