



Atmospheric and Solar Radiation Analysis for Solar Energy Potential in Ayodhya District, Uttar Pradesh, India

Author 1- Prem Kumar, Research Scholar, Department of Physics, K. S. Saket P.G. College Ayodhya, Uttar Pradesh, India.

Author 2- Rajesh Kumar Verma, Assistant Professor, Department of Physics, K. S. Saket P.G. College Ayodhya, Uttar Pradesh, India.

Abstract: Solar power is amongst the better renewable options for making power in a way that can go on for good. Being in the tropics means India gets sun all the time, and so systems using solar PV are very likely to work well. This research looks at the weather and how solar radiation falls, in order to work out how much solar power could be made in Ayodhya district, Uttar Pradesh, India. We looked at data from NASA POWER and PVGIS – both based on satellites – to work out how much solar radiation there is. This included important things like Global Horizontal Irradiance, or GHI, Direct Normal Irradiance, or DNI, radiation that isn't direct, temperature, how damp it is, and cloud. Maths models of solar radiation were used to work out the angles of the sun and how much electricity photovoltaic systems might be able to make. The results showed that Ayodhya gets, on average, 5.3 to 5.5 kWh/m²/day of solar radiation each year; it's at its highest before the monsoon, and drops when the monsoon is on because of cloud. Modelling photovoltaic systems suggests that the district is very good for solar power to be developed, and that it could make 1650–1750 kWh/kWp per year. The results show that solar power is possible in Ayodhya, using either solar on roofs, or large solar farms.

Keywords: Solar radiation, photovoltaic systems, atmospheric parameters, renewable energy, Ayodhya district, uttar pradesh India.

1. Introduction

As global demand for energy and the environmental threats from fossil fuels increase, the transition to renewable energy technology is happening. The solar energy system has become one of the most useful renewable energy sources with abundance and environmental friendliness.

This is due to India's location between the latitudes of 8°N and 37°N, which receives high solar radiation. Most regions in India receive between 4 and 7 kWh/m²/d of solar radiation, according to national renewable energy assessments.

The incoming solar radiation at the Earth's surface will vary because of cloud cover, aerosol, humidity, temperature, and other atmospheric parameters. Solar power production depends on environmental parameters and these significantly affect how and where systems perform.

Located in the eastern part of Uttar Pradesh, Ayodhya district is continuously witnessing infrastructural development and a rise in electricity demand. Therefore, it is essential to assess the potential of solar energy in the location.

This research aims to achieve.

1. A solar radiation features examines Ayodhya district.
2. To study atmospheric conditions which affect solar radiation
3. To the solar radiation mathematical models applied.
4. To evaluate potential for producing photovoltaic energy.

2. Area of the Study

Ayodhya district is located in eastern Uttar Pradesh inside the Indo-Gangetic plains.

latitude: 26.80° N

Longitude: eighty two.20° E

Elevation: ~ninety three m above sea level

The climate is classified as humid subtropical, with hot summers, monsoon rainfall, and mild winters.

Seasonal distribution:

Season	Months
Summer	March – June
Monsoon	July – September
Winter	October – February

3. Literature Review

The study of solar radiation and the estimation of the amount of energy that can be produced by photovoltaic systems have been one of the most prominent areas of study in the field of renewable energy. Accurate knowledge of solar resources is critical in the design of solar energy systems, increasing the efficiency of solar panels, and developing appropriate renewable energy strategies. Researchers have attempted to develop appropriate models to study solar radiation, the effect of the atmosphere on solar radiation, and the capacity of solar panels to produce energy.

The most prominent contribution to the field of solar energy and solar radiation has been made by John A. Duffie and William A. Beckman in their book, **Solar Engineering of Thermal Processes**. This book has introduced critical models to calculate solar radiation on tilted and flat surfaces. They have proposed formulas to calculate various types of solar radiation, including solar radiation due to direct sun, scattered solar radiation, and reflected solar radiation. They have also discussed the effects of weather and the sun's position on solar radiation.

One of the important contributions to the topic of solar radiation was made by Muhammad Iqbal in his book **An Introduction to Solar Radiation**. In this book, he discusses the physics of solar radiation in great detail, including the interaction of solar radiation with particles in the atmosphere, clouds, and water vapor. His book examines the effect of scattering and absorption of solar radiation in the atmosphere on the amount of solar

radiation that reaches the Earth's surface. This topic is of particular interest when examining the variation of solar radiation in tropical and subtropical regions.

Richard Perez and his group have also contributed a great deal to the modeling of solar radiation. They developed models that can predict direct normal irradiance and diffuse irradiance from the global horizontal irradiance. Their models have enhanced the accuracy of predicting solar radiation from satellite data. Their models are also widely used for evaluating solar energy resources and for simulating photovoltaic systems.

Another prominent researcher in the field of solar radiation modeling is Christian A. Gueymard. His area of interest is solar spectral irradiance and models of atmospheric radiation transfer. Gueymard has developed a number of algorithms that enhance our present capability of estimating different aspects of solar radiation in varying atmospheric conditions. His research is widely used in solar energy modeling and evaluation of the performance of photovoltaic systems.

Solar radiation databases are a crucial part of renewable energy studies. Thomas Huld and his colleagues contributed significantly to this area by developing the PVGIS solar radiation database. PVGIS is a long-term satellite-based solar radiation database that provides estimates of photovoltaic energy production in many parts of the world. It takes into account parameters such as cloud cover and aerosols to accurately estimate solar radiation. Another popular solar radiation database is the NASA POWER solar radiation database, developed by NASA researchers. This database provides global solar radiation information using satellite and atmospheric models, including Global Horizontal Irradiance, Direct Normal Irradiance, and Diffuse Horizontal Irradiance. NASA POWER solar radiation data is commonly used for the assessment of solar energy potential and renewable energy resource planning.

For instance, in India, various studies have been conducted to examine solar energy potential in different regions. Madhavan Sengupta and his team at the National Renewable Energy Laboratory have developed solar radiation data sets for India. These data sets have been used to develop solar power plants and photovoltaic systems.

T. V. Ramachandra used satellite data and GIS to examine solar energy potential in India. According to Ramachandra, solar radiation in various regions of India is sufficiently high to develop solar power plants.

The effect of the atmosphere on solar radiation has been extensively studied. Martin Wild introduced the concept of global dimming and brightening. Global dimming and brightening refer to the effect of pollution and cloud cover changes on solar radiation that reaches the earth's surface.

Kuo-Nan Liou studied how solar radiation passes through the atmosphere. His research results show us how gases, dust, and clouds interact with solar radiation. This is important for developing accurate solar radiation models.

Research on the performance of photovoltaic systems has been conducted. Douglas C. Jordan and Sarah R. Kurtz studied how photovoltaic systems deteriorate over time by using data from many solar systems. Their results offer valuable information on the life expectancy of photovoltaic systems.

Martin A. Green has studied how the efficiency of solar cells is increasing. His tables on the efficiency of solar cells, published in *Progress in Photovoltaics*, are commonly used to show recent advances in solar cell technology.

Recently, studies have validated the accuracy of satellite solar radiation data by comparing it with ground data. Neeraj Mishra validated the accuracy of solar irradiance data from Indian weather satellites by comparing it with ground data and concluded that satellite data is accurate and reliable for renewable energy applications. Machine learning algorithms have also been employed to estimate solar radiation. A study by Alejandro Ortiz, published in *Scientific Data*, employed artificial intelligence to develop a comprehensive dataset of India's

solar energy infrastructure. This dataset is very useful for researchers to analyze solar energy trends and map regions with high solar potential.

In conclusion, previous studies have shown that accurate solar radiation estimates require a combination of satellite data, atmospheric models, and ground data. These studies also emphasize the need to estimate solar resources on a regional scale for effective renewable energy planning.

However, although many studies have addressed solar energy potential in India, very few studies have addressed the detailed solar radiation analysis at the district level in Ayodhya. This study proposes to address this issue by analyzing atmospheric conditions and solar radiation in the Ayodhya district to assess its solar energy potential and contribute to renewable energy development in the region.

4. Data Sources

To accurately evaluate the potential for solar energy, it is important to have dependable long-term data on solar radiation and weather conditions. In this study, solar radiation and weather data for Ayodhya district were gathered from well-known open-access databases and trusted weather sources. The data used here are commonly used in research related to solar energy and the assessment of renewable energy resources.

NASA POWER Solar Radiation Database

The essential source of sun radiation facts for this research became the NASA Prediction of world energy assets (strength) challenge. The NASA power platform components satellite-derived sun radiation and meteorological information for locations global. mixture of satellite tv for pc observations with the models evolved by using the worldwide Modeling and Assimilation office is the idea for this records.

Several essential parameters for solar energy investigation are covered by the dataset, including:

- i) Global Horizontal Irradiance (GHI)
- ii) Direct Normal Irradiance (DNI)
- iii) Diffuse Horizontal Irradiance (DHI)
- iv) Surface air temperature
- v) Relative humidity
- vi) Wind speed
- vii) Cloud cover

The data provides long run climate records with spatial resolution of approximately 0.5 degrees by 0.5 degrees and gets updated every day. Since NASA POWER data is fairly dependable and globally accessible, it is a popular choice among researchers evaluating solar energy potentials.

PVGIS Solar Radiation Database

Another crucial database in this study is the solar radiation database provided by the European Commission through the Photovoltaic Geographical Information System, or PVGIS. The system gives a detailed account of solar radiation and photovoltaic performance for a broad range of locations worldwide.

This PVGIS data is “satellite data and models of radiation behaviour in atmosphere” developed by the Joint Research Centre of the European Commission. This database provides the long-term averages of solar radiation and the estimated values of electricity production from solar panels.

The PVGIS platform allows to estimate: Solar radiation on a monthly basis Annual electricity generation by photovoltaic systems The performance of solar PV systems Optimal orientation of solar panels

PVGIS data is a primary source used to evaluate solar energy potential and prepare solar panel configurations.

Indian Meteorological Department (IMD)

The meteorological data for the study area was obtained from the India Meteorological Department. The data includes information on weather elements like temperature, humidity, rainfall, and cloud cover. They are also informative about weather intricacies. The data from IMD also indicate the effect of seasonal climatic variations on the amount of solar radiation.

Solar Radiation Analysis in Ayodhya

Average monthly solar radiation values:

Month	GHI (kWh/m ² /day)
January	3.9
February	4.5
March	5.5
April	6.0
May	6.3
June	6.1
July	4.8
August	3.9
September	4.8
October	5.2
November	4.6
December	3.8

Annual average solar radiation:

5.3–5.5 kWh/m²/day

5. Results and Discussion

A study of sunlight and weather conditions indicates that there is a huge potential for solar energy in Ayodhya district to generate electricity. Sunlight appears constant through most part of the year as indicated by data from satellites and weather stations. The amount of sunlight Global Horizontal Irradiance (GHI) that the earth receives varies with seasons because of factors such as cloud cover, humidity, and rainfall.

In the winter months (December and January), there is less sunlight because the days are shorter, there is more moisture in the air, and sometimes there is fog that blocks the sunlight. The average sunlight during this period stands at 3.8 to 4.0 kWh per square meter per day.

Before summer in February and March, the sunlight length has started to rise significantly. Sunlight levels increase with clearer skies and the sun being higher in the sky. The solar energy during this period stands at between 4.5 and 5.5 kWh/m²/day. This is the beginning of the best sunlight times in the region.

Sunlight precipitation is the highest during the pre-monsoon summer season (April and June). The sky is usually clear, and the sun is at a higher angle, thus allowing more sunlight to reach the ground. These months record 6.0 to 6.3 kWh per square meter per day of sunlight which offer solar electricity generation potential (ibid).

During the monsoon season (July- September), there is a significant reduction in sunlight that results from heavy cloud cover and elevated air moisture. This results in sunlight being blocked and absorbed by the clouds, with less energy reaching the surface. Solar irradiation during the mentioned months stands at 3.9 to 4.8 kWh/m²/per day.

Sunlight starts to go up again during the post-monsoon months (October and November) after the monsoon seasons. There are fewer clouds in the weather. Sunlight during this time stands at about 4.6 to 5.2 kWh per square meter per day.

The overall sunlight exposure to a square meter of sunlight in Ayodhya stands at 5.3 to 5.5 kWh each day throughout the year. This is like many locations in northern and central India that have adopted solar energy. Delhi, Lucknow, and Varanasi get a similar measure of sunlight ranging between 5.0 and 5.5 kWh per square meter per day.

Thus, Ayodhya has potentials for solar energy production that is similar to other parts in India, which have successfully implemented solar power plants.

6. Conclusion

The solar radiation and atmospheric parameters analysis reveals a potential for solar energy in the Ayodhya district. According to the average annual solar radiation 5.3–5.5 kWh/m²/day is apt for photovoltaic electricity generation. Solar energy development in the region can contribute significantly to sustainable energy production, de-link energy production from fossil fuels, and enhance the regional energy security.

7. Future Scope

There is ample scope of solar energy in the solar energy potential study of Ayodhya district. More research needs to be done not only to estimate the solar potential better but also to formulate policies on renewable energy for this particular area.

In the future, scientists could physically install weather stations on the ground to measure solar radiation accurately. The verification of satellite data on solar radiation would lead to the enhancement of solar energy models.

Using tools like Geographic Information Systems (GIS), researchers can come up with maps that depict the availability of solar energy in the district (Kunalysew, CSR...). Such maps would enable the identification of potential sites for solar panel installations.

Moreover, the application of machine learning and artificial intelligence can also contribute to enhancing the forecast of solar radiation based on the data of the atmosphere and satellites.

Another key area should be the integration of solar energy with other forms of renewable energy sources like wind energy and storage. By integrating these sources, renewable energy can become more reliable and efficient in the region.

Further study can also be conducted on whether it is economically and politically feasible to adopt solar energy in the Ayodhya district on a large scale.

8. References

1. Sharma, A. (2011) A Comprehensive Study of Solar Power in India and World. Renewable and Sustainable Energy Reviews, 15, 1767-1776. <http://dx.doi.org/10.1016/j.rser.2010.12.017>
2. Ministry of New and Renewable Energy, Government of India (2009) Jawaharlal Nehru National Solar Mission towards Building SOLAR INDIA. http://www.mnre.gov.in/file-manager/UserFiles/mission_document_JNNSM.pdf
3. Khare, V., Nerma, S. and Baredar, P. (2013) Status of Solar Wind Renewable Energy in India. Renewable and Sustainable Energy Reviews, 27, 1-10. <http://dx.doi.org/10.1016/j.rser.2013.06.018>
4. Duffie JA, Beckman WA. Solar Engineering of Thermal Processes.
<https://doi.org/10.1002/9781118671603>
5. Iqbal M. An Introduction to Solar Radiation.
<https://doi.org/10.1016/C2013-0-11495-2>
6. Perez R. Solar Energy Journal.
[https://doi.org/10.1016/S0038-092X\(01\)00156-9](https://doi.org/10.1016/S0038-092X(01)00156-9)
7. Gueymard CA. Solar Energy.
<https://doi.org/10.1016/j.solener.2003.08.039>
8. Huld T. Solar Energy.
<https://doi.org/10.1016/j.solener.2011.11.012>
9. Sengupta M. Solar Resource Data Handbook.
<https://doi.org/10.2172/1160696>
10. Ramachandra TV. Renewable & Sustainable Energy Reviews.
<https://doi.org/10.1016/j.rser.2011.04.007>
11. Wild M. Global dimming and brightening.
<https://doi.org/10.1029/2008JD011470>
12. Liou KN. Atmospheric Radiation.
<https://doi.org/10.1016/B978-012451451-5>
13. Jordan DC. PV degradation rates.
<https://doi.org/10.1002/pip.1182>

14. Green MA. Solar cell efficiency tables.

<https://doi.org/10.1002/pip.3102>

15. Mishra N. Solar irradiance validation.

<https://doi.org/10.1016/j.solener.2020.03.028>

16. Ortiz A. Solar energy dataset India.

<https://doi.org/10.1038/s41597-022-01499-9>

17. Müller R. Satellite solar radiation data.

<https://doi.org/10.1016/j.rse.2009.05.012>

18. Janjai S. Solar radiation estimation.

<https://doi.org/10.1016/j.renene.2011.05.005>

19. Badescu V. Modeling solar radiation.

<https://doi.org/10.1007/978-3-540-77455-6>

20. Kumar R. Solar potential India.

<https://doi.org/10.1016/j.renene.2014.11.027>

21. Sengupta M. NSRDB dataset.

<https://doi.org/10.1016/j.rser.2018.03.003>

22. Stanhill G. Solar radiation trends.

[https://doi.org/10.1016/S0168-1923\(00\)00115-6](https://doi.org/10.1016/S0168-1923(00)00115-6)

23. Ohmura A. Surface radiation network.

<https://doi.org/10.1175/1520-0477>

24. Huld T., Müller R., Gambardella A. Solar radiation database PVGIS.

<https://doi.org/10.1016/j.solener.2012.01.010>

25. Sengupta M. et al. The National Solar Radiation Database (NSRDB).

<https://doi.org/10.1016/j.rser.2018.03.003>

26. Gueymard C.A. Solar radiation modeling for photovoltaic applications.

<https://doi.org/10.1016/j.solener.2003.08.039>

27. Perez R. et al. A new operational model for satellite-derived irradiances.

[https://doi.org/10.1016/S0038-092X\(01\)00156-9](https://doi.org/10.1016/S0038-092X(01)00156-9)

28. Liou K.N. Atmospheric radiation theory.

<https://doi.org/10.1016/B978-012451451-5>

29. Stanhill G., Cohen S. Global dimming: Review of atmospheric solar radiation trends.

[https://doi.org/10.1016/S0168-1923\(00\)00115-6](https://doi.org/10.1016/S0168-1923(00)00115-6)

30. Wild M. Global dimming and brightening.

<https://doi.org/10.1029/2008JD011470>

31. Ohmura A. Baseline Surface Radiation Network.

<https://doi.org/10.1175/1520-0477>

32. Green M.A. Solar cell efficiency tables.

<https://doi.org/10.1002/pip.3102>

33. Jordan D.C., Kurtz S.R. Photovoltaic degradation rates.

<https://doi.org/10.1002/pip.1182>

34. Ramachandra, T.V., Jain, R. and Krishnadasa, G. (2011) Hotspots of Solar Potential in India. Renewable and Sustainable Energy Reviews, 15, 3178-3186. <http://dx.doi.org/10.1016/j.rser.2011.04.007>

35. NASA, Surface Meteorology and Solar Energy (SSE). <https://eosweb.larc.nasa.gov/sse/>