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الصفحة	فهرس البحوث	ت
18 -1	The impact of social, economic and health factors on the employment of the elderly in the center of Amara district Wisam A. Dargal	1
40 - 19	Designing drugs by molecular docking to inhibit COVID-19 Abbas Kareem , Bahjat A. Saeed	2
53 - 41	Hexagonal Boron Nitride synthesis, its applications in dentistry and cytotoxicity: A literature review Al-Safa Malik Jaseim , Faiza Mohammed Hussain Abdul-Ameer	3
74 - 54	Racial Capitalism and the Architecture of Captivity in Colson Whitehead's The Underground Railroad Ibraheem Ajeel Dakhil	4
88 - 75	The Relationship between Linguistic Intelligence and Academic Achievement in Reading Comprehension among Students of English Department Dijla Abbood Shareef Al-Turfi	5
97 - 89	Sea Wave Energy Estimating in front of the Iraqi Coast, Northwest Arabian Gulf Adel Jassim Al-Fartusi , Sajjad k. Chasib	6
107 - 98	Reservoir Property Evaluation of the Mishrif Formation Using Integrated Petrophysical Analysis, West Qurna-1 Oilfield Zahraa Sh . Al-Maliki , Muwafaq F. Al -Shahwan	7
115 - 108	The Role of Molecular Biology in Cancer Treatment: Advances, Applications, and Future Perspectives Ali Isam Najm	8
127 - 116	Study of Morphometric Tectonic Indicators of the Wadi Al-Hay Basin in the Najaf desert using GIS data Latif Jabbar Farhan	9
140 - 128	Environmental Assessment of the Water of Haditha Dam and Reservoir for the Period (2023–2024) Using the Canadian Water Quality Index (CCME-WQI) Rajaa Kadhim Mutar	10
161 - 141	The Extent of Primary School Mathematics Teachers' Knowledge of Constructivist Teaching Skills from Their Perspectives Noor Ali Abdul Karim , Anwar Sabah Abdul-Majid	11
181 - 162	The Effectiveness of Teaching Based on Visual Interpretive Thinking in Developing Aesthetic Awareness among Art Education Students Mohsin Hameed Malik	12
198 - 182	Problems of Reliance on Lexicons in Linguistic Criticism: A Diachronic Study Murtadha Hamdan Ajib	13
214 - 199	The Integration of Artificial Intelligence and Public Relations:An Analytical Study of AI Use in Communication Messages to thePublic Aqeel Tahseen Fathallah , Ali Muhanad Hamid , Osama Kareem Rasheed	14

232 - 215	Mechanisms of domination and representations of resistance in contemporary Libyan narrative: A cultural approach to Najwa Bin Shatwan's novel, (Slave Pens). Raad Huwair Sweilem	15
243 - 233	logical analysis of the skeptical concept of faith Jabbar Nasser Yousef	16
260 - 244	The United States' Entry into World War I and Its Impact on U.S -Canadian Relations (1917-1918). Jawad Kadhil Dakhil , Ammar Khalid Ramadan	17
268 - 261	The Relationship Between Image Reading Skills and Visual Perception Among Students of the Art Education Department Fatima Jabbar Hussein	18
287 - 269	The significance of Ilm al-Rijāl and its connection with the Hadith sciences. Abbas Jassim Nasser	19
308 - 288	The Effectiveness of the Think Silently Strategy on Academic Achievement and Science Process Skills among First-Grade Intermediate Students in Biology Ali Jabbar Yaseen	20
328 - 309	Performance in Contemporary Plastic Art ,as an Evolutionary Manifestation of Perspectival Representation Zahraa Mahood Mohammad	21
359 - 329	Future Thinking and Professional Agency as Predictors of Academic Transition Shock among Newly Appointed University Instructors Seenaa Ahmed Ali	22
371 - 360	The Effect of an Educational Program Based on the Van Hiele Model on Developing Visual Culture of Contemporary Arts among Students of the Art Education Department Hussein Rishk Khدير	23
394 - 372	Geographical Factors and Their Impact on the Cultivation of Field Crops in Misan Governorate Sahar Rami Eidan	24
416 - 395	Intellectual Reform in the First Hijri Century (The Protest of the Companions in Defense of the Legitimacy of the Caliphate of Imam Ali Ibn Abi Talib (peace be upon him) in 11 AH/632 CE as a Model) Fatima Abd Saeed Al-Maliki	25

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Sea Wave Energy Estimating in front of the Iraqi Coast, Northwest Arabian Gulf

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Abstract:

The world is turning to alternative energies (wind energy, solar energy, and seawater energy) as eco-friendly and renewable energy. The monthly and seasonal averages of the sea wave energy (i.e., total and characteristic wave energy) were studied in the northwest Arabian Gulf in front of the Iraqi coast in the OUTER BAR. A mathematical analysis was conducted for 3560 wind speed values (2015-2024). The results showed that the total energy of the sea wave was limited between the two values 55.42 and 581.19 (Joules/m²), while the characteristic wave energy was restricted between 102.09 and 2855.87 (Joules/m²). Also, the seasonal wave energy is within the range of 73.84 - 423.53 (Joules/m²), and the seasonal wave energy median is within the range of 116.87-1579.21 (Joules/m²). The standard

deviation value σ was also determined, which reflects the extent of energy dispersion around the seasonal peak. The results may provide future insights into how sea structures and barriers are built when these calculations are used appropriately.

Keywords: Northwest Arabian Gulf, significant wave energy, wave energy, wave characteristics.

1. Introduction:

Excessive energy consumption and greenhouse gas emissions have contributed to increased global warming. The world primarily relies on nonrenewable energy resources, such as oil, gas, and coal. However, it is currently studying alternatives such as wind, solar, and geothermal, as well as water energy, including sea wave or ocean wave energy, and hence the possibility of benefiting from it as one of the best alternatives to minimise the negative effects of increased global warming. Wave energy resources offer the highest energy density, or amount of stored energy in a particular region, when compared to other renewable energy resources. Geographically, Iraq lies in West Asia and is partially encircled by the Arabian Gulf, with a

coastline of approximately 63 km (Al-Mahmood et al, 2016). Therefore, Iraq may employ sea wave energy to meet energy demands. The mechanism that forms wind waves could be clarified when the kinetic energy is transferred from the wind to the seas and the oceans, where a small fraction of it is consumed in the formation of surface sea currents (Gayle, 2003). Wind waves, on the other hand, can be composed mostly of shallow and deep water waves. These two varieties differ based on the depth of water along the wavelength (Komen, 1994). When the winds are high, the waves are composed in a spiral shape. When they reach 13 knots, the height of the waves starts to increase. Moreover, as wind speed increases, wave energy also increases. After that, the wave begins to decay and fade (Kinsman, 1965). The waves in the seas and oceans are complex; they depend on wind speed, fetch, duration of the wind, the bathymetry of the sea, physical properties of seawater, seawater currents, wind direction, mixing and circulation (Abdel Rahman, 1995). Just a few studies have been carried out on various scientific aspects in front of the Iraqi coast in the OUTER BAR (48°43'E, 29°50'N), compared to the importance of the area for Iraq. The researcher (Al-Mahmood, 2014) investigated the relationship between various atmospheric elements and marine phenomena, such as wind waves and confirmed that these elements affect the amount of wave height; hence, this amount is subject to the influence of the wind factor. Studied wind waves at three stations situated along the southern entrance of Khor Abdullah (Mahmood, 2008). The wave estimation depended on the method employed for computing the wind-sea significant wave height (Sverdrup and Munk, 1947; Bretschneider, 1952). Whilst the swell character wave height and its period were estimated by the method (Neumann and Pierson, 1966). The findings of the authors indicated that the wave height was approximately 1.7 m during the summer season from 1990 to 2000, as determined by the winds recorded at the Abadan station in the northern region of the Arabian Gulf. The higher swell and combined waves were about 1.3 and 2.1 m. Computed the breaker wave height root mean square H_{rms} as a function of water depth, in which the highest value was about 0.981 m. The authors estimated the breaker wave energy as a function of H_{rms} in Mean Higher High Water (MHHW) off the Iraqi coastline in the northwestern Arabian Gulf, where the maximum value reached about 1214.258992 joules/m² (Mahmood et al, 2009). Use (Mahmood, 2007) the Demirbilek and Coworkers method (Demirbilek and Thompson, 1993) to estimate the significant wave height over the period (1960 -1990) in the northwest of the Arabian Gulf. i.e. as a function of winds recorded at Abadan station. Results showed a higher wave in the summer season associated with the energy transfer from the wind to the sea surface. Presented wave energy in terms of the significant height of both wind and swell waves over the period (2000-2017) by using the (ECMWF) ERA5 reanalysis dataset in the Arabian Gulf, i.e. annual, seasonal, and monthly datasets (Mahmoodi et al, 2019). The authors derived a new equation for assessing wave energy that can be utilised in shallow and deep waters. The results confirmed that the central parts of the Gulf have the highest value of wave energy in winter, associated with the Shamal wind. Most of the wave energy occurred in February. Estimating evaporation rates was one of the physical process factors covered in the study, which was carried out in the area (Al-Fartusi, 2019). The researcher (Al-Fartusi and Al-Sayyab, 2021) studied the effect of tidal phase on some physical

and chemical properties of Khor Al-Zubair, southern Iraq. The general characteristics of surface waves in Iraq's marine water are studied (Lafta and Al-Fartusi 2022). The researcher (Al-Fartusi et al, 2023) estimated the spatial and temporal changes of the Iraqi coastline using remote sensing and also studied spectral indices to estimate total dissolved solids in the water body of the northwestern Arabian Gulf (Al-Fartusi et al, 2023). A study (Lafta et al, 2025) examined the temporal variability of atmospheric elements in Iraq Marine Water, Northwest of the Arabian Gulf.

2. Research objective:

The research aims to take advantage of the alternative energy we'll deal with in this kind of work, namely the energy of the sea waves, which must be taken into account when building any facilities along the Iraqi coast due to the strength resulting from these waves. Therefore, we analyzed the value of wave energy based on the wind speed in the region, Figure (1).



Figure 1: The study region in the north-west Arabian Gulf

2. Sea Wave Energy:

The energy of a sea wave is related to the height squared, H (the vertical distance between the wave trough and crest), depending on the following relationship (Brown et al, 1989).

$$E = 1/8 \rho g H^2 \dots\dots\dots(1)$$

Where:

$\rho = 1025 \text{ Kg/m}^2$ the density of seawater, $g = 9.81 \text{ m/sec}^2$ acceleration of Gravity, H(m) sea wave height.

3. Characteristic height of a sea wave:

Each area of the seas and oceans has unique characteristics that set it apart from other regions and impact the waves that surge through it. Specialists in the study of sea waves are interested in

waves with high altitudes and neglect those that have a small height. Characteristic wave height ($H_{1/3}$) is defined as the mean of the upper third of the registered wave heights and calculated from the relationship (2) (Abdel Rahman, 2003) .

$$H_{1/3} = 2.4821 * 10^{-2} W^2 \dots\dots\dots (2)$$

W (wind speed was measured in m/s)

4. Materials and Methods:

Approximately 3,560 wind speed values were studied and processed within the study area. These values were recorded daily over a decade, from 2015 to the end of 2024. Wind speed was measured at an altitude of 10 meters above sea level, and the corresponding wave height was registered at the Al-Faw station, the closest to the study area (Al-Faw Meteorological , 2024). Energy was then calculated using Equation (1).

5. Results and discussion:

In this study, we examined the monthly and seasonal variations over the specified period after calculating the total wave energy. The results were as follows:

5.1 The total energy of the sea waves

Estimated energy in Joules per square meter of sea surface depending on the relationship (1). Then, the monthly energy average was calculated according to the relationship ($\bar{E} = \frac{1}{n} \sum_{i=1}^n Ei$). Here n is the number of registration times, and the results were represented graphically in Figure 2.

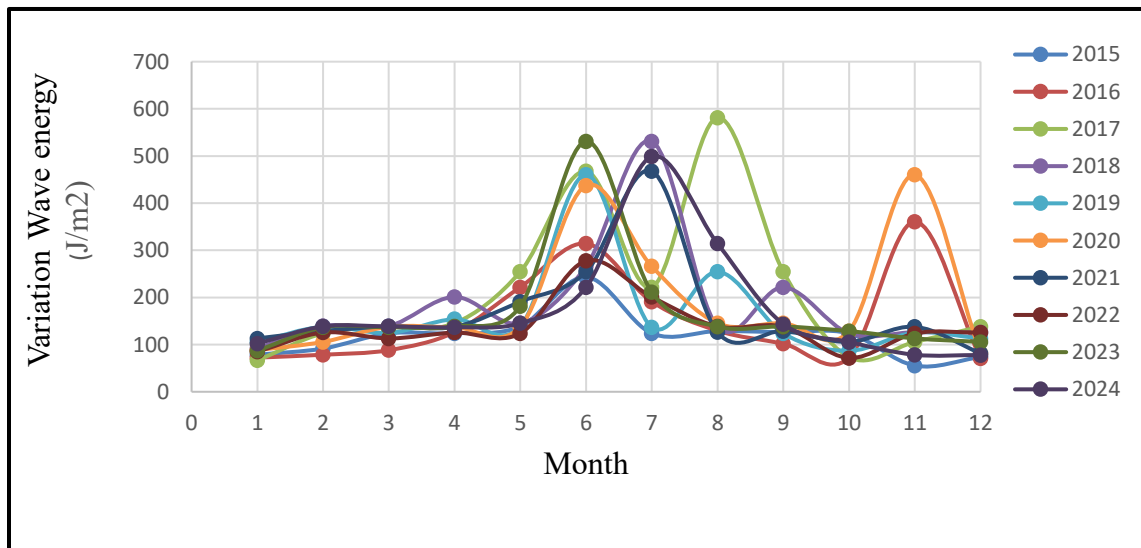


Figure (2): Monthly changes in the energy median of the sea wave during the period from 2015 to 2024.

Figure 2 shows that the median monthly energy for the total sea wave of the study area over a decade ranges from 55.42 to 581.19 (J / m^2), showing that the largest values of the monthly energy rate occur in June, July, and August, depending on prevailing winds in the region.

5.2 The characteristic sea wave energy:

Following the determination of the characteristic wave height ($H_{1/3}$) in the study region using equation (2), these values were entered to calculate the wave energy for each wind speed value in equation (1). The monthly energy medians were then recorded, and the results are shown graphically in Figure 3.

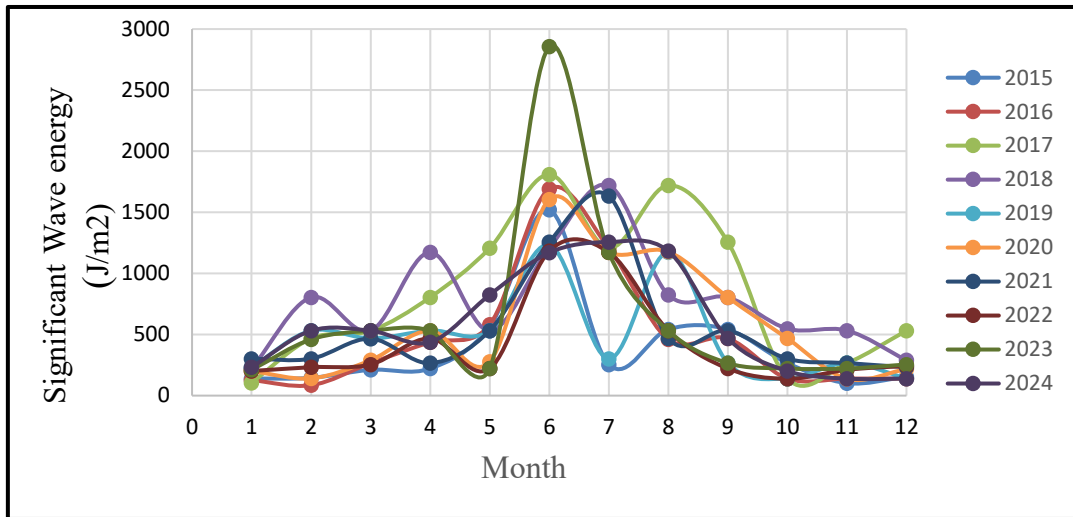


Figure (3): Monthly changes in the energy median of the characteristic sea wave during the period (2015 – 2024).

Figure 3 shows that the average value of the characteristic sea wave energy during the study period ranges between (102.09 - 2855.87) (J/m^2). It shows that the largest values of the characteristic energy of sea waves occur in June, July, and August.

5.3 Seasonal changes in the energy median of the sea wave:

After finding the median energy for each month throughout the study period, the seasonal average was calculated, and then the results were represented graphically in Figure 4.

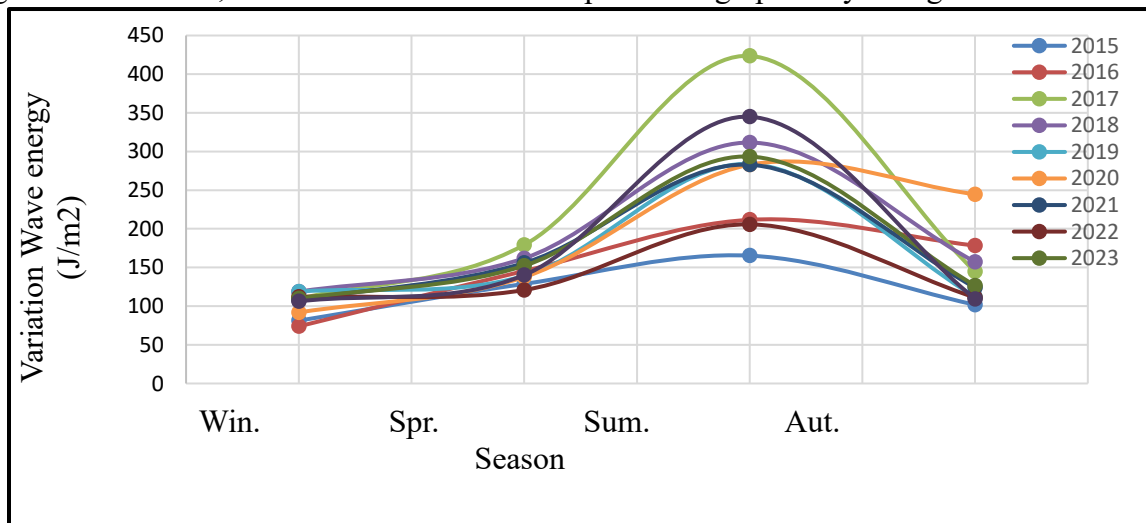


Figure (4): Seasonal changes in the energy average of the sea wave during the period (2015 – 2024).

Figure 4 shows that the average value of the seasonal wave energy is within the range of 73.84 - 423.53 (J/m^2), showing the largest values of the seasonal energy rate in the summer and the highest value during the study period in 2017 (423.53) (J/m^2). This is due to the nature of the study area, which is affected by the high speed of wind in the summer months, resulting in rapid and substantial sea waves, especially when coinciding with the period of high tide (Mahmood et al, 2008).

5.4 Seasonal changes in the energy median of the characteristic sea wave:

Similarly, calculating the characteristic sea wave energy for each season separately, we obtain the results graphically represented in Figure 5.

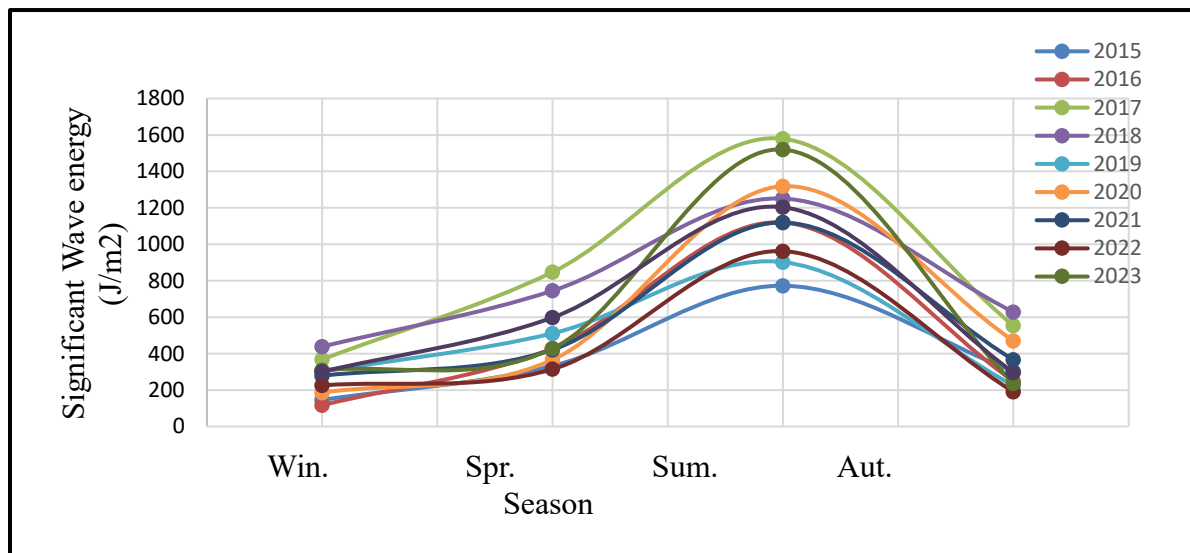


Figure (5): Seasonal changes in the energy average of the characteristic sea wave during the period (2015 – 2024).

Figure 5 shows that the average seasonal wave energy median is within the range (of 116.87- 1579.21) (J/m^2), showing that the maximum values of the seasonal energy rate of the characteristic sea wave occur at the same time that the seasonal energy total marine occurs.

To analyse seasonal variations in sea wave energy, a normal distribution model (Gaussian function) was adopted as a mathematical representation of the energy distribution across the seasons. This representation was based on actual seasonal values collected for the period from 2015 to 2024. These values were subjected to a nonlinear Gaussian curve fitting process based on a one-dimensional Gaussian function, using the nonlinear least squares regression technique.

The seasonal peak was assumed to be in summer, since this season produces the highest energy value in most of the years studied. With the peak position fixed at $x_0 = 3$ (which corresponds to summer), a fitting process was performed to derive the maximum energy coefficient E_{max} and the standard deviation coefficient σ , in addition to numerically integrating the curve E_0 , which represents the total energy distributed over the four seasons.

The curves for Figures (4& 5) were analysed using the Gaussian distribution according to the following relationship (2):

$$E(x) = \frac{E_0}{\sqrt{2\pi}\sigma} e^{-\frac{(x-x_0)^2}{2\sigma^2}} = E_{\max} e^{-\frac{(x-x_0)^2}{2\sigma^2}} \dots\dots (2)$$

The Gaussian distribution is specified by two parameters: the population mean x_0 and the population standard deviation. σ . Variables $x = 1, 2, 3,$ and 4 represent the seasons (win., spr., sum., and aut.) respectively.

The analysed values are recorded in Tables 1 and 2 using the Sigma Plot Program.

Table 1: contains the mean X_0 , maximum sea wave energy E_{\max} , and standard deviation σ , and the integral under the curve E_0 values of the sea wave energy are given in J/m^2

Year	X_0	$E_{\max} (J/m^2)$	σ	$E_0 (J/m^2)$
2015	3	165.31	0.9	272.45
2016	3	210.02	1.0	348.80
2017	3	423.53	0.73	698.04
2018	3	311.55	0.73	513.48
2019	3	281.62	0.9	467.71
2020	3	280.77	0.73	466.29
2021	3	282.83	1.2	466.14
2022	3	205.76	0.9	339.12
2023	3	293.45	0.73	483.65
2024	3	344.9	0.73	568.44

Table 2: contains the mean X_0 , maximum sea wave energy E_{\max} , and standard deviation σ , and the integral under the curve E_0 values of the significant sea wave energy are given in J/m^2

Year	X_0	$E_{\max} (J/m^2)$	σ	$E_0 (J/m^2)$
2015	3	772.63	0.9	1585.37
2016	3	1119.49	1.0	2297.09
2017	3	1579.21	0.73	3240.40
2018	3	1250.78	0.73	2566.49
2019	3	902.18	0.9	1851.19
2020	3	1318.52	0.73	2705.49
2021	3	1119.35	1.2	2296.81
2022	3	962.18	0.9	1974.31
2023	3	1519.93	0.73	3118.76
2024	3	1203.32	0.73	2469.11

6. Conclusions:

The current study shows that the monthly energy value of the sea waves in the study area occurs within (55.42-581.19) (J/m^2), while the average seasonal energy of the wave within the field (75.44-424.44) (J/m^2), As for the monthly energy value of the characteristic sea wave, it varies between the two values (102.09-2855.87) (J/m^2). The wave energy calculated in this research reflects the physical reality of the study area. Therefore, when constructing any marine facility, we must consider that its resistance to waves should be greater than the worth of this energy. The normal (Gaussian) distribution function is an effective tool for analysing the seasonal behaviour of sea wave energy. By fitting a Gaussian curve to the calculated seasonal energy values, the standard deviation (σ), which reflects the extent of energy dispersion around the seasonal peak, could be determined. Small values of σ (such as 0.73) indicate a sharp and strong seasonal pattern associated with winds. In contrast, larger values of σ (greater than 1.0) reflect a wider dispersion of energy across more than one season, indicating the influence of additional climatic factors such as transient disturbances or changing wind patterns.

7. Recommendations:

When designing coastal structures or sea barriers, a Gaussian model must be used. A Gaussian model not only provides an accurate mathematical description of the data but also enables the assessment of the nature of seasonal variation, which is essential for estimating the efficiency of sea energy utilisation and long-term environmental planning. It is also advisable to establish a station to measure sea waves and select an appropriate location to assess the economic feasibility and potential of harnessing sea wave energy for electricity generation, for example.

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Disclaimer of Conflict of Interest:

The researcher declares that he has no known financial interests or personal relationships that could influence the work presented in this paper.

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