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POTENTIALS FOR WAVE POWER GENERATION IN AYETORO, ONDO STATE NIGERIA

OLAKUNLE, G. W.[1], A. A. Osinowo [2] and B.A. Okunlola [2].

[1]Nigerian institute for oceanography and marine research, no.3, Wilmot point, Victoria Island Lagos,
[2]Federal University of Technology, Akure, Ondo state, Nigeria.
Corresponding author, Email: gideolak@yahoo.com, gideonwole@gmail.com;
Mobile phone: +234- 8055-306-942, +234-8147-453-385.
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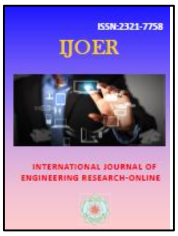

ABSTRACT

Ayetoro, a fishing coastal community in Ilaje Local Government of Ondo State had experienced severe ecological devastation orchestrated by climate change. High energy wave propagating along the shoreline had destroyed livelihood and cut off power supply from the national grid. This work Assesses the power generation potential of extreme significant wave height (SWH) within the return period of 2, 5,10,20,50 and 100years respectively, using Gumbel distribution scheme based on a 40-year (1980-2019) wave hind-cast. The overall annual forecast of storm surge revealed that extreme SWH will rise to 1.29m, 1.54m, 1.59m,1.91m, 2.12m and 2.27m respectively for the next 2yr, 5yr, 10yr, 25yr, 50yr and 100yr return periods. Seasonal analysis showed that for the different return periods, higher values of extreme SWH were recorded during summer. Evaluation method by Iglesias and Carballo (2011) was adopted to calculate power density for extreme SWH. Values of 0.65KW/m^2, 0.83 kw/m^2; 0.87 kw/m^2; 1.10 kw/m^2; 1.24 kw/m^2 &1.35 KW/m^2 was recorded in summer while lower values of 0.17kw/m^2; 0.21kw/m^2; 0.21kw/m^2; 0.26kw/m^2; 0.29kw/m^2; 0.32kw/m^2 was recorded for winter for5yr, 10yr, 25yr, 50yr and 100yr return periods respectively. The adverse extreme waves devastating Ayetoro could be exploited for power generation.

Keywords: Wave, Energy, Potential and Ayetoro.

Introduction

Wave power is a worldwide coastal resource estimated to be over two trillion watt which is limited in commercial use despite its high density per metre square (Czech et.,al, 2012). Documented patent for the use of wave energy dated as far back as 1799 in France. For many years this source of energy was neglected until the 1973 oil crisis. However, with the increased appreciation of the negative effect of global warming majorly attributable to the use of fossil fuel, the need to develop cleaner and renewable energy has awaken the interest of some scientists in ocean wave energy for power generation. Despite the increasing clamor for cleaner energy by various environmental group and many developed economies the great promise embedded with wave energy is yet to be realized due to limited or absence of relevant infrastructure that will be required to evacuate and transmit generated energy from the coastline to the mainland areas. Wave energy uses the vertical movement of surface water that produce tidal waves. Electricity is generated when the periodic up-and down movements of the ocean waves, which is in mechanical energy form is captured with the aid of specialised equipment deployed on the surface of the ocean and converts this mechanical energy into electrical power. Wave energy is a product of intense solar power generated by the action of the wind blowing across the surface of water. Heat emanating from the sun warms the atmosphere thereby producing temperature differentials of the air mass around the globe (Grabeman et.,al, 2008 ;Goda et.,al, 2008). The movement of these airmass from hotter region to t cooler regions produce wind. As this wind passes over the surface of the oceans, a portion of the wind kinetic energy is transferred to the water below generating waves. Waves are actually energy that moves along the ocean surface. These waves often propagate long distances across the open sea with little loss of energy. At the Shoreline, their speed is slowed due to reduced water depth but they increase in spread and finally crash into the shoreline releasing enormous kinetic energy convertible into electrical energy (Zieger et.,al, 2009). The depletion of the ozone layer exposes the earth to more intense heating of the air mass which consequently produce high energy wave with their devastating effect on coastal communities. The amount of wave power available is often location specific as highlighted by previous wave energy studies that identified few locations in the globe with the most potentials to generate energy from wave energy converters (WEC) with the exclusion of sub-Saharan Africa due to non-existent information. National renewable energy Laboratory (NREL) of United states has established that WEC can have efficiencies rate of 50% which is phenomenal in renewable energy. The challenge for now is the inability to come up with technologies that can produce portable WEC that can easily be deployed for a micro to medium scale energy generation. The amount of energy derivable from wave can be calculated using the equation below derived from the Airy wave theory often referred to as linear wave theory.

The linear wave theory gives the wave energy as

$$E = \frac{1}{16}\rho g H^2 \qquad (1)$$

where E is the mean wave energy density per horizontal area (j/m^2), the sum of kinetic and potential energy, *p* the water density, *g* acceleration by gravity and H is the wave height.

$$P = E\, C_g \qquad (2)$$

With P as wave power and *Cg* as the group velocity (m/s). The wave energy is directly proportional to the square of wave height. Eq (1); thus, the wave height can be used as a measure for wave energy (Bulteau et al., 2013).

Methodology.

Ayetoro is a major fishing community in Ilaje Local Government of Ondo State, Nigeria, located within Latitudes 06°00 & 06°30 North and Longitudes 004°45 and 005°45 East of the Greenwich Meridian. The location is characterized by high energy waves that have resulted into incessant sea incursion into the inhabited area.

WAVEWATCH III ™ (WW3), version 3.14 classified as third-generation spectral wave model, was used to simulate ocean wave parameters over the mid-Atlantic Ocean. The wave model is a product of National Centers for Environmental Prediction (NCEP) for ocean wave forecasts. NGDC (National Geophysical Data Center) ETOP 01 data, with a resolution of 0.017 ° × 0.017 °, the water depth field over the mid-Atlantic Ocean defined by coordinates 80°W, 30°S, 15°E and 40°N and which was processed by the Gridgen 3.0 packet was obtained. Source terms for energy spectra in the model are set to default. The model integrates the spectrum to a cut-off frequency, and above this frequency a parametric tail is applied. The model spatial grid covers the whole of mid-Atlantic from longitudes 80^{0}W to 15^{0}E and latitudes 30^{0}S to 40^{0}N with a 0.1^0 resolution. The model in an operational/forecasting mode, was forced with six-hour re-analysis wind fields extracted over longitudes 80.5^{0}W to 15.5^{0}E and latitudes 30.5^{0}S to 40.5^{0}N from the European Center for Medium Range Weather Forecast (ECMWF) ERA-Interim from 1980 to 2019 on a 0.125^0(longitude) by 0.125^0(latitude) Gaussian grid. The model output is a two-dimensional (2D) wave energy spectra obtained at each grid point with time period spanning from 1st January, 1980 to 31st December, 2019 and with a six-hour output data.

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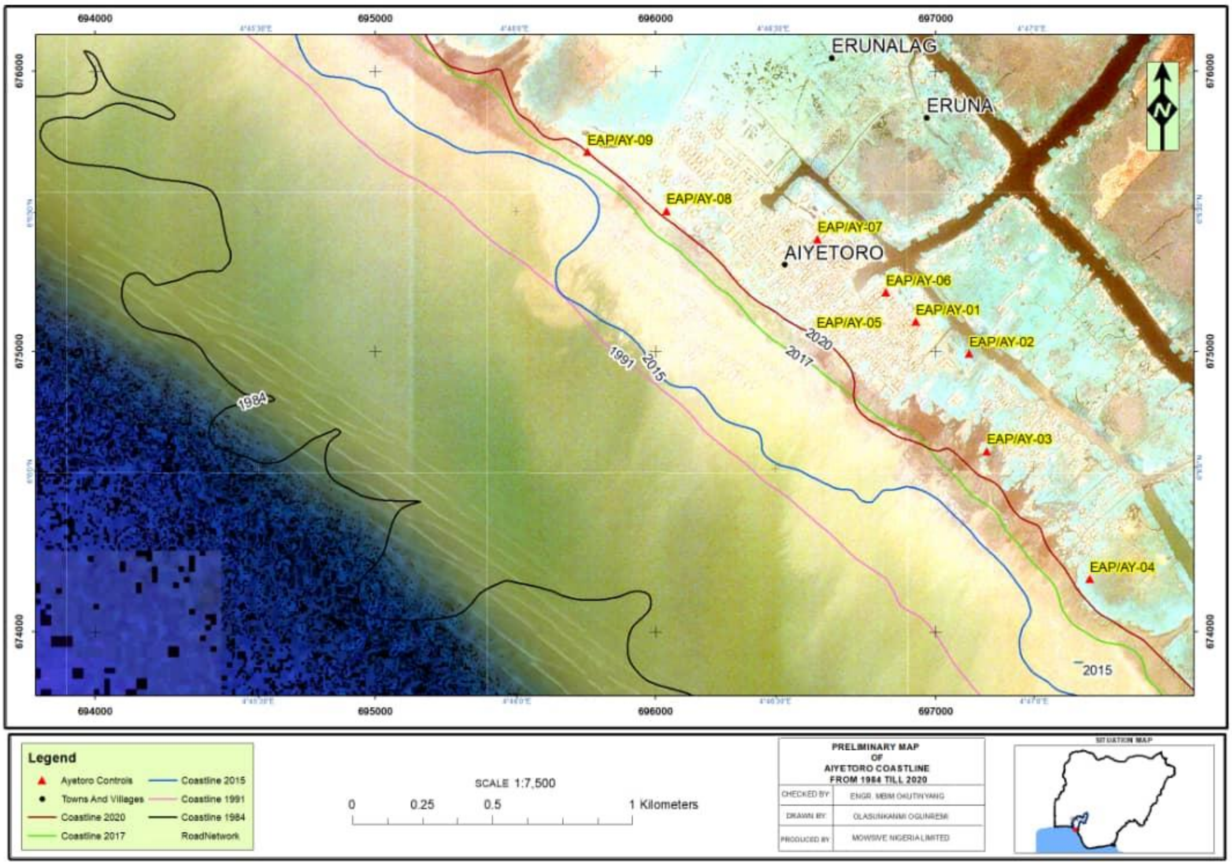

Figure 1. Ayetoro Coastal Community inset.

The model provides output of wave parameters including wave spectra, SWH (4√ E), mean wavelength (2Π k^{-1}), mean wave period (2Π k^{-1}2π), mean wave direction, peak frequency, and peak direction. The simulation provided a six-hour time series of SWH and other wave parameters over a box extending from 30°S to 40°N and 80°W to 15°E which contains nearshore and offshore locations. Results over water are extracted over 60°W, 10°S, 15°E and 20°N which contains the study location defined by coordinates 4.77°E, 6.1°N. Buoy (observational) data was obtained from the National Data Buoy Center (NDBC) for buoy 41040 in NORTH EQUATORIAL ONE, 470 NM East of Martinique, Coordinates 14.559 N 53.073 W (14°33'34" N 53°4'23" W) which is a buoy location in the mid-Atlantic and nearest to the study location, Ayetoro. The corresponding significant wave height data was computed by the model over the buoy coordinates. There is a good agreement between observations and simulations on the curve trends.

The accuracy of the wave parameter computed by the model was evaluated through a conventional statistical analysis that consists on calculating the following in Wilks, (1995):

$$cc = \frac{\sum_{i-1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i-1}^{n}(x_i - \bar{x})^2 \sum_{i-1}^{n}(y_i - \bar{y})^2}} \quad \text{--------(1)}$$

$$Bias = \bar{y} - \bar{x} \quad \text{--------(2)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i-1}^{n}(y_i - x_i)^2} \quad \text{-------(3)}$$

Where, x_i represents the buoy data, y_i represents the model data, x and y are mean values of buoy and model data, N is the total number of observations.

Analysis Methods.

For the 40-year hindcast, the WW3 model was positioned to output many ocean wave variables at a six- hour time space (Tolman, 2009).

The WAM4 parameterization was engaged in input and output. The mean SWH as one of the major output wave parameters was used to examine the variability of extreme SWH in the study location. Extreme SWH mentioned in this study are the highest values (99^{th} percentile) of SWH. Average extreme SWH for the seasons were considered by combining the November through March monthly mean for winter and April through October for summer. The annual and seasonal mean extreme SWH were also computed and noted as annual and seasonal mean extreme SWH. Linear trends in the annual and seasonal average 99^{th} percentile SWH were calculated for the study location. The trend computation of the year-combined 99^{th} percentile SWH climate was carried out through the linear least square fitting of time series of SWH and the p values were calculated to establish the significance of the trend. Statistically, trends at 95% confidence (p value < 0.05) were known to be significant. The wave direction climate over the study location was also determined. Computation was carried out to forecast storminess and extreme wave events in 2, 5, 10, 25, 50 and 100 years using the Gumbel distribution scheme. The annual and seasonal variations of swell at Ayetoro were also analyzed. Swells are storm generated and long crested waves that have traveled outside the area of their origin. The wave-age is defined as the developmental stage of the sea relative to the current state of wind force. It is computed as wave-age=(g*Tp./2pi)/u. Where g=9.8m/s, which is acceleration due to gravity. Tp is the peak wave period. u is the 10m wind speed and pi=3.142. Swell occurs when the wave-age is >=1.2m while wind sea occurs when the wave-age is <=1.2m.

Wave power was obtained using the evaluation method of Iglesias and Carballo (2011); Zieger et.,al (2009) and Vasough (2011), the wave power density at Ayetoro is estimated as follows:

$$P_w = \frac{\rho g^2}{64\Pi} H^2_{mo} T_e = 0.49 H^2_{mo} T_e$$

where P_w is wave power (unit: kW/m), ρ is the sea water density which is 1.25 kg/m^3, g is the acceleration due to gravity which is 9.8 m/s, Π is pi which is 3.142, H_{mo} is the significant wave height (unit: m), and T_e is the peak wave period (unit: s).

RESULT

Extreme Wave Events for Different Return Periods

The annual and seasonal mean SWH for different return periods are also plotted alongside the corresponding extreme values for comparison the return period of a storm, such as 100- year period, 50-year period, etc., indicates the probability of the storm (with the related strength) occurring during any given year. Figure 2a shows that for the different return periods, extreme SWH ranged between 1.29m and 2.27m. The overall seasonal (Winter and Summer) average extreme SWH for different return periods are displayed in figure 2b for Winter (Nov. - March) and Fig 2c for Summer (April – Oct.). For winter, extreme wave events range between 0.75m and 1.37m from 2yr through 100yr return periods. The monthly variation of wave power in figure 3 shows that higher values of 0.83 kW/m, 1.31 kW/m, 1.25 kW/m and 0.75 kW/m are observed in summer months of June through September. Least values of 0.18 kW/m, 0.12 kW/m, 0.13 kW/m and 0.2 kW/m are seen in winter months of November through February. In figure 4, the annual mean wave power stands at 0.5 kW/m while the averages for winter and summer respectively stand at 0.18 kW/m and 0.73 kW/m. For all return periods, power density and hence power generation will be highest between the month of June to September, with peak periods occurring in July with a mean value of 1.35 Kw/m^2. (Fig 3).

Table 1 presents the annual mean SWH and Extreme SWH(Forecast) mean Wave Power Density (kW/m) for different return period. the overall annual mean wave power of 0.5 kW/m is compared with a 2, 5, 10, 25, 50 and 100- year future projection of wave power. It is observed that for the 5 to 100- year return periods, the wave power rises by 0.0662 kW/m, 0.0962 kW/m, 0.2362 kW/m, 0.3362 kW/m and 0.4062 kW/m. The 2- year projection value for the wave power declined by 0.054 kW/m from the overall annual mean value. The seasonal analysis is shown in figure 2 and 3 S(Winter and Summer). The overall winter mean

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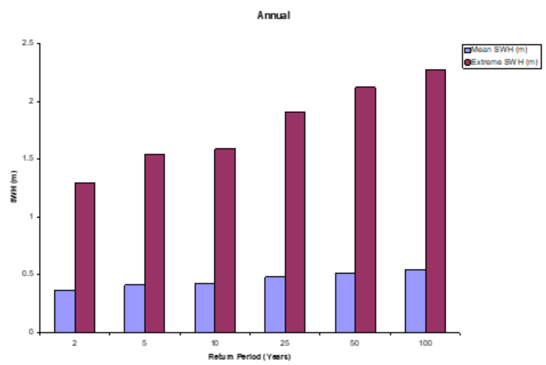
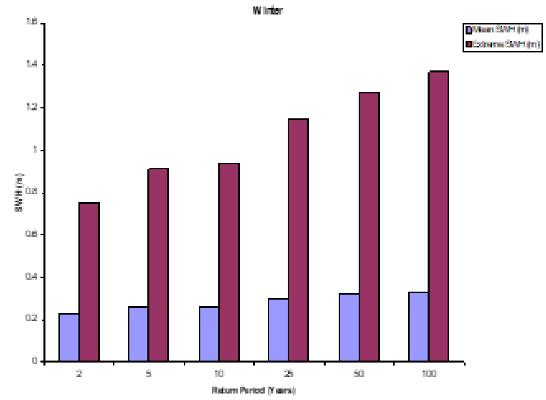
wave power of 0.18 kW/m is compared with a 2, 5, 10, 25, 50 and 100 -year future projection of wave power. It is observed that for the 5 to 100- year return periods, the wave power rises by 0.026 kW/m, 0.026 kW/m, 0.076 kW/m, 0.106 kW/m and 0.136 kW/m. The 2- year projection value for the wave power declined by 0.014 kW/m from the overall annual mean value. Also, for summer, the overall summer mean wave power of 0.73 kW/m is compared with a 2, 5, 10, 25, 50 and 100 -year future projection of wave power. It is observed that for the 5 to 100 -year return periods, the wave power rises by 0.1 kW/m, 0.14 kW/m, 0.37 kW/m, 0.51 kW/m and 0.62 kW/m. The 2-year projection value for the wave power declined by 0.08 kW/m from the overall annual mean value.

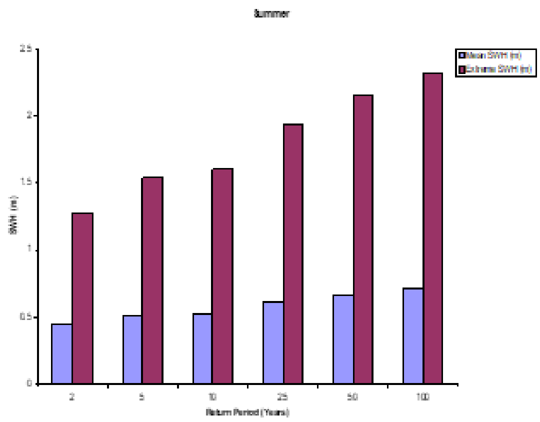
For different ranges of the wave power shown in table 4, an analysis of the annual and seasonal wave power density (wp) over the study area is expressed in percentage cumulative frequency f(wp) Where n is the frequency of wp satisfying each of the defined interval of wp relative to different wave power and N is the sum of wp values. The seasonal mean wave power characterization is considered by merging: the November to March monthly mean wave power for winter and April to October for Summer. The table clearly shows that wave power density lesser or equal to 5kW/m^2 occurred all the time (above 99%) at Ayetoro.



(A)



(B)



(C)

Figure 2: Bar plots of the (a) annual mean and (b) seasonal mean (Winter &summer) extreme SWH predicted by Gumbel distribution for different return periods at Ayetoro. (Unit: m.)

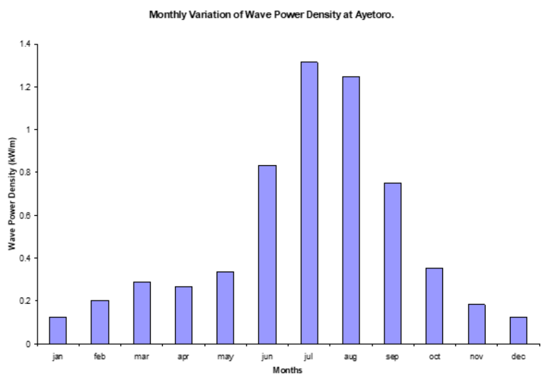


Fig 3: Monthly Variation of Power Density

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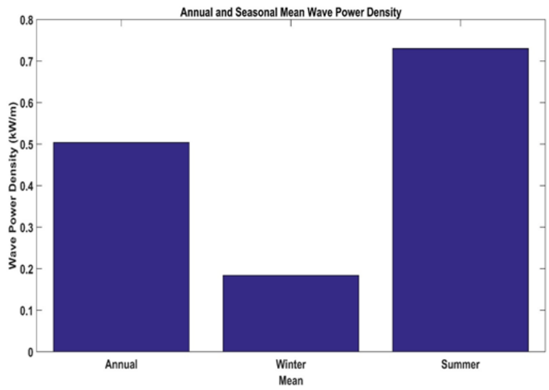

Figure 4: Annual and Seasonal mean values of wave power at Ayetoro.

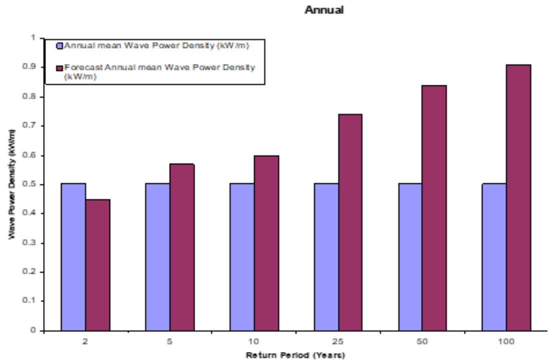

Fig 5 (a): Annual mean wave power for mean SWH and Extreme SWH

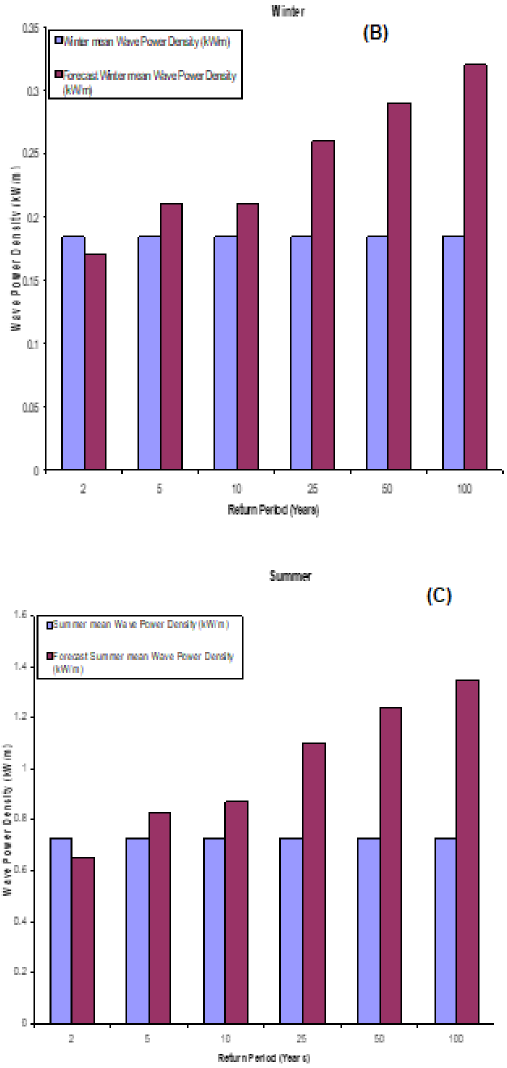

Figure 5 (b &c): Wave Power Density (kW/m) for mean SWH & Extreme SWH in (a) winter (b) Summer for different return periods at Ayetoro.

Table 1: Annual mean and Extreme wave energy and Power density for different return period in Ayetoro

Return Period (Years)	Mean SWH	Mean wave Energy	Mean wave Power (Kw/m)	Extreme SWH	Extreme Wave Energy	Extreme Wave Power (Kw/m)
2	0.36	79.14	0.5	1.29	1016.20	0.45
5	0.41	102.65	0.5	1.54	1448.25	0.57
10	0.42	107.72	0.5	1.59	1543.82	0.60
25	0.48	140.70	0.5	1.91	2227.76	0.74
50	0.51	158.83	0.5	2.12	2742.71	0.84
100	0.54	178.07	0.5	2.27	3146.68	0.91

Table 2: Winter mean and Extreme wave energy and Power for different return period in Ayetoro

Return Period (Years)	Mean SWH	Mean Wave Energy	Mean Wave Power (Kw/m^2)	Extreme SWH	Extreme Wave Energy	Extreme Wave Power (Kw/m^2)
2	0.23	32.30	0.18	0.75	343.50	0.17
5	0.26	41.28	0.18	0.91	505.69	0.21
10	0.26	41.28	0.18	0.94	539.58	0.21
25	0.30	54.96	0.18	1.15	807.60	0.26
50	0.32	62.53	0.18	1.27	984.94	0.29
100	0.33	66.50	0.18	1.37	1146.15	0.32

Table 3: Summer mean and Extreme wave energy and Power density for different return period in Ayetoro.

Return Period (Years)	Mean SWH	Mean SWH Energy	Mean SWH Power (Kw/m)	Extreme SWH	Extreme SWH Energy	Extreme SWH Power (kw/m)
2	0.45	123.66	0.73	1.28	1000.51	0.65
5	0.51	158.83	0.73	1.54	1448.25	0.83
10	0.53	171.54	0.73	1.60	1563.30	0.87
25	0.61	227.23	0.73	1.94	2298.29	1.10
50	0.67	274.10	0.73	2.15	2822.79	1.24
100	0.71	307.83	0.73	2.32	3286.82	1.35

Table 4: Percentage cumulative frequency of the annual and seasonal wp values for Ayetoro (f is computed using Equation $f(wp)100\left(\frac{n}{N}\right)$

Year	0≤wp≤5	5≤wp≤10	10≤wp≤15	15≤wp≤20
Annual	99.74	0.26	0.01	0.00
Season	0≤wp≤5	5≤wp≤10	10≤wp≤15	15≤wp≤20
Winter	100.00	0.00	0.00	0.00
Summer	99.55	0.44	0.01	0.00

Discussion.

Results show clearly that the significant wave height computed by the model and the observed values are highly correlative with a correlation coefficient (cc) of 0.927 and significant at the 99% level. The calculated positive mean bias error (MBE) which is 0.094 m is quite low and showed that the buoy data is slightly underestimated. The error of model data which is 0.221 m is low when analyzed by the root mean square error (RMSE). In general, the simulation results are consistent with the observations, which show that WW3 can well reproduce the significant wave height and also a reliable model to model surface waves in the study area.

Recent technologies have shown considerable prospect for the development of wind farms using medium sized buoy-like WEC (Falnes, 2007). The commercial viability of wave energy has been been demonstrated by Bombara wave power projct based in Perth, Western Australia , CETO wind farm off the coast of western Australia, Agucadoura wave farm in Portugal, the wind farm in Scotland pioneered by the firm, pelamis. The prospect for the development of a wind farm in Ayetoro could turn the devastating ravaging waves into a growth opportunity for the community. The power density for the study areas is between 0.45m to 0.91 Kw/m2 for the annual mean, 0.17 to 0.32Kw/m for winter and 0.65 to 1.35Kw/m2 for winter. The highest values for power density occurred between the moths of June, July, August and September. With the renewed interest of the G-7 nations to drastically reduce global carbon emission and combat climate change impact, Nigeria could attract substantial foreign aid for this alternative energy source.

Conclusion

The current environmental challenges confronting Ayetoro community can be transformed into an opportunity for growth and development if requisite resources are channeled towards solving this ecological disaster. The high energy wave that characterizes the shoreline of the community could be converted to wave energy for electricity generation.

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