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MODELING OF SOLAR RADIATION INTENSITY DISTRIBUTION IN TANGERANG AREA USING INVERSE DISTANCE WEIGHTING ALGORITHM

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Abstract

Increasing energy demand due to economic growth has driven the need to diversify energy sources from fossil fuels to New and Renewable Energy (NRE), with solar energy being one of the most promising alternatives in Indonesia due to its strategic location on the equator. This study overcomes the cost limitations of direct measurement of solar radiation intensity through the application of Geographic Information System (GIS) technology to perform spatial analysis and mapping of solar energy potential, the results of which are expected to form the scientific basis for sustainable renewable energy planning and development. This study was conducted to: (1) analyze the level of solar radiation intensity potential in the Greater Tangerang area, and (2) identify the spatial distribution of locations with the highest solar radiation intensity potential. Solar radiation data for 2023 and 2024 were obtained from five BMKG stations, then the Global Horizontal Irradiance (GHI) value was calculated using the Angstrom–Prescott equation and processed using the Inverse Distance Weighting (IDW) interpolation method based on Geographic Information System (GIS). The analysis results show that the GHI values in the Greater Tangerang area range from 3.98 to 5.97 kWh/m²/day in 2023 and 4.11 to 5.58 kWh/m²/day in 2024. Spatial variations show that the city of Tangerang, especially the northeastern part, has the highest solar energy potential, while the southwestern part of the regency.

Keywords: *Global Horizontal Irradiance, IDW, Geographic Information System, Power Plant, Solar Energy*

INTRODUCTION

The increasing economic condition of the region is directly proportional to the demand for energy, so that national economic growth requires an evenly distributed electricity supply (Sansuadi, 2025). Electricity plays a role in various sectors, including industry, households, public services, and so on. Along with this, technological modernization and urban growth are driving an increase in electricity consumption (Fevriera & Hartatdji, 2023). The national electricity system still relies on fossil fuels. Energy diversification is a strategy to encourage the energy transition process, one of which is renewable energy sourced from natural processes and can be renewed (Dwisari et al., 2023). Energy utilization that is managed efficiently will ensure a long-term energy supply (Alim et al., 2023a). Renewable energy is categorized into several types, such as solar energy, water energy, biomass energy, and energy from waste management conversion (Solikah & Bramastia, 2024). Solar energy is a form of renewable energy whose potential is continuously used using solar panels so that it can be converted into electrical energy (Hasrul, 2021). Solar energy is an ecofriendly primary energy source that does not cause pollution and is unlimited in quantity. In the energy transition, the government supports the development of renewable energy sources (Konorop, 2024).

The potential for solar energy development in Indonesia is high, given its geographical location on the equator (Afif & Martin, 2022), so the intensity of sun radiation is relatively constant. The majority of Indonesia's regions have solar energy potential between 4.6 and 7.2 KWh/m^2 (Kananda, 2017). Being a large archipelago, Indonesia has a great challenge in measuring solar radiation intensity (Mubiyn & Ilmannafik, 2024). The measurement process is quite expensive. The Greater Tangerang area is located in a land area that is both urban and populated. The city demands a significant amount of electricity. Accordingly, this region is required to be assessed for its solar radiation potential. Based on the preceding description, measuring solar radiation intensity is expensive, so this study implemented GIS technology to map the distribution of solar radiation intensity potential. The aims of this study were 1) to determine the potential solar radiation intensity in the Tangerang area, and 2) to identify the distribution of locations with potential solar radiation intensity.

LITERATURE REVIEW

Solar Energy

Solar energy is the sun's power production capacity that can be used to convert other forms of energy to run various devices (Alim et al., 2023a). Solar energy is categorized as a form of renewable energy that has high supply potential in tropical regions (Ferdyson & Windarta, 2023). This condition is caused by Indonesia's location on the equator (Syaifullah, 2015). The solar energy is environmentally friendly, so it can minimize environmental pollution. The use of solar energy as an alternative energy source has the potential to reduce CO2 emissions and support improvements in environmental quality (Pijoh et al., 2024). The solar energy is used by absorbing the sun's radiant heating to generate thermal energy, which increases energy efficiency and reduces carbon dioxide emissions (Ali & Windarta, 2020). By implementing solar power plants, solar energy is converted into electrical energy using solar panels (Karjadi, 2025). The primary indicator used to determine the level of solar energy potential is Global Horizontal Irradiation (GHI) (Karonigi & Iriane, 2025). Global Horizontal Irradiance (GHI) is the total amount of solar radiation received by the Earth's surface on a horizontal plane. This includes both direct solar radiation and diffuse radiation received at the observation site.

Geographic Information System

Geographic Information Systems have the function of processing spatial data interpolation modeling (Sabihi et al., 2022). Spatial interpolation techniques contained in GIS applications consist of, among others, IDW (Inverse Distance Weighting). The IDW technique is an interpolation model based on each data point influencing the surrounding area, but this when the distance increased (Huda & Imro'ah, 2023). This approach refers to the inverse distance value from the mathematical equation, and the proportion of each sampling point's influence can be adapted. The IDW value depends on the level of involvement of the sample points in the interpolation result. The sample points that are located close to each other have a high impact, so that the surface representation results are clearer and more detailed. Instead, if the points are distant from each other, the resulting surface will be less detailed and smoother.

RESEARCH METHOD

This research method uses a quantitative approach. The data used comes from BMKG (Meteorology, Climatology, and Geophysics Agency), which data is the duration of solar radiation in 2024 and 2023. The location of the study was in the Greater Tangerang area, so the coordinates used were those of five BMKG stations located in that area. The spread of the coordinates of the BMKG stations in the Greater Tangerang area is as follows:

a. Budiarto Meteorological Station
b. Tangerang Geophysical Station
c. Soekarno Hatta Meteorological Station
d. Banten Climatological Station
e. Regional II Meteorological, Climatological, and Geophysical Agency

The solar radiation data for each station was analyzed to determine the GHI value using the Angstrom-Prescott equation, a formula that describes the correlation between actual solar radiation duration and maximum daily radiation duration.

Angstrom-Prescott formula

$$\frac{H}{H0} = a + b\left[\frac{n}{N}\right]$$

Description:

H	:	The global daily solar radiation absorbed at the Earth's surface (MJ/m²/day)
H0	:	Maximum solar radiation (MJ/m²/day)
n	:	Actual duration of sun exposure (hours)
N	:	Maximum exposure time (hours)
a, b	:	Empirical constant (depending on location)

Source: (Paulescu et al., 2016)

The empirical constant values in Indonesia are a = 0.25 and b = 0.50. The value of H0 can be calculated using the formula below:

$$H0 = \frac{24\ x\ 60}{\pi} = G_{sc}d_r\ [\omega s\ \sin(\emptyset)\ \sin(\partial) + \cos(\emptyset)\ \cos(\partial)\ \sin(\omega s)]$$

Description:

H0	:	Daily extraterrestrial solar radiation (MJ/m²/day)
G_{sc}	:	Solar radiation constant
d_r	:	Correction of the relative distance between the Earth and the Sun
ωs	:	The angle of the sundial at sunset
$\emptyset$	:	Latitude
δ	:	Solar declination

Source: (Paulescu et al., 2016)

The GHI results were processed using IDW (Inverse Distance Weighting) analysis. This approach is deterministic, considering the proximity of location points. The proximity of location points affects the magnitude of the interpolation value.

RESULT AND DISCUSSION

Global Horizontal Irradiation (GHI) is defined as the total amount of solar energy reaching a surface on Earth (Mubiyn & Ilmannafik, 2024). This parameter is very important and fundamental for evaluating the potential of a location for the construction and operation of a solar power plant (Hadi et al., 2025). The angle of the sun in Indonesia is considered optimal because the sun is relatively positioned perpendicular, or close to being vertical, throughout the year. This condition causes high solar radiation intensity, because the sun's energy only passes through a shorter layer of the atmosphere. The irradiation duration in Indonesia tends to be rather stable, with an average daylight hour of about 12 hours throughout the year. This is different from countries in high latitudes that experience extreme differences in the length of daylight and night between summer and winter (Susilo, 2021).

Indonesia's location near the equator causes it to have quite high Global Horizontal Irradiation (GHI) potential, because this region absorbs sunlight throughout the year with a radiation angle that is close to perpendicular. The GHI intensity peak generally occurs during the dry season, when the sky is clearer due to fewer clouds and lower air humidity levels (Iskandar, 2020). The regions of central Sumatra, Kalimantan, Sulawesi, and most of eastern Indonesia, including Nusa Tenggara, Maluku, and Papua, generally have solar radiation intensities between 4 and 6 kWh/m² per day (Alim et al., 2023b; U & Dewata, 2020). These numbers reflect the high potential of the solar energy available and its potential as an alternative energy source. During this period, direct solar radiation increases significantly, so the amount of solar energy received on the Earth's surface is at its maximum level.

These conditions make Indonesia, especially areas with dry climates and longer periods of solar radiation, highly potential for development as solar energy utilization areas. This finding is in line with the estimated Global Horizontal Irradiation (GHI) value in the Greater Tangerang area, which reached around 4.7 kWh/m² per day in 2023 and 4.6 kWh/m² per day in 2024, which indicates that this area has a relatively high intensity of solar radiation. The changing average daily Global Horizontal Irradiation (GHI) in the Greater Tangerang area represents the dynamics or variations in annual meteorological and climatic conditions that affect the level of solar radiation in the region. GHI is a parameter that is highly sensitive to changes in atmospheric conditions. The difference in values between 2023 and 2024 is mostly influenced by an increase in the number of clouds covering the atmosphere, which is the main factor causing a decrease in Global Horizontal Irradiation (GHI) values (Mubiyn & Ilmannafik, 2024).

The increasing number of cloudy days or the longer duration of thicker cloud cover in 2024 compared to 2023 could prevent direct solar radiation (Direct Normal Irradiance/DNI) from reaching the Earth's surface. This phenomenon is in accordance with the assumption that the 2023–2024 rainy season will tend to be longer or accompanied by higher rainfall intensity compared to the previous year, which scientifically could imply an increase in the frequency of days with lower solar radiation intensity.

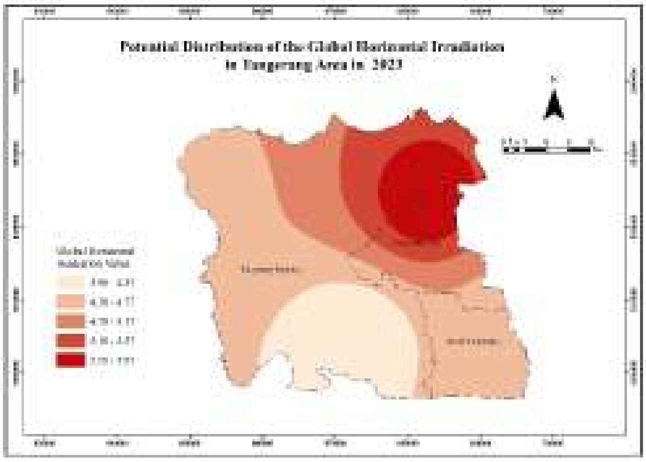
Increasing cloud cover causes most of the solar radiation to undergo reflection and absorption by water and ice particles in the atmosphere, so that only a small portion of the radiation reaches the Earth's surface in the form of diffuse radiation (Anggreni et al., 2018; Sianturi & Simbolon, 2021). The condition has an impact on the decreasing total solar energy that can be utilized, especially in areas with high rainfall intensity frequency. Thus, the increase in average cloud cover from year to year can be identified as a dominant factor contributing to the decrease in Global Horizontal Irradiation (GHI) values in an area (Taufiqi et al., 2025; Wang et al., 2018), including in the Tangerang Raya region.

In addition, the variability of GHI is also significantly influenced by the circulation patterns of the monsoon because the dynamics of the monsoon play a role in determining the humidity distribution, cloud formation, and the intensity of solar radiation reaching the Earth's surface. The flowing monsoon winds carrying moist air masses from the ocean play a role in increasing atmospheric humidity and strengthening the intensity of the convective process (K & C, 2023). In the Tangerang region, this phenomenon has the potential to increase the formation of convective clouds in more significant numbers, thereby reducing the level of solar radiation penetration reaching the earth's surface. The accumulation of convective clouds not only limits the direct transmission of solar radiation but also causes a decrease in the total global radiation received on the horizontal surface of the earth. Thus, the variability of the monsoon pattern, which triggers an increase in atmospheric humidity and the frequency of cloud formation, has a direct impact on the decrease in Global Horizontal Irradiation (GHI) values in the region.

In particular, the dynamics of global climate phenomena such as El Niño and La Niña also influence the annual fluctuations in Global Horizontal Irradiation (GHI) values. In 2023, atmospheric conditions in Indonesia were dominated by the El Niño phase, which was generally characterized by reduced rainfall and increased frequency of sunny days. This situation tends to strengthen the intensity of solar radiation received on the earth's surface, thereby contributing to an increase in GHI values in various regions of Indonesia. In contrast, if atmospheric components transition to a neutral or La Niña phase in 2024, the resultant increase in air humidity and rainfall will enhance cloud cover in the region. This condition causes a reduction in solar radiation penetration to the surface, thereby directly lowering the daily Global Horizontal Irradiation (GHI) value. The combination of these various factors indicates that GHI variability in Greater Tangerang is a consequence of complex interactions between local meteorological conditions and global climate phenomena, which simultaneously affect the distribution of solar radiation both temporally and spatially.

In this study, the Inverse Distance Weighting (IDW) method was used to model the spatial distribution of Global Horizontal Irradiation (GHI) in the Greater Tangerang area. IDW is a deterministic geostatistical method based on the principle that the value of a variable at a location is more influenced by nearby measurement points than by measurement points that are further away. Through this approach, GHI estimates can be obtained at locations that do not have direct measurement data, thereby overcoming spatial gaps in the dataset. Interpolation results using the IDW method produce a representative solar radiation distribution map that reflects variations in GHI intensity on a local scale and can be used as a basis for further analysis.

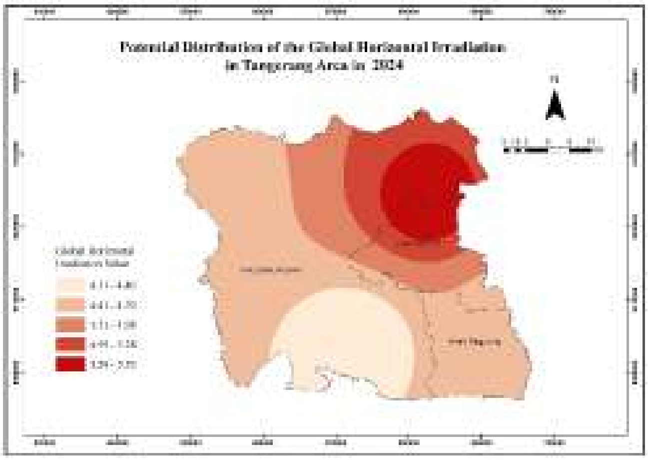
Figure 1. Map of GHI potential distribution in Tangerang in 2023



Spatial analysis of the distribution of Global Horizontal Irradiance (GHI) in 2023 in the Greater Tangerang area shows significant variations in solar energy potential, which are systematically classified into five value classes. The class with the lowest intensity, ranging from 3.98 to 4.37 kWh/m²/day, was identified mainly in suburban areas, particularly in the southwestern part of Tangerang Regency. In contrast, the class with the highest GHI value, namely 5.58 to 5.97 kWh/m²/day, was concentrated dominantly in Tangerang City. The Global Horizontal Irradiance (GHI) value in the study area is classified into five main groups to identify the level of solar energy potential that can be utilized in the development of Solar Power Plant (SPP) systems. This division represents the variation in solar radiation intensity received by the earth's surface in each zone, which directly affects energy conversion capacity and solar-based electricity production efficiency. The first class, with a range of 3.98–4.37 kWh/m²/day, reflects the lowest level of solar energy potential, generally found in areas with high cloud cover and significant rainfall. The second class, ranging from 4.38 to 4.77 kWh/m²/day, shows a moderate increase in solar radiation intensity, which is still feasible for small-scale rooftop solar power plant installations or household systems.

On the other hand, the third class (4.78–5.17 kWh/m²/day) indicates areas with moderate potential, where radiation intensity allows for the efficient implementation of solar power systems on public buildings or residential areas. In the fourth class (5.18–5.57 kWh/m²/day), radiation intensity is categorized as high, describing areas with long and consistent sunshine duration, making them highly suitable for the implementation of medium to large-scale solar power plants. The fifth class (5.58–5.97 kWh/m²/day) is the category with the highest potential, indicating areas with clear and stable atmospheric conditions, making them the most promising zones for the development of efficient and sustainable high-capacity rooftop solar power systems.

Figure 2. Map of GHI potential distribution in Tangerang in 2024



Based on the results of spatial analysis of Global Horizontal Irradiance (GHI) distribution in the Greater Tangerang area in 2024, five categories of solar energy potential were obtained, classified based on the range of radiation intensity values. This classification provides a quantitative representation of the feasibility of the area for the development of solar power plants, both large-scale and rooftop. The lowest category, with a range of 4.11–4.40 kWh/m²/day, represents minimal solar energy potential, spread across the southwestern part of Tangerang Regency and the southern part of South Tangerang City. The low GHI value in this area is thought to be influenced by high rainfall and significant cloud cover, requiring further technical feasibility studies. Moreover, the 4.41–4.70 kWh/m²/day class is categorized as medium–low potential, which include the central and western areas of Tangerang Regency and a small part of the north of South Tangerang City.

Although the radiation intensity in this class tends to decrease, the area can still be utilized for the construction of small-scale solar power plants, considering technical factors such as panel module orientation and energy conversion efficiency. In the 4.71–4.98 kWh/m²/day class, which is classified as medium–high, covers the transition zone in the north of Tangerang Regency and the suburbs of Tangerang City. This region has quite moderate radiation intensity, making it suitable for the implementation of medium-scale solar power systems such as integrated housing installations. The category of 4.99–5.28 kWh/m²/day is classified as high potential, distributed across most of Tangerang City and expanding into the northern part of Tangerang Regency. The sun exposure is sustained and consistent, making this area highly suitable for rooftop solar power plants and hybrid renewable energy systems. The highest class, between 5.29 and 5.58 kWh/m²/day, is categorized as very high potential and is concentrated in the northeast of Tangerang City. This area has the most optimal level of solar radiation, making it the most effective zone for the development of large-capacity solar power plants and the commercial and domestic use of solar energy.

This comparative analysis between the 2023 Global Horizontal Irradiance (GHI) distribution map and the 2024 projection shows consistency in spatial patterns but with significant differences in peak values. In terms of spatial patterns, the distribution of GHI in the Greater Tangerang area shows high levels of stability. Both maps consistently place the highest potential in the northeastern part of Tangerang City, which is thought to be influenced by geographical and environmental factors such as proximity to the sea and relatively stable wind patterns. Meanwhile, a radial decrease in GHI values towards the west and south is also observed, with the southwestern part of Tangerang Regency being the zone with the lowest values in both years. The major difference is within the GHI range. In 2023, the maximum value is 5.97 kWh/m²/day, and the minimum is 3.98 kWh/m²/day, while in 2024, the maximum value decreases to 5.58 kWh/m²/day and the minimum value increases to 4.11 kWh/m²/day. Thus, the total GHI range narrows from around 2.00 to 1.47 kWh/m²/day, indicating a decrease in peak values of around 6.5%.

Integrating environmental factors that influence Global Horizontal Irradiance (GHI) values is an important element in interpreting spatial analysis results and acquiring a more comprehensive understanding of solar radiation variations in the Greater Tangerang area. In this case, the analysis needs to be expanded to include several key determinant variables that could potentially affect the intensity of radiation received on the earth's surface. First, land cover plays a significant role in determining GHI distribution. The area with dense vegetation coverage, a water body, or agricultural land generally shows a lower GHI value due to high humidity levels and increased cloud formation, which can inhibit solar radiation penetration. Second, aerosol density and air pollution levels in urban areas need to be further studied because particulates in the atmosphere can absorb and reflect some of the sun's radiation, thereby reducing the intensity of radiation reaching the surface. Third, although the elevation in Greater Tangerang is relatively plain, small variations in altitude can still affect the distribution of local radiation due to differences in air temperature and atmospheric layer density.

The integration of these three variables is expected to provide strong scientific justification for the spatial distribution of GHI, particularly in explaining why the Tangerang City area shows the highest values and identifying the factors contributing to the observed decrease in GHI values in 2024. In addition, an analysis of both annual changes and long-term trends is needed to understand the temporal dynamics of GHI fluctuations. The decrease in the maximum GHI value of ±6.5% from 2023 to 2024 needs to be studied, considering various potential factors, such as regional climate change, extreme weather anomalies (e.g., El Niño or La Niña phenomena), and differences in the resolution and source of satellite data used in modeling. This study aims not only to determine whether these changes are temporary or part of a long-term trend of declining solar radiation.

In this study, we conducted a long-term trend analysis of Global Horizontal Irradiance (GHI) data to understand the dynamics of GHI values. In addition to understanding the dynamics of GHI value changes, long-term trend analysis also plays a strategic role as an early warning for policymakers and renewable energy developers to be more careful in developing planning strategies and making decisions based on solar radiation data. The use of multi-annual data with a minimum observation period of 5 to 10 years is crucial to obtain a more accurate representation of climate variation and the stability of solar energy potential in a region. This approach allows for a more precise analysis of annual fluctuation patterns, while minimizing the potential for bias caused by short-term climate anomalies such as El Niño and La Niña phenomena.

CONCLUSION

The analysis results show quite significant spatial variation, with Tangerang City, particularly the northeastern part, having the highest GHI value, while the southwestern part of Tangerang Regency shows the lowest value. A comparison between 2023 and 2024 shows a relatively stable distribution pattern, despite a decrease in the maximum GHI value of around 6.5%, which is thought to be influenced by climate and atmospheric dynamics. The integration of environmental factors such as land cover, air pollution levels, and elevation variations is an important scientific basis for explaining these distribution patterns. Further studies with long-term data are needed to understand the temporal trends in GHI changes and to support sustainable solar energy utilization planning in the Greater Tangerang area.

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