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Original article

Estimation and Analysis of Solar Radiation Components on Horizontal and Tilted Surfaces in Jadu City, Libya

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Abstract
Accurate assessment of solar radiation on horizontal and inclined surfaces is essential for the design and optimization of photovoltaic systems, solar collectors, and solar-based building applications. This study estimates the global, diffuse, and beam components of solar radiation in Jadu, Libya, using a validated mathematical model based on solar geometry and the modified Ångström-type relationship. Monthly average daily radiation was evaluated for horizontal surfaces and for tilt angles of 30°, 45°, 60°, and 90°. The results demonstrate that Jadu possesses a strong and reliable solar resource throughout the year. Global horizontal solar radiation reaches a maximum of approximately 7,848 Wh/m^2·day in July and a minimum of 3,444 Wh/m^2·day in December. The clearness index remains relatively high, ranging from 0.66 to 0.70, indicating favorable atmospheric transparency. A 30° tilt angle provides the highest cumulative annual solar yield, while steeper angles of 45° and 60° improve winter energy collection and reduce seasonal variations. Vertical surfaces exhibit an inverted seasonal pattern, with maximum radiation occurring in December, supporting their potential for passive solar heating applications. The optimum monthly tilt angle varies substantially, from approximately 9° in summer to 55° in winter. Overall, the findings confirm Jadu's suitability for solar-energy applications.
Keywords. Global Radiation, Direct, Diffuse Radiation, Horizontal, Tilted Surfaces.

Introduction

Due to developments in technology, the energy needs of modern society have increased exponentially. The sources of energy have varied according to technological progress. Historically, humanity transitioned from wood to coal, and later to oil and natural gas, ensuring continuous energy growth to meet industrial and domestic demands [1,2]. However, energy demand continues to increase annually, absorbing most of the requirements for energy development. While new technologies improve the efficiency of existing energy consumption, such as fluorescent lamps, efficient engines, improved insulation, and cogeneration in power plants, these measures only delay the inevitable depletion of conventional energy reserves.

Consequently, the global decrease in fossil fuels has catalyzed a strategic orientation towards renewable energy sources. Renewable energy, derived from natural processes that are replenished constantly, such as sunlight, wind, rain, tides, and geothermal heat, is considered the most critical energy source for the future [1, 2]. In 2008, about 19% of global final energy consumption came from renewables, with this share growing rapidly worldwide. Renewable technologies are well-suited to both large-scale power generation and small-scale off-grid applications, which are crucial for human development in rural and remote areas where millions of households rely on solar PV systems and biomass digesters [2].

Among all renewable energy resources, solar energy is the most abundant and universally usable. Driven by thermonuclear fusion converting hydrogen to helium, the Sun radiates vast amounts of electromagnetic energy [3]. Although only a tiny fraction reaches the Earth, this radiation is the indirect source of nearly all terrestrial energy and supports all life via photosynthesis. Specifically, solar energy occupies the forefront of alternative power generation through photovoltaic and solar thermal systems.

The design and performance assessment of any solar energy conversion system requires precise knowledge regarding the availability of global solar radiation and its direct, diffuse, and reflected components at the specific location of interest [4]. Libya, located on the Tropic of Cancer, is exposed to high-intensity sun rays throughout the year with long sunshine hours. On the flat coastal plains, daily solar radiation averages about 7.1 kWh/m^2/day, while in the southern regions, it reaches about 8.1 kWh/m^2/day [4]. It is estimated that if Libya utilized merely 0.1% of its landmass for solar power generation, it could produce the energy equivalent of nearly seven million barrels of crude oil per day [5,6].

Despite this vast potential, renewable energy technology remains in its early stages in Libya. Clear strategies, detailed theoretical resource assessments, and comprehensive feasibility studies are urgently needed [6]. Specifically, for cities in the Nafusa Mountains like Jadu, detailed site-specific radiation data is scarce but necessary for system sizing. Therefore, the primary objective of this paper is to estimate and analyze the various components of solar radiation in Jadu city. Several studies have evaluated solar radiation components across various geographical locations and configurations. Chandel and Aggarwal [7] investigated the total, diffuse, and direct components of solar radiation on both horizontal and inclined surfaces. Similarly, McAneney and Noble [8] analyzed and approximated daily and monthly solar radiation values on sloping planes. In a study conducted in Malaysia, Muzathik et al. [9] estimated hourly and daily global solar radiation on a horizontal plane using empirical models, validating their findings against measured data. Focusing on surface geometry, McAneney and Noble [10] evaluated the influence of tilt angle and orientation on solar radiation flux in Muscat, Oman. Furthermore, Baklouit et al. [11] employed a distinct model to estimate solar radiation intensity on horizontal and inclined surfaces in Sfax, Tunisia. Lastly, Kumar et al. [12] provided a comprehensive monthly assessment of solar position parameters in India.

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In this paper, a comprehensive solar resource assessment was performed for the target region to evaluate the intensity of solar radiation on horizontal and inclined surfaces at tilt angles of 30°, 45°, 60°, and 90°, investigating the impact of seasonal tilt variation on overall system energy yield.

Renewable energy systems and solar applications

To contextualize the importance of solar energy in Jadu, it is essential to review the broader spectrum of renewable systems and specific solar applications that could be deployed.

Solar Energy: Solar radiation provides around 1.4 kW/m^2 at the top of the atmosphere (the solar constant). With the global human power consumption standing around 18 TW, the solar energy striking the Earth (174 PW) is about 10,000 times greater [13,14]. Capturing even a fraction of this could easily avert global energy crises. Solar energy can be converted mechanically or directly into electricity, thermal heat, or chemical fuels.

Wind Energy: Wind is the horizontal movement of air driven by pressure differences caused by unequal solar heating of the Earth's surface. Coastal areas and mountainous regions often experience strong, consistent winds due to localized geography and the Coriolis force [15].

Biomass and Geothermal: Biomass utilizes organic material (plants, agricultural waste) that can be burned directly or processed into biofuel. Geothermal energy taps into the Earth's subterranean heat, harnessed for electricity generation or direct use [16-19].

Hydropower and Ocean Energy: Hydropower uses flowing water for electricity, contributing significantly to global energy matrices [20]. Ocean energy harnesses waves, tides, and thermal gradients [21].

Solar Specific Applications: The applications of solar energy are diverse and robust. Solar Water Heating systems use flat-plate collectors to transfer thermal energy to water reservoirs. Solar Photovoltaic Generation directly converts radiation into electricity utilizing semiconductor band gaps. Solar Space Heating and Cooling utilize thermal mass and absorption/desiccant cycles, potentially saving up to 95% of conventional electricity [22]. Other vital applications include Solar Crop Drying for agricultural preservation, Solar Pumping for irrigation directly aligned with peak summer transpiration rates, Solar Thermal Distillation for desalination, and Solar Natural Ventilation via thermal chimneys driven by convective buoyancy. These applications showcase how heavily localized radiation data dictates engineering viability.

Materials and Methods

Study Site Description

The study focuses on Jadu city, situated at latitude 31° 36' N and longitude 12° 02' E [23]. It is a prominent highland city in western Libya, located in the Nafusa Mountains. Jadu overlooks the Jeffara Plain to the north. Its high-altitude semi-arid climate features hot, dry summers and intense cold winters. Rainfall is sparse and highly irregular. These specific climatic and topographic characteristics necessitate precise modeling to evaluate its unique solar yield profile.

Theory and Calculation

Mathematical Modeling

The estimation of the monthly average daily global solar radiation on horizontal and tilted surfaces was conducted using a modified version of the original Angstrom-type equation. This regression model relates monthly average daily solar radiation to extraterrestrial radiation and the average fraction of possible sunshine hours [24,25]. The foundational relationship is given by the modified Angstrom equation:

$$\frac{\bar{H}}{\bar{H}_O} = a + b\left(\frac{\bar{S}}{\bar{S}_O}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where

$\bar{H}$ is the monthly average daily global radiation.

$\bar{H}_O$ is the monthly average daily extraterrestrial radiation.

$\bar{S}$ is the monthly average daily hours of bright sunshine (in hours).

$\bar{S}_O$ is the monthly average day length (in hours).

a and b are regression empirical coefficients obtained from the relationship given by Tiwari and Suneja [26] as follows :

$$a = -0.11 + 0.235\cos L + 0.323\left(\frac{\bar{S}}{\bar{S}_O}\right) \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$b = 1.449 - 0.553\,cos\,L - 0.694\left(\frac{\bar{S}}{\bar{S}_O}\right) \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

The monthly average daily extraterrestrial radiation on a horizontal surface $\bar{H}_O$ can be calculated using the following equation [27]:

$$\bar{H}_O = \frac{24I_{SC}}{\pi}\left[1 + 0.033\,cos\left(\frac{360N}{365}\right)\right]\left[\left(\frac{\pi h_{SS}}{180}\right)sin(L)\,sin(\delta) + cos(L)\,cos(\delta)\,sin(h_{SS})\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where

I_{SC} is the solar constant (1366.1W/m^2).

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L is the latitude of the city or location.
δ is the solar declination angle.
h_{SS} is the mean sunrise hour angle for the given month, and
N is the day of the year starting from the first of January as shown in (Table 1).
The solar declination angle (δ), and the mean sunrise hour angle (h_{SS}) can be calculated using the following equation [27]:

$$\delta = (23.45)\sin\left[\frac{360}{365}(N+284)\right] \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

$$h_{SS} = cos^{-1}(-tan(L)\,tan(\delta) \dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

For a given month, the maximum possible sunshine duration (monthly average day length $\bar{S}_O$) cab be computed by using the following equation [25]:

$$\bar{S}_O = \frac{2}{15}h_{SS} \dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

The monthly average of daily global solar radiation incident on a horizontal surface $\bar{H}$ is calculated by equation (1).

Table 1. Days on which extraterrestrial radiation is equal to the monthly mean value [27]

Month	Day	Day of the year	Month	Day	Day of the year
January	17	17	July	17	198
February	16	47	August	16	228
March	16	75	September	15	258
April	15	105	October	14	318
May	15	135	November	15	288
June	11	162	December	10	344

The clearness index (K_T) is defined as the ratio of the measured horizontal terrestrial solar radiation to the calculated horizontal extraterrestrial solar radiation and is calculated from the following relation:

$$K_T = \frac{\bar{H}}{\bar{H}_O} \dots\dots\dots\dots\dots\dots\dots\dots (8)$$

The monthly mean daily diffuse fraction of solar radiation is calculated by the following equation:

$$\frac{\bar{H}_D}{\bar{H}} = 1.39 - 4.027K_T + 5.531K_T^2 - 3.108K_T^3 \dots\dots\dots\dots\dots (9)$$

The beam solar radiation is calculated from the following relation

$$\bar{H}_B = \bar{H} - \bar{H}_D \dots\dots\dots\dots\dots\dots\dots\dots (10)$$

Radiation on Tilted Surfaces

Usually, collectors are not installed horizontally but at an angle to increase the amount of radiation intercepted and reduce reflection and cosine losses. Therefore, system designers need data about solar radiation on such tilted surfaces; measured or estimated radiation data, however, are mostly available either for normal incidence or for horizontal surfaces. Therefore, there is a need to convert these data to radiation on tilted surfaces.
The amount of insolation on a terrestrial surface at a given location for a given time depends on the orientation and slope of the surface.
A flat surface absorbs beam ($\bar{H}_{Bt}$), diffuse ($\bar{H}_{Dt}$), and ground-reflected ($\bar{H}_{Gt}$) solar radiation; that is,

$$\bar{H}_t = \bar{H}_{Bt} + \bar{H}_{Dt} + \bar{H}_{Gt} \dots\dots\dots\dots\dots (11)$$

$$\bar{H}_t = \bar{H}_B\bar{R}_B + \bar{H}_D\left[\frac{1+\cos\beta}{2}\right] + (\bar{H}_B + \bar{H}_D).\rho_G\left[\frac{1-\cos\beta}{2}\right] \dots\dots\dots\dots\dots\dots\dots (12)$$

The term R_B is the ratio of the monthly average beam radiation on a tilted surface to that on a horizontal surface. Actually, this is a complicated function of the atmospheric transmittance, but according to Liuand Jordan(1977), it can be estimated by the ratio of extraterrestrial radiation on the tilted surface to that on a horizontal surface for the month. For surfaces facing directly toward the equator, it is given by:

$$\bar{R}_B = \frac{\cos(L-\beta).\cos(\delta).\sin(\bar{h}_{ss}) + \left(\frac{\pi}{180}\right)\bar{h}_{ss}.\sin(L-\beta).\sin(\delta)}{cos(L).cos(\delta).sin(h_{ss}) + \left(\frac{\pi}{180}\right)h_{ss}.sin(L).sin(\delta)} \dots\dots\dots (13)$$

Where $\bar{h}_{ss}$ is sunset hour angle on the tilted surface (degrees), given by:

$$\bar{h}_{ss} = min\{h_{ss}, \cos^{-1}[-\tan(L-\beta)\tan(\delta)]\} \dots\dots\dots\dots (14)$$

Where
$\bar{H}_B$ is beam radiation on a horizontal surface (W/m^2).
R_B is called the beam radiation tilt factor.
$\bar{H}_D$ is diffuse radiation on a horizontal surface (W/m^2).
ρ_G is the coefficient of reflectivity of the earth's surface which varies 0.07 for water to 0.75 for ice, and is 0.22 for concrete [19]. In most cases an average of 0.2 is taken as in our study.

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The total radiation tilt factor (R) is calculated from the following relation:

$$R = \frac{\bar{H}_t}{\bar{H}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The theoretical optimum tilt angle is primarily based on the solar geometry models established by Liu and Jordan (1961), which suggest that the tilt should be adjusted according to the difference between the local latitude and the solar declination.

$$\beta_{Optimum} = L - \delta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Mathematical Expressions and Symbols

The mathematical expressions used for solar geometry, extraterrestrial radiation, clearness index, diffuse and beam radiation, and tilted-surface radiation are presented in the preceding modeling section. The equations are retained as native Microsoft Word equation objects from the source manuscript. Symbols are defined immediately after each expression where applicable.

Results and Discussion

The mathematical models were utilized to simulate and estimate the monthly average solar radiation components incident on horizontal, tilted, and vertical surfaces in Jadu. The results are presented as monthly average values to establish a precise analytical reference for the region's solar potential.

Regression Constants and Extraterrestrial Radiation

The input parameters for Jadu, presented in (Table 2), confirm that the declination angle varies between -23.05° (December solstice) and +23.09° (June solstice), passing through zero twice a year during the equinoxes. Jadu experiences a high percentage of sunshine duration, approximately 76% throughout the year, which serves as a highly reliable basis for calculating regression constants a and b.

Table 2. Input parameters for estimation of monthly average daily global solar radiation at Jadu

Month	$\delta°$	$h_{SS°}$	$\bar{S}$ *Hours*	$\bar{S}_o$ *Hours*	$\frac{\bar{S}}{\bar{S}_o}$
January	-20.92	76.24	7	10.16	0.69
February	-12.95	81.77	8	10.90	0.73
March	-2.42	88.5	9	11.8	0.76
April	9.41	96	9	12.79	0.70
May	18.79	102.23	10	13.63	0.73
June	23.09	105.39	11	14.05	0.78
July	21.18	103.95	12	13.86	0.86
August	13.45	98.56	11	13.14	0.84
September	2.22	91.38	9	12.18	0.74
October	-9.60	83.96	9	11.19	0.80
November	-18.91	77.69	8	10.36	0.77
December	-23.05	74.64	7	9.95	0.70

Variation of Extraterrestrial Solar Radiation

The variation in extraterrestrial solar radiation demonstrates a distinct seasonal curve. Values begin to rise after winter, peaking in mid-summer (June) at an impressive 11466 Wh/m^2-day due to the high solar altitude and extended daylight hours, as illustrated in (Figure 1). The energy levels gradually decrease toward the end of the year, reaching a minimum in December at approximately 5199 Wh/m^2-day. Despite this drop, the winter figures remain excellent, confirming Jadu's status as a natural energy reservoir highly suitable for solar installations.

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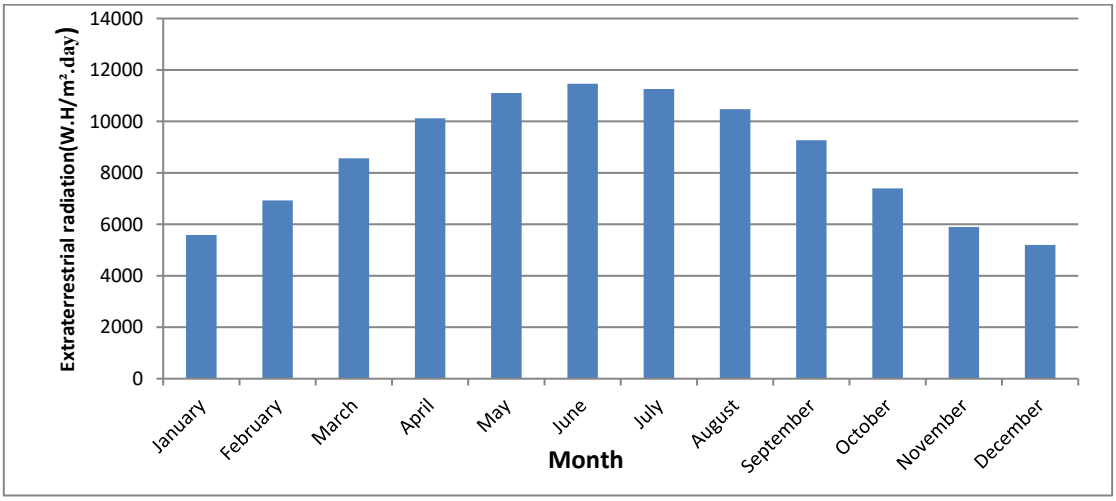


Figure 1. Monthly average daily extraterrestrial radiation on a horizontal surface

Radiation on Horizontal Surfaces and Sky Conditions

Empirical modeling of a horizontal surface reveals a typical seasonal fluctuation corresponding to solar altitude changes. Global solar radiation hits its absolute peak in July, recording approximately 7848 Wh/m^2. day, indicating exceptional radiative density. Conversely, it drops to its lowest in December at nearly 3444 Wh/m^2. day.

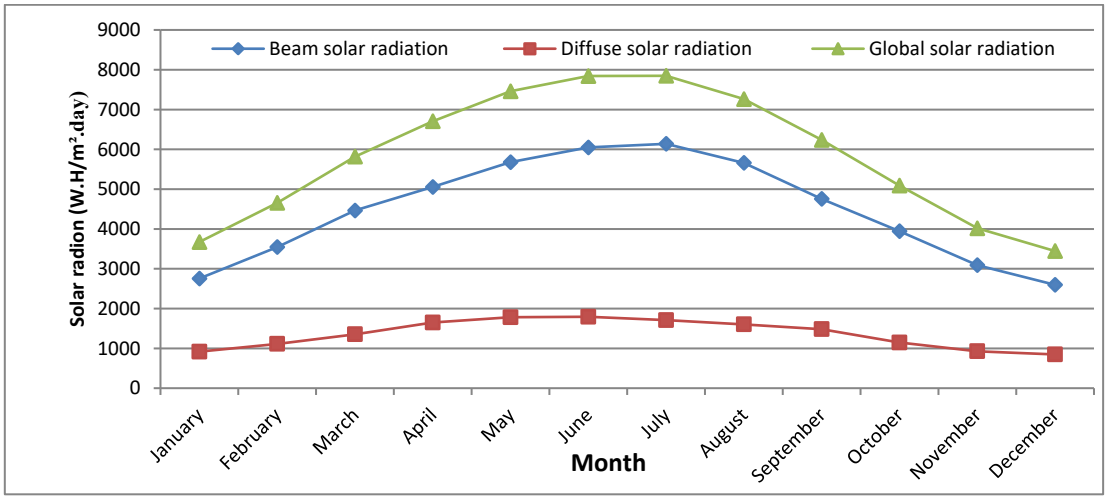


Figure 2. Monthly average daily solar radiation on horizontal surface

Beam solar radiation is the dominant driver of the global curve, accounting for more than 75% of the incoming energy during peak months like May, June, and July. Meanwhile, the diffuse radiation curve remains remarkably stable at lower values (between 847 and 1800 Wh/m^2. day), indicating that atmospheric scattering caused by clouds or particulates is minimal. This low scattering is corroborated by the Clearness Index, a pivotal parameter quantifying atmospheric transparency. In Jadu, this index consistently fluctuates within a high range of 0.65 to 0.70. It exceeds 0.66 in almost every month, signifying that over 66% of potential extraterrestrial energy penetrates to the surface. Transparency peaks in July at nearly 0.70. The fact that the sky remains fairly clear even during winter months (January and December) guarantees a high-quality, reliable solar resource year-round.

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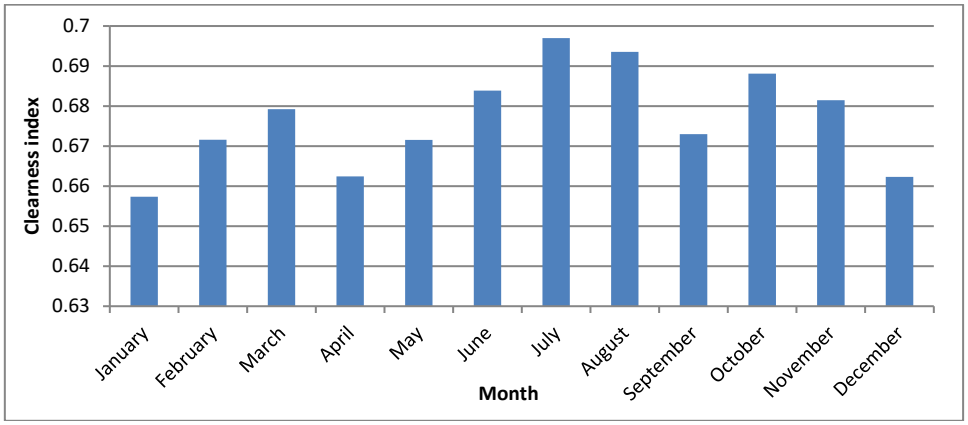


Figure 3. Monthly variation of clearness index

Variation of Solar Radiation on Tilted Surfaces

Tracking the radiation incident on surfaces tilted at 30°, 45°, and 60° reveals the physical impact of inclination on absorption efficiency. At a 30° tilt angle, the surface approaches a state of perpendicularity with direct rays during the summer maximum, thereby achieving the highest radiation yield in the mid-year months.

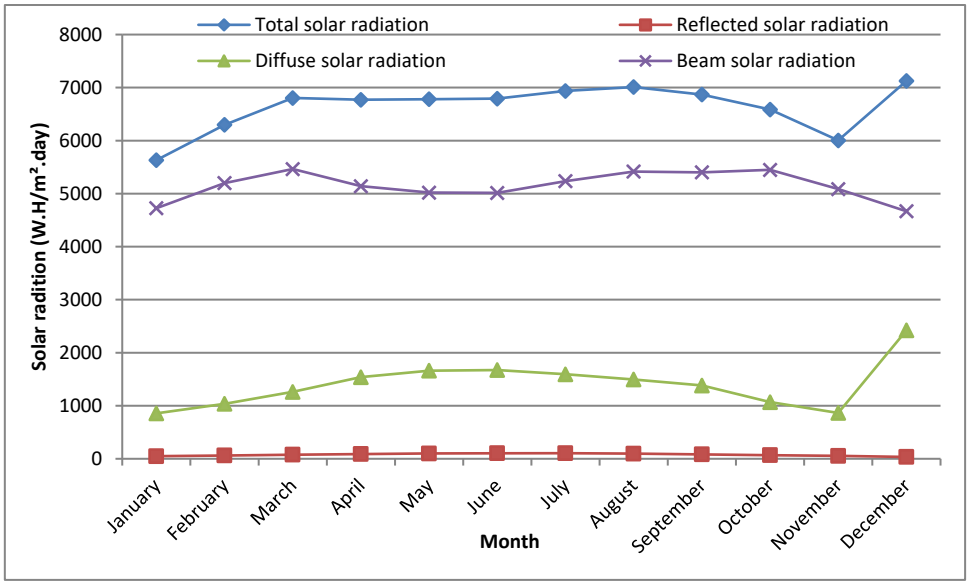


Figure 4. Solar radiation parameters on tilted surface for solar collector angle 30°

As the inclination steepens to 45° and 60°, the radiation distribution shifts. Summer peak values decline, but there is a marked improvement in energy collection during the winter months (November, December, and January).

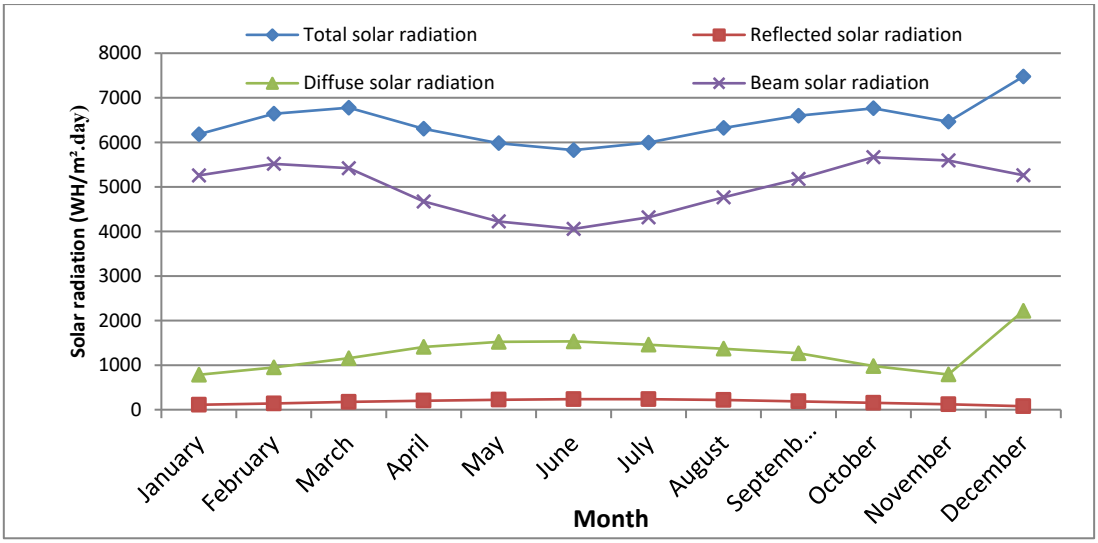


Figure 5. Solar radiation parameters on a tilted surface for a solar collector angle of 45°

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These steeper angles act as a compensatory mechanism for the low winter sun path, reducing seasonal energy fluctuation and enhancing system reliability during the colder seasons. Across all angles, diffuse radiation maintains relative stability, confirming that maximizing solar harvesting relies predominantly on capturing the sensitive direct beam component.

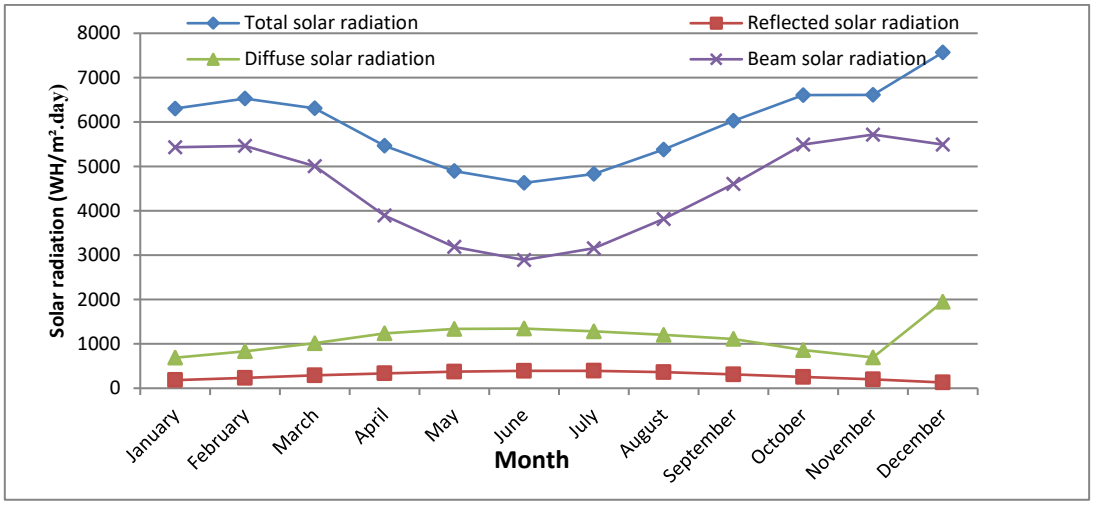


Figure 6. Solar radiation parameters on tilted surface for solar collector angle 60°

Overall, a 30° tilt emerges as the optimal engineering choice for maximizing cumulative annual production in Jadu, while higher angles are viable for flattening the seasonal supply curve.

Analysis of Vertical Surfaces

On a vertical surface (90° tilt), the radiation pattern completely inverts into a deep concave profile during summer and a sharp convex profile in winter. Solar radiation values in December significantly exceed those in June. This inversion occurs because the vertical plane sits nearly perpendicular to the low-angled solar path during the winter solstice. Consequently, a vertical orientation is perfectly suited for passive solar architectural applications, such as solar facades, to maximize winter thermal gain.

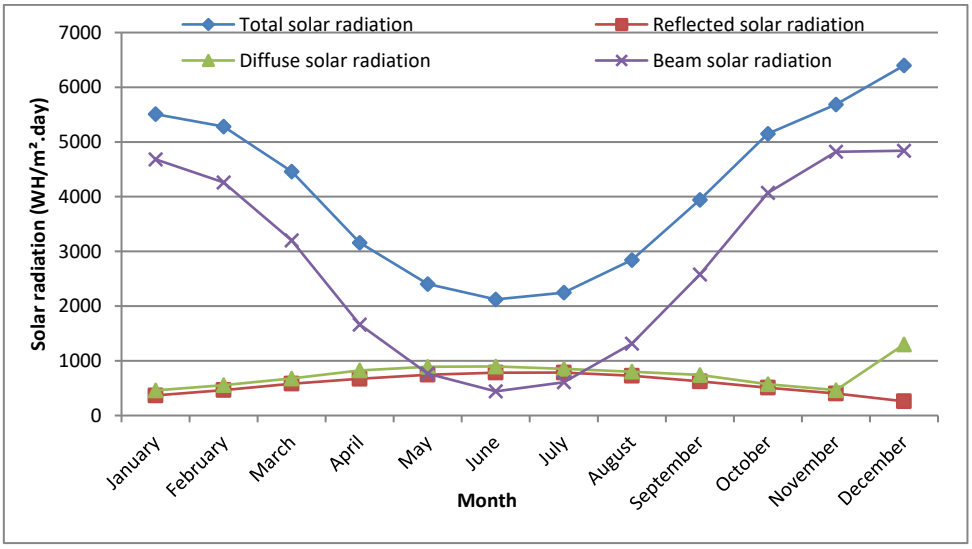


Figure 7. Solar radiation parameters on a vertical surface

Component Sensitivity to Tilt Angle

A fundamental comparison reveals that horizontal surfaces (β=0°) harvest 30% to 40% more energy during summer than steeply tilted surfaces. This behavior reverses in winter, where high angles β =60°and β =90°achieve an energy surge of up to 50% compared to horizontal placement.

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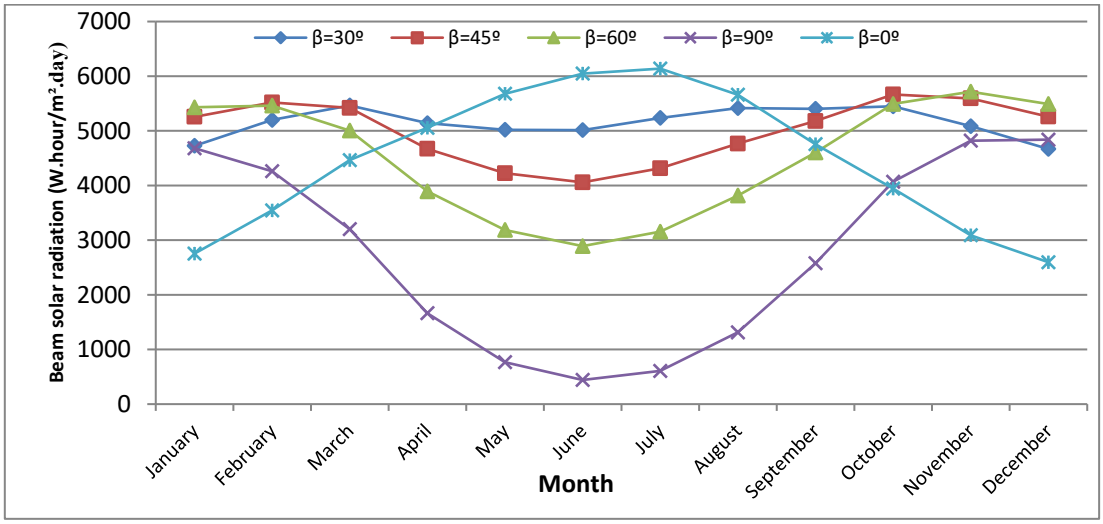


Figure 8. Effect of tilt angle of surface on beam solar radiation

For diffuse radiation, the horizontal surface is dominant due to its unobstructed 100% view of the sky dome. This exposure decreases as tilt increases, reaching its lowest point on vertical surfaces.

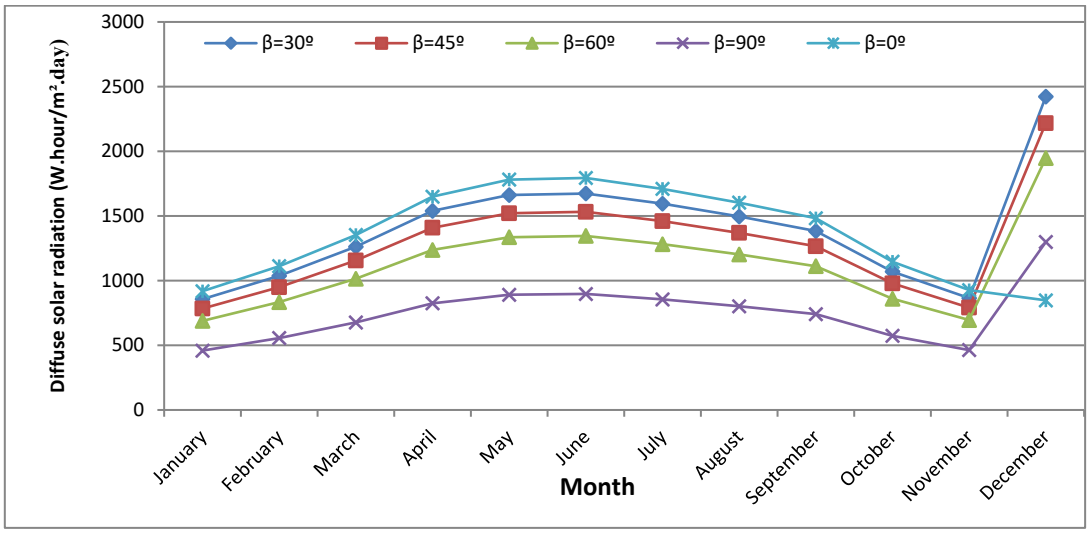


Figure 9. Effect of tilt angle of surface on diffuse solar radiation

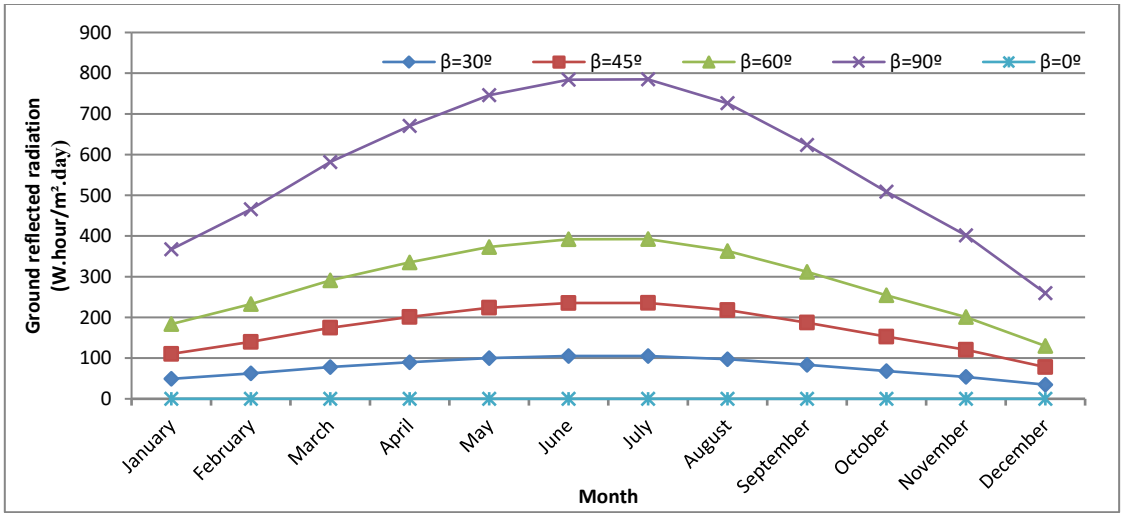


Figure 10. Effect of tilt angle of surface on reflected solar radiation

Merging these dynamics into a global radiation metric confirms that the 30° tilt angle restricts monthly energy fluctuation to no more than 15% from the annual average, striking the optimal engineering trade-off. Adjusting from horizontal to vertical fundamentally restructures the system's output, sacrificing approximately 25% of the summer harvest to secure up to a 60% gain in winter.

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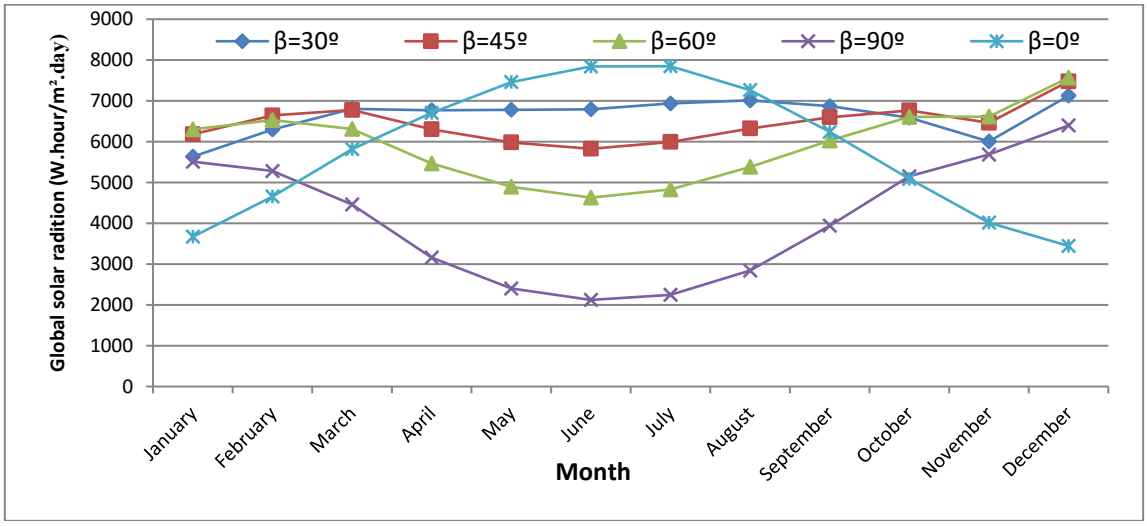


Figure 11. Effect of tilt angle of surface on global solar radiation

Optimum Tilt Angle Dynamics

The monthly optimum tilt angle exhibits a distinct V-shaped profile to compensate for the sun's seasonal apparent motion. The angle peaks in the winter months (January and December) at 53°-55° to effectively intercept the low-altitude sun. Conversely, it drops to about 9° in June as the sun nears the zenith. During equinoxes (March and September), the optimal tilt aligns closely with the local latitude, ranging from 32° to 35°. Adjusting the tilt angle monthly rather than fixing it annually minimizes incidence angles and drastically enhances the daily solar harvest in the Nafusa Mountains.

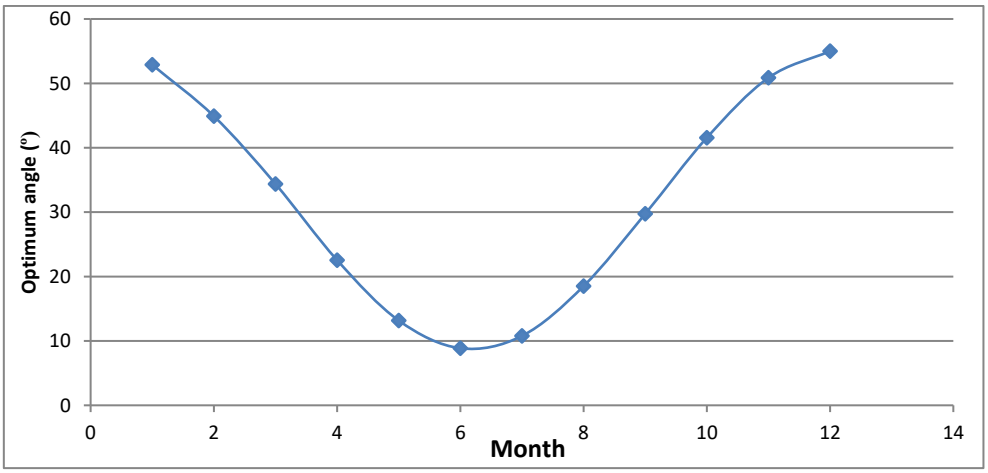


Figure 12. Variation of monthly optimum tilt angle throughout the year

Discussion

The results indicate that Jadu has a strong solar resource throughout the year, with a clear seasonal dependence on solar altitude and surface orientation. The high clearness-index range and the dominance of beam radiation during the high-production months support the suitability of the site for solar-energy applications. The finding that a 30° fixed tilt maximizes cumulative annual radiation is consistent with the physical expectation that a moderate inclination provides a favorable annual compromise between summer and winter solar geometry. The stronger winter performance observed at 45° and 60° is also important for applications where winter energy demand is significant. The inverted seasonal response of vertical surfaces further demonstrates that façade-oriented solar design should be evaluated separately from photovoltaic optimization. The main limitation of the study is that the radiation values are model-based and require comparison with field measurements before being used for bankable system design. In addition, the reported geographic coordinate notation should be verified against an authoritative GIS or surveying source before final publication.

Conclusions

Based on the mathematical modeling of solar geometry and tilt angle optimization in Jadu, the study concludes the following:

Extraterrestrial solar radiation in Jadu reaches a maximum of 11466.68 Wh/m^2-day in June and a minimum of 5199.84 Wh/m^2-day in December.

Global solar radiation on a horizontal surface peaks in July at approximately 7,848 Wh/m^2.day (indicating exceptional radiative density) and hits its lowest point in December at nearly 3444 Wh/m^2.day.

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The Clearness Index is highly stable, ranging from 0.66 to 0.70, confirming exceptional atmospheric transparency that guarantees over 66% of potential solar energy reaches the surface year-round.
A 30° tilt angle represents the optimal choice for maximizing the annual solar yield, while higher angles are strategic for ensuring performance stability and offsetting winter deficits. Diffuse radiation notably enhances the total output during December across all tilt angles.
Vertical surfaces experience an inverted radiation pattern, peaking in December and bottoming in June, making them ideal for Jadu's passive solar architecture aimed at winter thermal gain.
Horizontal surfaces dominate in summer by 40% due to beam perpendicularity, while high angles excel in winter by 50% by leveraging the low solar path.
Horizontal surfaces maximize diffuse radiation capture due to a full sky-view factor, but vertical surfaces compensate by capturing ground-reflected radiation (Albedo), which contributes up to 20% of their total energy.
Transitioning from a horizontal to a vertical tilt trades a 25% loss in summer yield for a 60% gain in winter harvest, demonstrating the necessity of aligning system tilt with specific operational loads.
The optimum tilt follows a V-shaped trend, peaking at 55° in winter and dropping to 9° in summer, while aligning with local latitude during equinoxes.

Recommendations

To further advance renewable energy adoption and research in the region, the following actions are recommended: Conduct a comparative study between the estimated mathematical results and field-measured data in Jadu to validate the models and align them with actual meteorological conditions. Initiate a technical and practical feasibility study for establishing solar thermal collectors in Jadu, optimizing efficiency based on optimum tilt angles to maximize winter thermal gain. Execute a comprehensive analysis of solar energy resources across various Libyan regions to identify optimum tilt angles and expected yields, leading to the development of a national solar radiation map. Carry out a technical feasibility study of a hybrid solar-wind energy system in Jadu, modeling the integration between solar radiation and wind speeds to overcome seasonal fluctuations and ensure a stable power supply.

Declarations

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Data Availability: The data supporting the findings are contained in the calculations and tabulated results presented in this manuscript. No public dataset was used.

Ethical Approval: Ethical approval was not required because the study involved mathematical modeling of solar radiation and did not involve human participants, animals, or personal data.

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