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Review Article

Assessment of Wave Energy Resources at Brass Coast in Rivers State, Nigeria

Dickson Festus[1], Jamu Benson Yerima[2]

[1,2]*Department of Physics, Modibbo Adama University Yola, Nigeria.*

[1]*Corresponding Author : ibwijen5@gmail.com*

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Abstract *- Wave energy is regarded as one of the most consistent and potent renewable sources due to its high energy density. The global reliance on conventional energy systems—such as coal, fossil fuels, and nuclear power—has led to an urgent need for cleaner and more sustainable alternatives. Among these, ocean wave energy presents a promising green solution. This study investigates the wave energy potential off the coast of Brass (longitude 515.130'E, latitude 518.890'N) using ten years (2014–2023) of oceanographic data, including significant wave height (Hs), peak wave period (Tm), and wave direction. Results show that Hs varies from 0 to 5 meters, with an annual average of 1.67 meters, peaking in July through September. Tm ranges between 13.14 and 20.03 seconds, averaging 18.28 seconds annually, with its highest and lowest values in August and December, respectively. The statistical probability of occurrence for Hs and Tm are 53% and 64%. Predominant wave directions fall within 206° to 209°, aligned SSW. Wave power ranges from 7.63 to 56.51 kW/m, with an annual mean of 31.42 kW/m. Seasonally, energy levels are highest in summer (47.41 kW/m) and autumn (38.02 kW/m) and lowest in winter (12.85 kW/m). The total annual wave energy with a 93.6% chance of Hs ≥ 1.5 m is estimated at 1712.1 MWh/m.*

Keywords *- Brass coast, Renewable energy, Wave direction wave energy, Wave heights.*

1. Introduction

The rising momentum in the Blue Energy sector presents valuable opportunities for fostering the sustainable development of marine-based economies and optimizing the use of ocean resources. This sector primarily operates through technologies that utilize ocean wave and thermal energy, which are increasingly being recognized as practical alternatives to conventional fossil fuel power generation. Among these approaches, wave energy has gained prominence due to its availability, renewability, and potential to enhance energy stability and environmental sustainability [4]. Moreover, ocean waves' inherent consistency and predictability position wave energy as a more dependable power source than other intermittent renewables such as wind and solar [15].

The enhancement of wave energy converter (WEC) systems significantly depends on ongoing innovation and experimental development. A broad spectrum of marine energy technologies—including offshore wind farms, wave and tidal energy systems, current-driven turbines, ocean-based solar installations, and OTEC—are engineered to extract and convert marine energy into electrical power. Crucial to optimizing their performance is the rigorous assessment of site-specific wave parameters, particularly wave elevation, periodicity, and propagation direction [4].

This research emphasizes coastal nations such as Nigeria, which boasts a lengthy Atlantic coastline and numerous internal waterways. Despite this significant potential, marine renewable energy sources (MRES) are still underdeveloped in Nigeria, where fossil fuel remains the dominant energy source [16].

In 2023, the Nigerian government inaugurated the Ministry of Marine and Blue Economy to advance the responsible exploitation of marine assets and to tap into the blue economy as a driver for economic diversification. The ministry's mandate includes the development of strategic sectors such as aquaculture, marine-based biotechnology, offshore renewable energy systems, desalination infrastructure, and maritime logistics. One of its core initiatives involves promoting clean energy solutions like wave energy to minimize fossil fuel usage and enhance energy access for coastal regions with limited infrastructure [2].

Many riverine communities, particularly those in the Niger Delta, remain unconnected to the national electricity grid and instead rely on diesel-powered generators. These systems are costly and pose environmental risks through emissions and fuel leaks. In contrast, wave energy offers a cleaner and more reliable energy source that could help electrify these areas while reducing carbon footprints and mitigating the ecological harm of oil exploitation [3]. Previous research also highlights how wave energy can aid in curbing greenhouse gas emissions and support improved energy access across coastal regions of Africa [5].

Fossil fuel exploration in Nigeria has long been associated with adverse environmental consequences, including repeated oil spills that harm ecosystems and disrupt local livelihoods. Integrating wave energy into the nation's energy mix offers a path to lessen dependence on hydropower—which is vulnerable to climatic conditions such as droughts and floods—and to develop a more resilient and environmentally sustainable power system [9]. Conducting wave energy resource assessments is crucial to evaluate the viability of applying wave-based technologies at specific coastal sites.

One promising location is Brass Creek in Rivers State, where consistent wave patterns and its shoreline position make it a suitable candidate for wave energy installations. An in-depth investigation of wave behavior—such as height, period, and direction—at this location will yield vital data for assessing its energy generation capacity and inform the structural design of energy systems [17]. This research presents a viable response to some of Nigeria's pressing energy and ecological challenges. The findings from Brass Creek's wave analysis are expected to enhance understanding of the site's potential, paving the way for future investments and strategic policies in marine-based renewable energy.

Currently, more than 90% of the communities situated along the coastal areas of the Niger Delta remain without access to the national electricity grid [17]. Their main source of electricity comes from diesel generators supplied by oil companies. However, these generators often face operational issues due to a lack of maintenance or inconsistent diesel availability.

Additionally, diesel used by these companies to power their equipment frequently results in significant oil spills. Such environmental pollution negatively affects fishing and agriculture, contaminates water sources, and can trigger outbreaks of waterborne diseases, especially without proper healthcare facilities [18]. These challenges further contribute to regional problems such as rising unemployment, oil theft, and insecurity. Since the region lies entirely along the Atlantic Ocean, harnessing wave-based renewable energy offers one of the most practical and dependable approaches to addressing energy instability. While global interest in this field continues to grow, Nigeria has yet to significantly engage in wave energy utilization despite the progress already made by other developing nations. Although research into wave energy is ongoing worldwide, its practical implementation in Nigeria remains minimal. As this coastal zone plays a critical role in the nation's economy, there is a pressing need to explore wave energy for national development [19]. This study was therefore initiated to evaluate the wave energy potential of Brass Creek in Rivers State, Nigeria.

2. Materials and Method

2.1. Study Area

The evaluation takes place at Brass Creek, located in Rivers State, Nigeria, within the Gulf of Guinea and adjacent to the Atlantic Ocean. The site is positioned at approximately 518.8900N and 515.1300E and lies about 0.39 nautical miles from the shoreline. The site's proximity to the Atlantic makes it ideal for wave energy research.

Fig. 1 Map of the study area (Brass Creek River)

2.2. Wave Data

The oceanographic data used in this study was sourced from "The Nigerian Institute for Oceanography and Marine Research (NIOMR)". This dataset provides a solid foundation for analyzing the study area's wave climate characteristics, including significant wave height (defined as the average height of the largest one-third of waves), wave direction, and the zero-crossing wave period.

3. Theory

3.1. Wave Power Estimation

Recent studies in wave energy resource assessment focus on wave power density as a crucial parameter, generally derived by integrating spectral models from numerical wave simulations [20]. When estimating wave power density, factors such as shoaling, refraction, bottom dissipation, and the proximity of coastlines or islands are incorporated, particularly in shallow or medium-depth nearshore waters [10]. As a result, the wave energy density E (J/m²) is expressed by [8].

$$E = \frac{\rho g H_s^2}{16} \tag{1}$$

The expression for wave power per unit length of the crest in deep water conditions can also be derived in a different form, as detailed in [20].

$$P = \frac{\rho g^2 H_S^2 T_e}{64\pi} \quad (2)$$

The equation utilizes ρ to represent seawater density (1025 kg/m³), *g* as the standard gravitational acceleration (9.81 N/kg), Hs for the significant wave height in meters, and Te as the energy period in seconds. When the peak wave period (Tp) is known, Te may be calculated through Equation (3), as indicated in Table 1.

$$T_e = \alpha T_p \quad (3)$$

The value of the coefficient α is determined by the specific shape of the wave spectrum. Likewise, the energy period of the wave, Te is closely related to the zero-crossing period, Tz, as outlined in [3].

$$T_e = \beta T_z \quad (4)$$

A fixed value of 1.3 is used for β in this analysis. This equation supports a comprehensive study of significant wave height distribution relative to the zero-crossing and energy periods within the study timeframe. When Te is missing, but Hs, Tm, and Tz are known, β can be derived from the gradient of a Tm vs Tz plot, allowing for the estimation of Te. The zero up-crossing period (Tz) connects the mean wave period with the energy spectrum through the equation Tm = *1.09Tz* [29; 30]. As summarized in Table 1, researchers have also related Te to Tp through the coefficient α, which varies with the spectral profile.

$$P = \frac{1.15\rho g^2 H_S^2 T_m}{64\pi} \quad (5)$$

Table 1. Values of α by different authors

Alpha (α)	Author(s)
0.80	[24]
0.86	[33]
0.90	[1; 26]
0.29-1.50	[31; 23]
1.09	[30; 32]

Furthermore, the cumulative wave energy retained within a specific unit area is quantified as described by [21].

$$E_w = P t_h \quad (6)$$

The symbol t_h signifies the total number of hourly records in a calendar year, typically taken as 8,766 hours. This parameter was used to compute the mean wave energy density, power density, and total wave energy per unit area by applying Equations (1), (5), and (6), respectively.

3.2. Wave Energy Resource

Equation (5) assesses the total wave energy potential at the extraction site by analyzing the temporal distribution of significant wave height (H_s) and peak period (T_p) [9], while equation (14) estimates annual wave energy density for the study area [20, 12, 24, 28]. Table 2 provides the decadal average occurrences of H_s–T_p pairs, presented in a wave scatter diagram to capture seasonal variability. The recoverable energy (E_t) is obtained by multiplying the mean yearly wave power ($P^a{}_v$) by t_h—equivalent to 8,766 hours annually—as shown in equation (7) [21].

$$E_T = P_{av} t_h \quad (7)$$

4. Results and Discussion

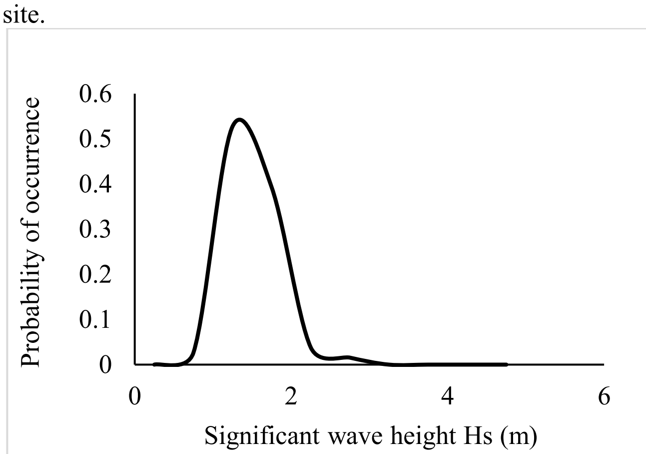
4.1. Sea-Wave Short-Term Delineation

Table 2. Wave scatter table from satellite oceanographic data parameters for the Brass Creek River (2014-2023)

H_s (m)	Mean wave energy period T_m (s)								
	<5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	No. of hours
5.0-4.5	0	0	0	0	0	0	0	0	0
4.5-4.0	0	0	0	0	0	0	0	0	0
4.0-3.5	0	0	0	0	0	0	0	0	0
3.5-3.0	0	0	0	0	0	0	0	0	0
3.0-2.5	1	9	165	1182	0	0	0	0	1357
2.5-2.0	0	23	987	2202	129	0	0	0	3341
2.0-1.5	0	187	5045	22443	3964	971	0	0	34410
1.5-1.0	0	98	9621	30102	5534	854	2	0	46211
1.0-0.5	0	37	245	954	1046	21	0	0	2303
< 0.5	0	0	0	0	0	0	0	0	0
No. of hours	1	354	16063	56883	10673	1846	2	0	87622

This research investigates Brass Creek River's wave conditions and energy resources. Table 2 illustrates the Dispersion of energy within the spectrum of wave occurrences Derived from the extracted significant wave height (H_s) ranging from 0 to 5 meters and their associated mean wave-peak period (T_m) ranging from 0 to 40 seconds. It also presents the frequency of wave occurrences across different intervals of both H_s and T_m over a period of 10 years or 87,622 hours of study.

The results indicate that no wave occurrences were recorded for H_s values greater than 3.0 meters or less than 0.5 meters, nor T_m values exceeding 35 seconds. Therefore, wave occurrences are mostly confined within $0.5 < H_s < 3$ meters and $0.5 < T_m < 35$ seconds. The highest frequency of wave occurrences, totalling 46,211 events, falls within the $1.0 < H_s < 1.5$-meter range. Similarly, the maximum number of occurrences in terms of T_m, which totals 56,883 events, is observed in the $15 < T_m < 20$-second range. Table 2 provides an in-depth overview of the site's wave climate, offering essential insights for engineers or designers aiming to build a wave energy converter capable of optimal performance at this site.



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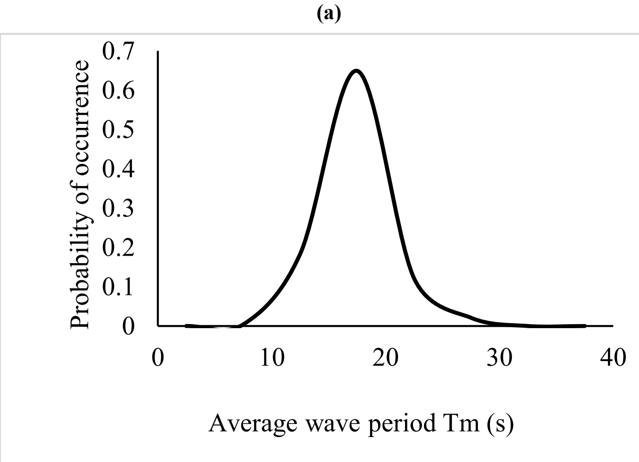
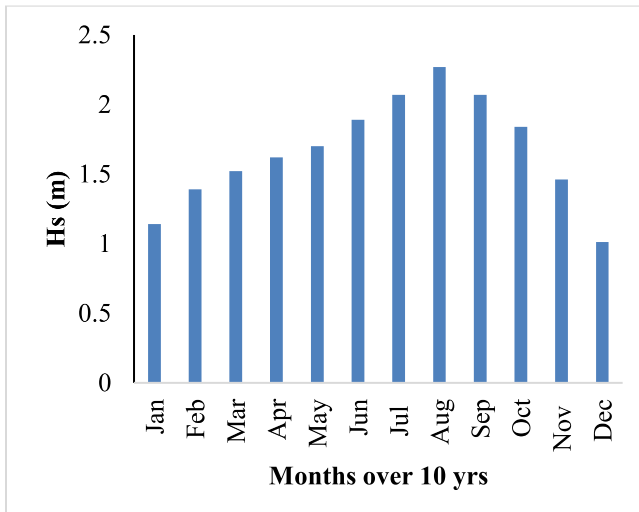


(b)

Fig. 2 Probability of occurrence at Brass Creek River for 10 years for (a) wave average Period (b) significant wave height

Table 2 contains data collected over a decade (2014–2023) and provides a systematic breakdown of wave occurrence frequencies within specific intervals of significant wave height and mean wave period at Brass Creek River. This dataset serves as a foundation for estimating the probability of wave events within these defined ranges. The table details the total number of wave occurrences observed for each interval of significant wave height and mean wave period over a recorded timeframe of 87,622 hours. The probability of wave occurrence within a given significant wave height range is determined by dividing the number of hours when those waves occurred by the total number of study hours. Likewise, the probability of occurrence for specific mean wave period intervals is computed by the ratio of hours corresponding to those waves to the overall observation time. Figures 2a and 2b depict the probability distributions for (a) significant wave height and (b) mean wave period during the 10-year observation period. The outcomes show a 53% chance for significant wave height and a 64% chance for the mean wave period, suggesting that the mean wave period has a greater impact on wave occurrences in this area



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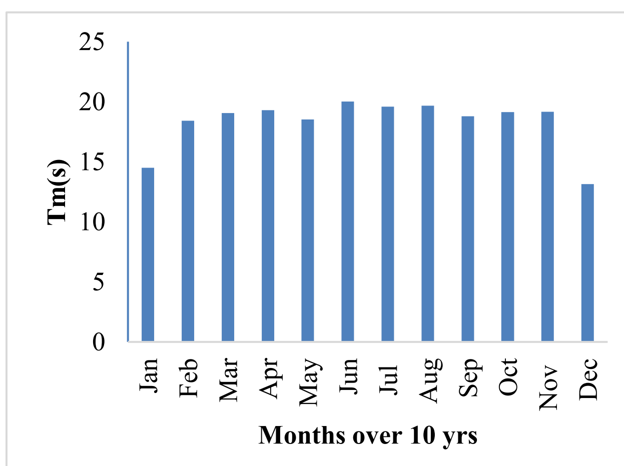

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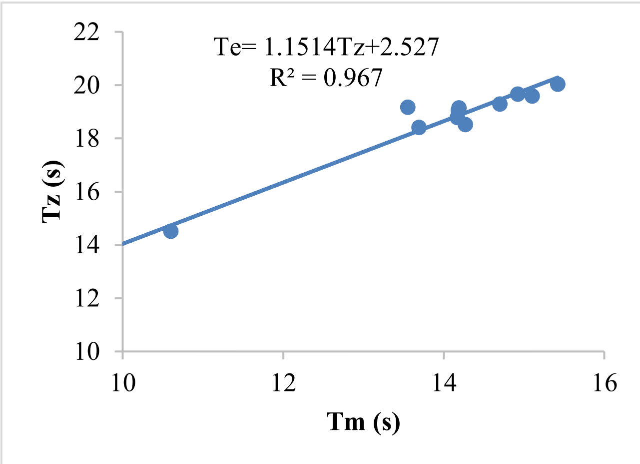


(c)

Fig. 3 Average (a) H_s vs month, (b) T_m vs month, and (c) T_z vs T_m in Brass's coastal area

Figures 3a and 3b illustrate the A decadal analysis (2014–2023) of marine wave parameters, specifically the significant wave height (H_s) and average wave period (T_m), while Figure 3c demonstrates the correlation between the zero-crossing wave period (Tz) and T_m over time.

On a seasonal scale, the peak values of H_s are recorded between May and October, ranging from 1.01 to 2.27 meters, with an average annual value of 1.67 meters. The highest values are observed in July, August, and September. As seen in Figure 3a, H_s follows a rising trend from January to August and then gradually declines until December.

This pattern suggests that wind intensity in the Brass Creek River is strongest in August, increasing from January through August and then tapering off by December, mirroring trends reported in the South Atlantic Ocean [1,34,11]. In contrast, T_m varies between 13.14 and 20.03 seconds, with an annual mean of 18.28 seconds, peaking in August and hitting its lowest point in December. Unlike the trend in H_s (Figure 3a), the T_m mode in Figure 3b does not exhibit the same increasing and decreasing seasonal pattern.2.2 Sea-wave long-term delineation.

Table 3 presents the mean sea-wave conditions based on Hs and Tm, and the wave rose is displayed in Figure 4. It clearly shows how significant wave heights (Hs) are distributed based on their average directional occurrence (θ_m) at the Brass Creek site. The findings reveal that most waves come from directions between 206° and 209°, which aligns with the South-Southwest (SSW) direction. This suggests that the dominant wave activity is from the SSW, indicating influence by long-fetched ocean swells from the South Atlantic Ocean and the steady wave-generating system that impacts the area. The significant wave heights primarily range from 1.4 m to 2.2 m, with a few instances going beyond 2.2 m. This indicates that the site experiences a mix of moderate to relatively high wave activity, making it suitable for marine applications like wave energy harvesting. Smaller waves, measuring between 1.0 and 1.4 m, are less common. Including compass labels (N, NE, E, SE, S, SW, W, NW, etc.) in Figure 4 improves its readability and helps to visualize the geographic orientation of wave directions. The narrow directional spread points to a stable wave climate, which is advantageous for planning and installing marine structures.

Table 3. Average monthly significant wave height H_s(m), significant wave height squareH_s^2(m^2), mean wave direction. θ_m (°), zero mean period $T_z(s)$, mean wave energy period $T_m(s)$, mean power, $P_w(kW/m)$ and mean wave energy density, E_w (MWh/m) for the Brass Creek River over 10 years

Month	Mean monthly wave resource parameters						
	$H_s\ (m)$	$H_s^2\ (m^2)$	$\theta_m\ (o)$	$T_z(s)$	$T_m(s)$	$P_w(kW/m)$	$E_w\ (MWh/m)$
Jan	1.14	1.38	208.81	10.60	14.51	11.13	866.66
Feb	1.39	1.96	207.08	13.69	18.41	19.79	1232.97
Mar	11.52	2.34	206.58	14.18	19.05	24.19	1469.47
Apr	1.62	2.67	208.32	14.70	19.29	28.18	1677.24
May	1.70	2.92	207.19	14.27	18.52	29.77	1832.33
Jun	1.89	3.59	206.07	15.42	20.03	39.51	2253.06
Jul	2.07	4.30	208.26	15.10	19.59	46.20	2702.05
Aug	2.27	5.26	207.34	14.92	19.66	56.51	3303.40
Sep	2.07	4.41	206.21	14.17	18.79	45.33	2768.13
Oct	1.84	3.49	208.35	14.19	19.15	36.40	2189.88
Nov	1.46	2.51	207.68	13.55	19.17	32.33	2045.44
Dec	1.01	1.06	206.02	9.34	13.14	7.63	662.62
Annual mean	1.67	2.99	207.33	13.68	18.28	31.42	1916.85

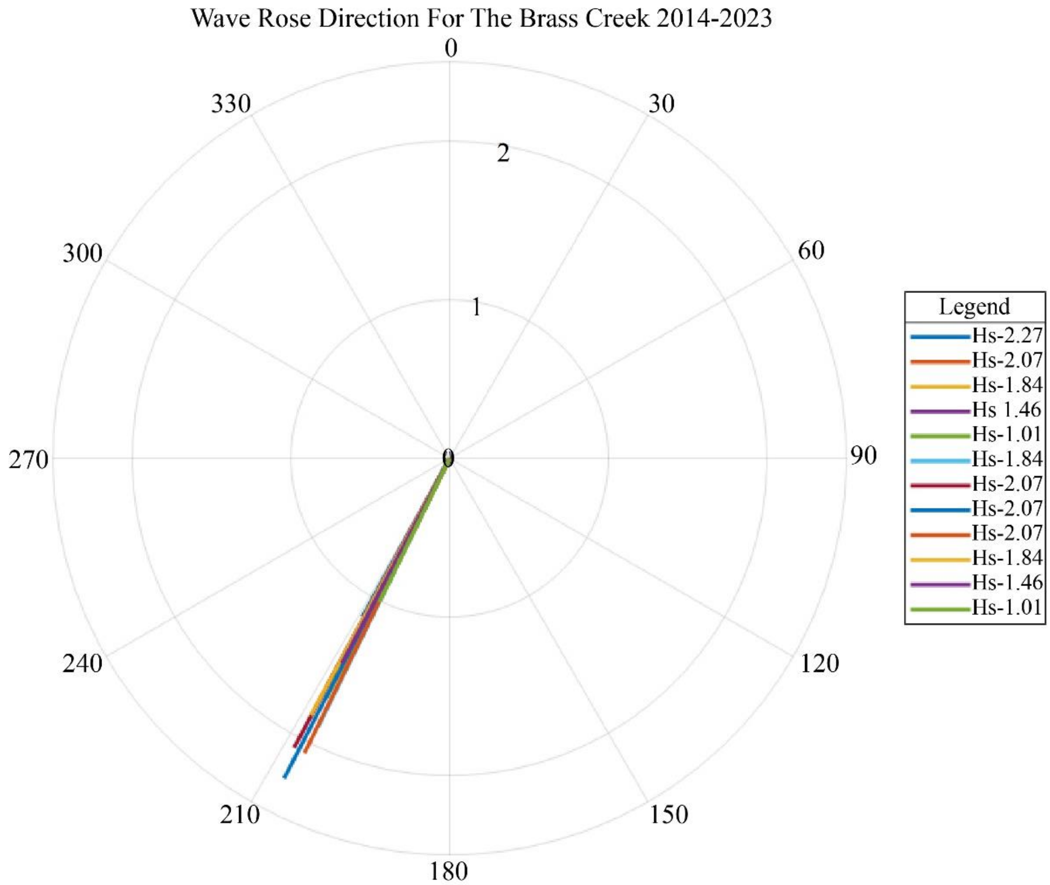


Fig. 4 Table 3 illustrates the directional distribution of wave activity from 2014 to 2023 along the Brass coastal zone, visualized through a compass rose derived from oceanographic data

5. Wave Energy Potential Assessment in Brass Coastal Area

5.1. Annual Wave Energy Variability

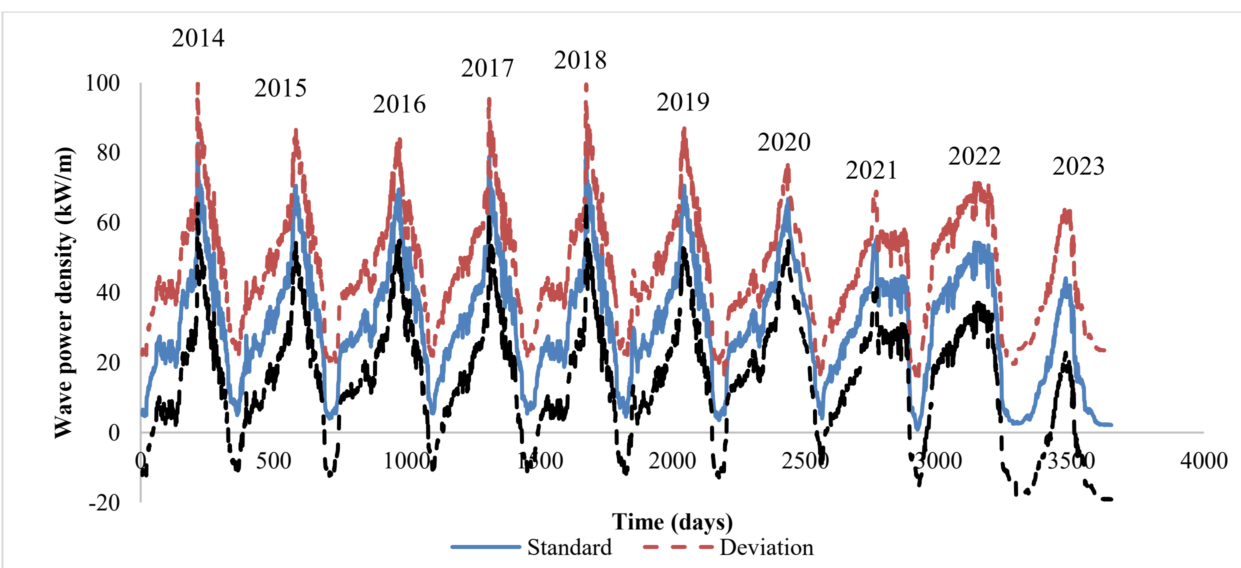
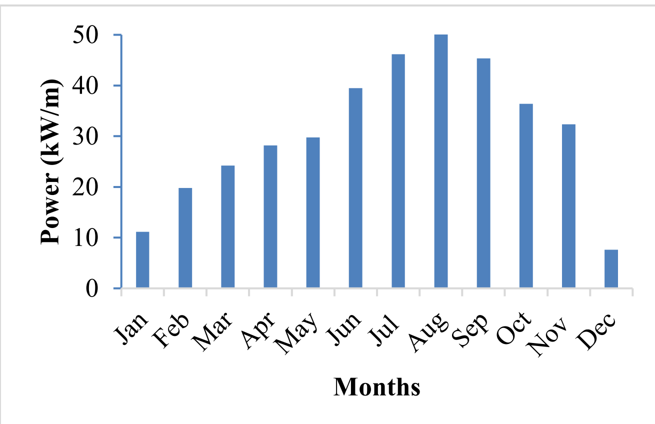


Fig. 5 The ten-year trend of mean annual wave power (2014–2023) is illustrated in Figure 5, with dashed lines denoting the variability through standard deviation

Figure 5 illustrates the annual mean wave power variability over a decade (2014–2023), calculated based on equation (5), accounting for the full spectrum of wave conditions. Standard deviations of the yearly power estimates are shown using dashed lines. Several researchers [1,11,7,13] have documented the occurrence and trend of wave power with respect to global average wave energy [27]. Their findings suggest that energy estimates made under medium-water depth assumptions often deviate from those obtained under deep-water conditions. When compared to global datasets, the current findings show strong alignment. According to global wave energy distribution maps, the Brass Creek region exhibits deep-water wave power values ranging between 7.6 and 56.5 kW/m.

5.2. Seasonal Wave Power Variability



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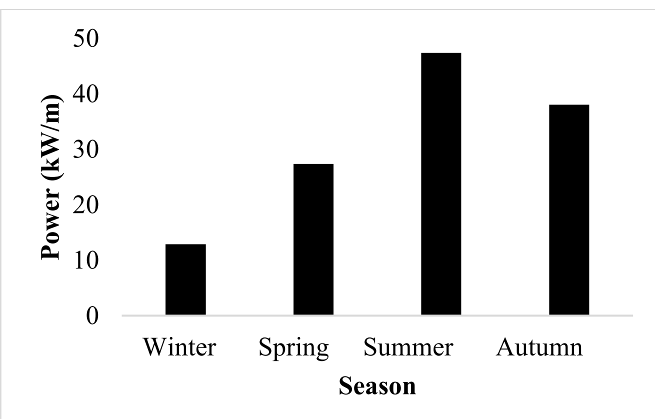

(b)

Fig. 6 Illustrates Brass Marine's average wave power density: (a) on a monthly scale and (b) for each seasonal period

Seasonal dynamics exert a dominant influence on wave energy characteristics in the Brass Creek River. As illustrated in Figure 6a, the mean wave power (P), calculated using equation (5) over the period 2014–2023 and incorporating all wave conditions, exhibits a pronounced seasonal fluctuation. The power steadily increases from January to a peak in August, then declines through December, with values ranging from 7.63 to 56.51 kW/m and an annual average of 31.42 kW/m. This pattern largely mirrors the seasonal variations in significant wave height reported by [8]. Notably, wave power drops below the annual average during December and January, whereas higher values persist from March through November, underscoring distinct seasonal variability in the region's wave energy. Figure 6b presents the seasonal average wave energy for the four climatological seasons, revealing higher energy availability in summer (47.41 kW/m) and autumn (38.02 kW/m) compared to spring (27.38 kW/m) and winter (12.85 kW/m). Consequently, the summer and autumn months emerge as the most favorable for wave energy exploitation. This observed trend aligns with global patterns, where average wave power is generally. In January, the measurement is below 11 kW/m, but by August, it reaches a range of 11 to 22 kW/m [22, 33].

5.3. Wave Energy Resource in Brass Coastal Area

Table 4. Wave energy resource in Brass coastal area

Average annual wave energy density (kW/m)	Probability of exploitable SWH (m)	Annual wave energy storage (MWh/m)	Status
8.7	96.2% (H_s≥1.0 m)	760.6	Available
19.5	93.6% (H_s≥1.5 m)	1712.1	Available

Probability calculations, for H_s≥1.5 m, $p(H_s \geq 1.5\text{ m}) = \frac{46211\times100}{87622} = 93.6\%\ and\ for\ H_s \geq 1.0\text{ m}, \text{p}(H_s \geq 1.0\ m) = \frac{48514\times100}{87622} = 96.2\%$. These values show that 96.2% of the recorded wave heights are at 1.0 m while 93.6% are at 1.5 m, indicating strong wave energy potential at the year site.

Total wave energy, which refers to the aggregate energy content of waves, is a fundamental criterion for assessing the energy-generating capacity of specific marine settings [32]. The concentration and spatial availability of wave energy directly influence site selection for the placement of wave energy converters or power stations. According to established thresholds, wave energy becomes technically viable when the power density (P) meets or exceeds 2 kW/m, and it is considered abundant when it surpasses 20 kW/m [21, 27]. Energy accumulation per unit surface area was determined to evaluate the practical wave energy potential. The average yearly wave power density (Pav) was calculated through equation (5), and the corresponding data is provided in Table 3.

The Brass coastal area, positioned at 515.130' E and 518.890' N, was the focus of a comprehensive study on wave energy potential, drawing on data collected over ten years

(2014–2023). The findings indicate that the study area experiences moderate to relatively high levels of wave activity, suggesting a promising outlook for energy exploitation. The seasonal modulation of wave energy is primarily driven by the influence of waves propagating in a clockwise direction from the south-southwest (SSW), with peak intensities typically recorded between June and November. The seasonal wave power values vary substantially, ranging from 7.63 to 56.51 kW/m.

Furthermore, the annual cumulative wave energy storage per meter of wave front has been estimated at approximately 1712.1 MWh/m. According to the analysis in Table 4, the probability of encountering wave conditions with a significant wave height (Hs) equal to or greater than 1.5 m is 93.6%, reinforcing the site's reliability for sustainable wave energy extraction.

Wave energy represents a valuable supplementary renewable energy source whose exploitation enhances national energy autonomy and contributes significantly to environmental sustainability and national security. This investigation constitutes, to the best of our knowledge, This investigation stands out as an early effort to harness long-term marine data for understanding wave variability over time and estimating the region's wave energy resources. A key contribution is the revelation of an energy system marked by moderate to high wave strength. It offers strategic insight for guiding future decisions regarding deploying marine energy infrastructure and developing wave-powered systems within the area.

6. Conclusion

This study demonstrates that the Brass Coast in Rivers State, Nigeria, possesses substantial wave energy potential, as evidenced by a decade of oceanographic data analysis. The site is characterized by moderate to high significant wave heights and favorable wave periods, with annual mean wave power density reaching 31.42 kW/m and seasonal peaks observed during summer and autumn. The prevailing wave direction aligns with the Atlantic swell, further supporting the site's suitability for wave energy extraction. The high probability of occurrence for significant wave heights above 1.5 m (93.6%) underscores the reliability of the resource. These findings highlight the Brass Coast as a promising location for wave energy development, which could help address energy access challenges in coastal communities and support Nigeria's transition to renewable energy. Further research should focus on pilot project deployment and techno-economic assessments to facilitate the practical implementation of wave energy technologies in the region.

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