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Spatial Analyses of Reliability of Solar Power in the Western Part of Iraq

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ABSTRACT

This study presents a comprehensive statistical and meteorological investigation of the western part of Iraq, specifically focusing on the Anbar governorate. To facilitate a detailed analysis, the study area was divided into four sections corresponding to the geographical directions: north, south, east, and west. The primary objective was to evaluate the potential for solar power exploitation in this region by analyzing a wide range of physical and meteorological data. The study encompassed various parameters including solar irradiation, air temperature, and other climatic variables that influence solar power generation. The physical and meteorological data demonstrated a strong correlation in most cases, indicating a consistent trend across the study area. However, two variables—diffuse horizontal irradiation and air temperature—showed inverse trends, deviating from the general pattern. These deviations were carefully analyzed to understand their impact on solar power potential. Furthermore, the analysis revealed that regions with elevated terrains, particularly in the western and southern parts of the Anbar governorate, exhibited higher solar power gains. This finding is significant as it highlights the influence of topography on solar energy potential. The combination of statistical and meteorological data provided a robust framework for assessing the feasibility of solar power projects in the region. The results of this study indicate the promising potential for solar power generation in the Anbar governorate. The integration of statistical and meteorological analyses offers valuable insights for policymakers and stakeholders involved in renewable energy planning and development. This investigation paves the way for future research and practical applications aimed at harnessing solar energy in western Iraq.

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INTRODUCTION

It is a clear fact that the energy demand has enormously increased during the last few decades due to population expansion. Fossil fuel is no longer the best energy source due to its negative effect on the environment (Balat 2005). Moreover, fossil fuel is a depleted source of energy, so it may be exhausted after a couple of decades (Nacke et al. 2022), leaving us in total darkness and stopping vital systems. Therefore, the demand for clean and renewable energy resources become one of the highest priorities of recent researchers (Sankari & Kumar 2023). The sun is the main source of the whole biological, physical, and chemical activities on Earth. Thus, its power can be considered as the major renewable energy source that can be used to produce clean and non-depleted amounts of energy. According to the literature, solar energy has been used since the 7th century B.C., either in lighting fires using the solar concentrating glassware (Glassmeier 2007, Schoch 2012) or in sustainable nutrition applications such as drying seeds and fruits for consumption in other seasons (Delyannis 2003, Silvi 2008). Therefore, solar energy is considered to be the eldest renewable source used by the human being. After discovering electricity, several solar energy techniques were developed to help generate electric power. However, only two among them maintained the world energy demands for thermal and electric applications (Quaschning 2016). The first technique is the photovoltaic solar panels, in which solar radiation photons are absorbed by semiconductor-based material layers to produce electric current via the photoelectric effect (Techo et al. 2024, Salman 2019, Rabehi 2017). The other technique is the solar concentrators, in which the electrical energy is produced by the thermal solar radiation in special power plants besides their fundamental purpose of buildings' heating (Tyagi et al. 2018).

Iraq has one of the longest daylight intervals countries during the whole year (Al-Kayiem & Mohammad 2019). Baghdad receives more than 3,000 hours of sun radiation each year. The intensity of sun radiation ranged between 416 W.m^{-2} in January to 833 W.m^{-2} in June (Kazem & Chaichan 2012, Al-Kayiem and Mohammad 2019). The western part of Iraq, represented by the Anbar governorate, is the largest part of the country with an open desert enclosure.

With a total population of 1,780,467 people, Anbar needs a huge amount of energy that reaches a peak estimated value of 1500MW(1.5GW) (International Organization for Migration (IOM) 2024). This amount of power comes due to the expansion in publicity during the last decades. However, due to the conflicts that the country generally and the nominated region specifically undergone, the real amount of power provided to the province is only about 400M. This enormous shortage of power needs to be substituted, which urged the engineers and researchers to search for the best solution for this issue. The geographic location of Anbar makes it exposed to high solar radiation in comparison with the other parts of Iraq (see Fig. 1), with the longest interval during the day. Therefore, solar power is the key to the power shortage problem solution. The provincial capital of Anbar is Al-Ramadi, which lies 100 km northwest of Baghdad. Al-Ramadi contains the highest population among the other province districts, with about 620,480 individuals.

Many relative studies have been conducted. One of the most common studies focused on the design and optimization of solar energy systems to improve their efficiency and reduce costs (Al-Naffakh & Al-Qassab 2021, Alturki 2021, Aziz 2022). These studies focused on factors such as the selection of solar panels, the design of the electrical system, and the integration of energy storage systems. Another study related to evaluating the economic feasibility of a hybrid power station that combines solar panels and wind turbines and connects it to the national grid in Al-Hayy City in the center of Iraq. That study involved a detailed analysis of the technical and financial aspects of the project, including the cost of the solar panels and wind turbines, the projected revenues from the sale of electricity, and the potential savings on fuel costs. It has also considered the current state of the electricity grid in the city and the potential benefits and challenges of connecting the hybrid power station to the national grid (Abass 2021). Another comprehensive study looked at the potential for solar energy in Iraq, covering the topic from the early stages of development to the present day. That article covered the historical background of solar energy development in Iraq, including the current state of solar energy infrastructure and technology in the country, as well as the current policies and regulations that impact the development of solar energy in Iraq (Istepanian 2020).

Overall, the literature studies either concentrated on solar technology or aimed at other parts of Iraq in their research.

The current study aims to investigate the reliability of Anbar, the Iraqi governorate, for solar power exploitation. It looks into the specific geographical, topological, and physical characteristics of different areas in the governorate that can determine its ability to host solar power and what is the best technology that can be utilized within.

MATERIALS AND METHODS

Assessment of Solar Radiation in Iraq

It is well known that the solar constant on the earth is 1353 W.m^{-2} (Green 1981). The high value of solar radiation in Iraq indicates its high potential for solar energy development, but it is also important to take into account other factors, such as cost, the availability of financing, and the regulatory environment when evaluating the feasibility of solar energy projects in the country. However, the first task in this field is to assess the region's potential itself and the solar physical parameters related to its location. It's noteworthy

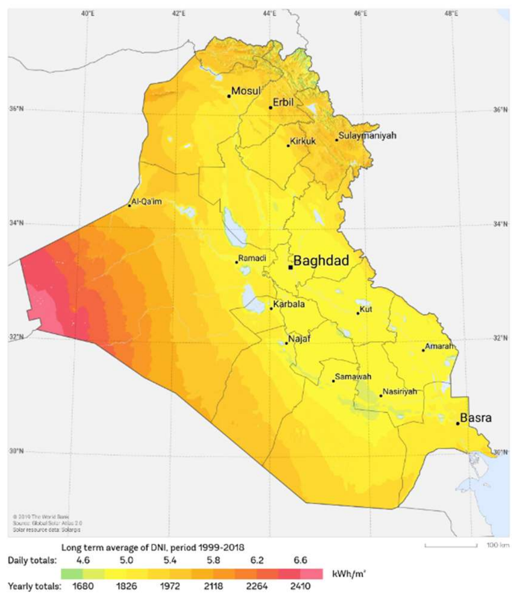

Fig. 1: Iraq's normal solar irradiation means during the year.

to mention that using the solar constant alone isn't enough to estimate the actual solar energy that can be harnessed, and it's important to use other solar parametric measures to estimate the solar energy depending on the location, weather conditions, and other factors that can affect the solar energy reaching the earth surface. Therefore, statistical techniques are essential along with the meteorological data for acquiring precise determinations in this type of investigation. Global Solar Atlas (GSA) was used to collect the location solar parameters. It is an online tool that provides information on the solar resource potential of different locations around the world. It is a comprehensive, interactive map that displays data on solar radiation, temperature, and other meteorological parameters (GSA 2022). Meteorological data were collected by selecting the areas under consideration by navigating the map controls and acquiring their coordinates. The map was then investigated using (the layers) feature to view the types of data such as Global Horizontal Irradiation, Direct Normal Irradiation, etc. The result data were then downloaded using CSV and Excel format. The downloaded data were then analyzed using Pearson's correlation statistical technique to finally get the required data and collect valuable information.

Determination of the Study Locations

Anbar is the western part of Iraq. It is the largest governorate in the country, bordered by Syria, Jordan, and Saudi Arabia. The capital of Anbar is Al-Ramadi. The other major cities are Fallujah, Haditha, Ana, Rawa, and Al-Qaim. Anbar is an important region in Iraq as it contains several key oil fields, as well as the Haditha Dam, which is one of the largest hydroelectric power stations in the country. Four distinctive locations were chosen as areas of this study, distributed according to the four geographical directions (west, North, East, and South), as illustrated in Fig. 2. The reason behind this procedure is to collect meteorological data from different parts of the province with variations in topological and geographical environments. This information may help optimize the province's reliability statistically for solar power exploitation. The specific regions within the four areas were selected according to security, population density, and social criteria. For instance, due to the conflict status in the regions, the areas were selected to be near the defense and security formations around the governorate. Regarding the social factor, the study gives attention to community structure since some of the areas include conscious and well-educated individuals who can use power sources rationally. Meanwhile, other areas have less awareness about power exploitation.

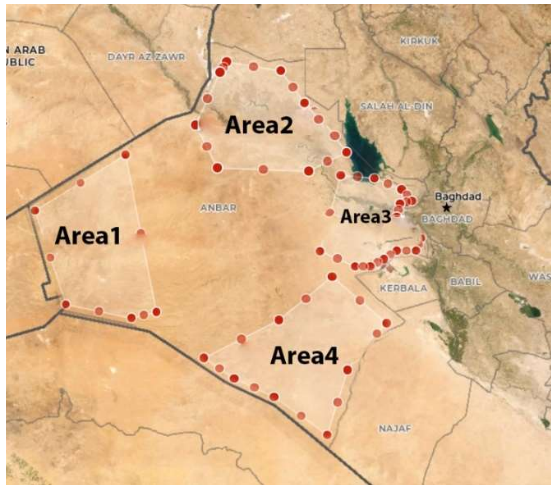

Fig. 2: Areas of study chosen in Anbar governorate.

RESULTS AND DISCUSSION

Spatial Optimization

Table 1 illustrates the physical and meteorological data for each one of the nominated areas. Where PV_{OUT} is the specific photovoltaic power output, DNI is the direct normal

Table 1: Spatial chosen areas and their meteorological data.

Region	Centre (deg)		PVout	DNI	GHI
	Lat	Long	kWh/kW$_p$	kWh/m^2	kWh/m^2
Areal (West)	32.861449	40.166016	5.03 - 5.22	5.86 - 6.51	5.62 - 5.84
Area2 (North)	31.448154°	42.539063	4.71 - 4.94	5.05 - 5.55	5.28 - 5.51
Area3 (East)	33.431718	43.483887	4.62 - 4.87	4.72 - 5.20	5.29 - 5.51
Area4 (South)	31.298118	42.539063	4.96 - 5.07	5.40 - 5.71	5.65 - 5.75

Region	DIF	GTl_opta	TEMP	OPTA	ELE
	kWh/m^2	kWh/m^2	^{o}C	^{o}	m
Areal (West)	1.71 - 1.93	6.41- 6.65	19.0 - 20.7	32 - 33	513 - 812
Area2 (North)	1.99 - 2.15	6.03 - 6. 29	21.2 - 23.1	31- 34	125 - 387
Area3 (East)	2.15 - 2.26	5.92 - 6. 26	23.2 - 24.6	29 - 33	41 - 185
Area4 (South)	2.08 - 2.17	6.39 - 6.51	22.4 - 23.6	32 - 33	266 - 412

irradiation, GHI is the global horizontal irradiation, DIF is the diffuse horizontal irradiation, GTI_{opta} is the global tilted irradiation at the optimum angle, TEMPs the air temperature, OPTA optimum tilt of PV modules and ELE is the terrain elevation.

All the physical properties illustrated in Table 1 meet the meteorological trends except for the air temperature and the diffuse horizontal irradiation, which showed distinctive behavior, as Fig. 3 shows. This behavior required statistical correlation between the anomaly parameters and the other regular trended parameters, which will be shown in the next section including the statistical tests and their potential in this study. The variation of the specific photovoltaic power output within the different parts of the governorate may be attributed to the topological characteristics. This is confirmed by the elevation graph, which shows that the north region with the greatest height has the highest photovoltaic output capacity PVout. Meanwhile, the least high area (the west region) also has opposite low PVout. The north and east areas exhibit very similar behavior. Very low variation was shown in direct normal irradiation, though the north surface area is still slightly dominant.

Fig. 3: Physical and meteorological characteristics comparison.

Statistical Analyses

Correlation analysis: As shown before, most parameters show a good agreement with each other, but the Diffuse horizontal irradiation and temperature data showed different trends that need to be investigated statistically. The best technique for this issue is Pearson's correlation test for one of the common parameters and one of the anomaly variables, which can be given by the following equation (Emerson 2015):

$$r = \frac{\Sigma_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\Sigma_{i=1}^{n}(X_i - \bar{X})^2 \Sigma_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where n is the number of data points (sample size)

X_i and Y_i are the individual data points of the two variables being correlated.

$\bar{X}$ and $\bar{Y}$ Are the mean (average) of the data points for X and Y, respectively?

The result of r suggests three probabilities

r=+1 indicating perfect positive correlation (if X increases, Y linearly increases)

r=-1 indicating perfect negative correlation (if X increases, Y linearly decreases)

r=0 indicating no correlation between the tested variables

SPSS was used to run the correlation test. Table 2 shows Pearson's correlation test between the two distinctive variables, the specific photovoltaic power output, and the diffuse horizontal irradiation. The Pearson correlation coefficient is -0.799, indicating a strong negative correlation between the two variables. However, the negative correlation suggests an inverse relation between diffuse horizontal irradiation (DIF) and the specific photovoltaic output (SPVout). These statistical indications render an atmospheric factor that can negatively affect the solar power output. This may be attributed to the cloudy and/or overcast days that can disperse and hence reduce the light reaching the photovoltaic panels. Which in turn leads to a reduction in the photovoltaic power output.

Table 2: Statistical Correlation data.

		SPVout	DIF
PVout	Pearson Correlation	1	-0.799
Sig. (2-tailed)		0.201	
	N	4	4
DIF	Pearson Correlation	-0.799	1
Sig. (2-tailed)	0.201		
	N	4	4

Cumulative distribution graphs: A cumulative distribution graph is of high importance graph that can help predict the behavior of the variable under consideration. Fig. 4 shows the cumulative distribution graph for the different areas. In general, all the areas follow the same pattern with slight variation in the west and south areas. The photovoltaic output probabilities from east and north areas show steadiness at lower profiles (from 4.4.- 4.7 KW/KWp), after which they increased dramatically. No such steadiness can be observed in the west and south regions. Indicating that the optimized areas in relation to the photovoltaic technology exploitation are the west and south areas. The output is also greater within these regions than in the remaining areas. The cumulative data for the four areas propose the following indications:

1. Area 1: This area exhibits a gradual increase in the output of SPV, which implies solar radiation consistency. In other words, it suggests minimal cloudy times and more clear skies.
2. Area 2: The area 2 curve shows stepping behavior, in which the SPV values are higher at lower percentages. This implies intensive sunlight receiving throughout specific intervals. In other words, this area might occasionally undergo cloudy days.
3. Area 3: This area shows balanced weather and moderate solar irradiation, which is revealed by the flat curve and the consistency in the curve developing with the percentage.
4. Area 4: lastly, Area 4 shows similar behavior to Area 1, but might be with additional factors such as topological factors that affect the solar irradiation.

CONCLUSIONS

The western region of Iraq, represented by Anbar governorate, showed promising indications regarding with possibility of using solar photovoltaic panels. The west and south areas

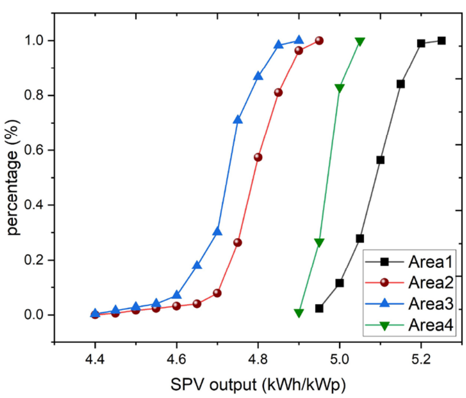

Fig. 4: Cumulative distribution graph for SPVout for the four areas.

of the governorate exhibited greater potential regarding the nominated technology. The elevation of terrains plays a major role in photovoltaic gain. Air temperature and diffuse horizontal irradiation have a negative potential on the solar power gain within these areas.

The four selected areas in the governorate show inconsistency regarding their meteorological parameters. The west and southwestern areas have more stable sunny days in comparison with the other two areas. The eastern area has modest weather, so the solar power output from it would be more stable but less than the output of the western and southwestern areas. The northern part of the governorate exhibits fluctuated intervals of sunny days, so on some days, high solar power output may be yielded. Meanwhile, on other days, the weather is more cloudy, and only minimum output may be produced.

Overall, the analyzed data revealed promising indications and significant feasibility for the governorate to exploit solar power technology.

REFERENCES

Abass, A.Z., 2021. Economic feasibility study of a hybrid power station between solar panels and wind turbine with the national grid in Al-Hayy City in the central of Iraq. *IOP Conference Series: Materials Science and Engineering*, 75, pp.10213-10236.

Al-Kayiem, H.H. and Mohammad, S.T., 2019. Potential of renewable energy resources with an emphasis on solar power in Iraq: *International Journal of Energy Studies*, 8(1), p.42.

Al-Naffakh, J. and Al-Qassab, S., 2021. Comparing the growth of renewable energy sources in Turkey, Iran, and Iraq. *Journal of Renewable Energy Studies*, 2(2), pp.21-26.

Alturki, F.A., 2021. Optimal sizing of autonomous hybrid energy system using a supply-demand-based optimization algorithm. *International Journal of Energy Research*, 45(1), pp.605-625. [DOI]

Aziz, A.S., 2022. Design and optimization of a grid-connected solar energy system: Study in Iraq. *Sustainability*, 14(13), p.8121. [DOI]

Balat, M., 2005. Usage of energy sources and environmental problems. *Energy Exploration & Exploitation*, 23(2), pp.141-167. [DOI]

Delyannis, E., 2003. Historic background of desalination and renewable energies. *Solar Energy*, 75(5), pp.357-366. [DOI]

Emerson, R.W., 2015. Causation and Pearson's correlation coefficient. *Journal of Visual Impairment and Blindness*, 109(3), pp.242-244. [DOI]

Glassmeier, K.H., 2007. The Rosetta mission: Flying towards the origin of the solar system. *Space Science Reviews*, 128(1), pp.1-21. [DOI]

Green, M.A., 1982. *Solar cells: Operating principles, technology, and system applications*. Englewood Cliffs.

GSA, 2022. *Global Solar Atlas*. Available at: Global Solar Atlas

International Organization for Migration (IOM), 2024. *Progress toward durable solutions in Iraq: Anbar.* IOM, Iraq. Available at: IOM Report

Istepanian, H.H., 2020. *Iraq solar energy: From dawn to dusk*. Friedrich-Ebert-Stiftung Jordan et Iraq.

Kazem, H.A. and Chaichan, M.T., 2012. Status and future prospects of renewable energy in Iraq. *Renewable and Sustainable Energy Reviews*, 16(8), pp.6007-6012. [DOI]

Nacke, L., Cherp, A. and Jewell, J., 2022. Phases of fossil fuel decline: Diagnostic framework for policy sequencing and feasible transition pathways in resource-dependent regions. *Oxford Open Energy*, 1, p.26. [DOI]

Quaschning, V., 2016. *Understanding Renewable Energy Systems*. Routledge. [DOI]
Rabehi, A., 2017. Direct and diffuse solar radiation components estimation based on RBF model: Case study. *Renewable Energy Studies*, 31, pp.93-110.
Salman, R., 2019. Research note: Light-emitting diodes as solar power resources. *Lighting Research & Technology*, 51(3), pp.476-483. [DOI]
Sankari, S.S. and Kumar, P.S., 2023. A review of deep transfer learning strategy for energy forecasting. *Nature Environment and Pollution Technology*, 22(4), pp.1781-1793. [DOI]
Schoch, R.M., 2012. *Forgotten Civilization: The Role of Solar Outbursts in Our Past and Future*. Simon and Schuster.
Silvi, C., 2008. History and future of renewable solar energy. *Desalination*, 51(3), pp.409-414. [DOI]
Techo, J., Techo, S., Palamanit, A., Saniso, E., Chand, A.A. and Prasannaa, P., 2024. Enhanced solar photovoltaic power production approach for electric vehicle charging station: Economic and environmental aspects. *Nature Environment and Pollution Technology*, 23(1), pp.215-223. [DOI]
Tyagi, H., Agarwal, A.K., Chakraborty, P.R. and Powar, S., 2018. *Introduction to applications of solar energy* (pp. 10-3). Springer Singapore.