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Assesing wave power potential in Nkhatabay, Malawi

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ABSTRACT
Background: This thesis is an investigation of the wave power resource on Lake Malawi, precisely Nkhatabay, focusing on the spatial distribution of wave power of the said places exposed to the highest wave power. **Findings:** The main objective of this study was to determine the wave potential of Lake Malawi in Malawi in order to allow design and usage of wave energy in Malawi. **Methods:** The study methodology employed to achieve this main objective entails an analysis of measured wave data recorded at wave recording station along Lake Malawi. **Conclusion:** The analysis provided a general description of wave power at the location for which wave data exist. From this analysis,it was found that Nkhatabay is exposed to average wave power of approximately 202 KW/m annually. Data was collected from the Department of Climate Change and Meteorological Services (DCCMS), who have implanted a Lake buoy at Usisya in Nkhatabay. The data gathered was analyzed using Microsoft excel and R studio to come up with graphs for proper description of results. Power calculations were conducted as well to determine the output of turbines used with respect to the wave data observed.

KEYWORDS: assesing; potential; power; wave.

1. Introduction

Wave energy is an indirect result of solar radiation. Winds are generated by the differential heating of the earth, and as they blow over large areas of ocean, part of the wind energy is converted to water waves (Joubert, 2008). Accurate analysis and forecasting of water levels are very important tasks for human activities in lakes and coastal areas. They can be crucial in catastrophic situations like occurrences of floods in order to provide a rapid alerting to the human population involved and to save lives. Wave power is the use of rise and fall of waves to generate electric power. The power produced by the surge of water during the rise and fall of waves is called wave energy. Since water is denser than air, water speeds of nearly one tenth of the speed of wind provide the same power for the same size of turbine system (Yun Seng, 2000). It is generally evident that Malawi lacks enough power to support its socio- economic development activities since about 3.2 million households have no power connection. The demand for power seen through persistent blackouts throughout the year has made it necessary to assess the capability of Malawi as a country to generate power using waves which are available on Lake Malawi and other potential sites in the country. This is in line with priorities set up by the Malawi Growth and Development Strategy (MGDS) which are, among others, energy generation and supply.

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1.1 Background

Wave power is practically inexhaustible and classified as a renewable energy source. The renewable resource market is steadily growing in the African continent that can provide itself to possess in abundance a good mix of resources such as the sun, water, biomass and wind (Tiyou, 2016). Malawi produces inadequate energy supply which leads to challenges in social, economic and industrial development. According to the United States Agency for International Development (2019), Malawi has a high population density and has one of the lowest capita GDPs in the world. The country has a capacity to generate 439 megawatts (MW) and there is a high potential for new hydro technologies to enter into the market. From the 439 megawatts (MW) power generation capacity of Malawi, 384 megawatts are generated from hydroelectric energy sources and 55 megawatts (MW) is generated from solar energy sources.

Malawi's energy sector has gone through important sector reform efforts recently, including the unbundling of the national utility, the Electric Supply Company of Malawi (ESCOM) and the establishment of the Electricity Generation Company of Malawi (EGENCO). Restructuring of Malawi's power market is underway, with strong investor interest and political will for independent Power Producers (IPPs) to enter the market. The 2003 Malawi Energy Policy recognizes that the country has huge natural resource potential for energy generation which is heavily untapped. Yet according to Biomass study of 2009, over 80% of the country's energy supply is obtained from bio firewood and charcoal whose use causing deforestation and land degradation. (William Dzekedzeke, 2019).

It is in line with this background that wave energy should be considered among many other renewable energy sources, to relieve power generating companies which are struggling to generate adequate electricity because they have limited capacity to generate adequate power to meet the country's energy demands. Since waves are predictable, generation of wave energy would greatly depend on the accuracy and precision of the forecasts. This calls for meteorological assessment of potential sites of generation, to provide detailed knowledge of water waves and to determine the available water wave resources that will allow design and usage of wave energy conversion systems, into sites that can be used to generate wave energy.

1.2 Problem Statement

Malawi is endowed with a number of renewable energy resources yet utilization of these resources is still in infancy stages (IJSED, 2014). Detailed knowledge of water wave characteristics and distribution of a particular location is important to wave power production industry This basic information enables the turbine designers to optimize the output of their turbines at the lowest generating cost. Wave power investors use it to estimate possible income from their investment, and it also serves as a control tool for utility operators charged with generation dispatch to reduce threats to the security of the power system as a result of variation in wave speed. Lack of detailed knowledge of wave characteristics is one of the barriers to wave technology development in Malawi (UNFCCC, 2003). Therefore, this project provides detailed knowledge of the wave characteristics and estimated energy output which are essential to allow optimizing the design and the usage of Wave Energy Conversion Systems in Malawi.

1.3 Objectives

The main objective of this study is to determine the wave power potential of Lake Malawi in order to allow design and usage of wave energy in Malawi. Data gathered for selected sites was analyzed, in order to support the evaluation and planning of future wave energy projects in the selected areas.

1.4 Specific objectives supporting objectives include

Analysis of water wave characteristics to estimate wave power output.

1.5 Research questions

What is the wave power potential of Nkhatabay. What are the wave characteristics in the area. What is the estimated wave power output of the area.

1.6 Significance of study

Increasing population, rising energy consumption, climate change and peak oil are accelerating the search for practical alternative energy sources. Some renewable sources of energy such as, wind and solar energy have established markets all over the world. Wave energy is projected to dominate the energy sector in the next decade, as it is far more effective. Wave energy produces more energy than both wind and solar energy. Since Malawi is struggling to provide enough energy for various activities, it is important that studies be undertaken to assess the capability of the nation to generate wave power. Detailed knowledge of wave prevalence on Lake Malawi, which will be analyzed in this study, will be very useful in future wave power projects. Using the information gathered from this research, decision making will be made in consideration of these results before investing into the wave power projects. Successful wave power projects will provide the much-needed energy to the country for socio economic development.

2. Methods

To investigate the feasibility of the wave energy resource in Nkhatabay, the best method was to calculate the wave power output based on the measured data of the recording station. Data was analyzed and calculations were made to determine the wave potential of the site.

2.1 Site location and data collection

Nkhatabay is a township in the Northern Region of Malawi that lies on the coordinates 11036'00" S and 34018'00" E.

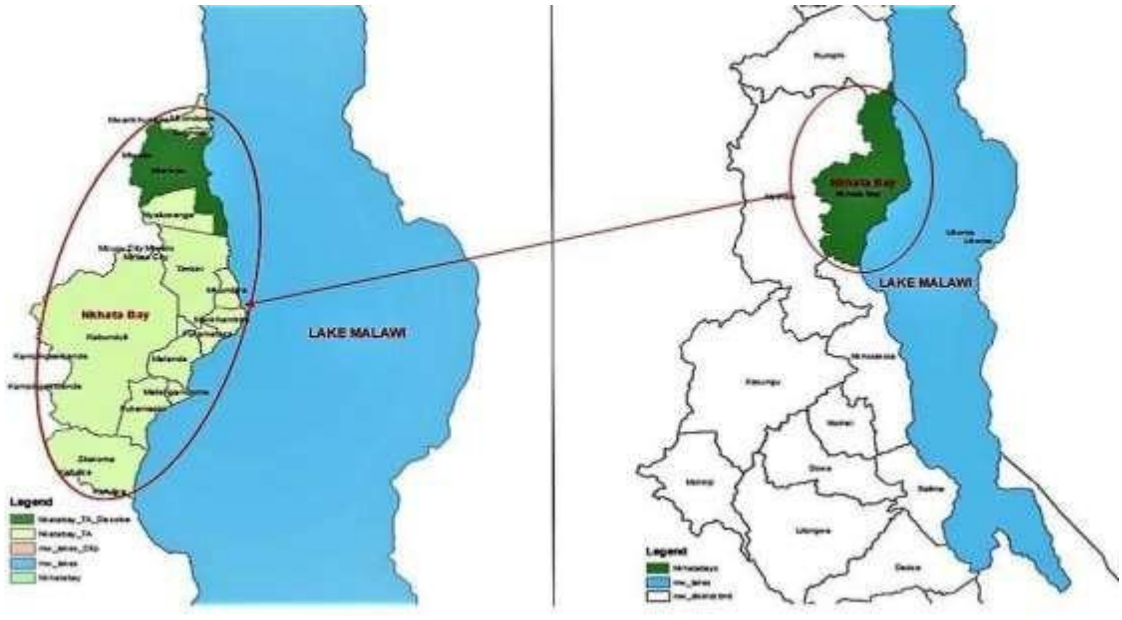

Figure 1. Map of Nkhatabay District

2.2 Data collection

The Department of Meteorology and Climate Change has setup a recording station at Usisya in Nkhatabay which has lake buoys that record water waves. Wave height, wave time period data from 2019 to 2021 was collected at National Meteorological Centre in Blantyre where they keep all weather data from all government weather stations in Malawi. Wave height data from 2019 to 2021 was used for analysis.

3. Result and Discussion

This review of literature related to global wave power distribution, Malawian meteorology and wave prediction techniques (Numerical Weather Prediction) provide background on the study topic of wave power.

3.1 Origins of wave power and its global distribution (Boud, 2003)

Wave energy is an indirect result of solar radiation. Winds are generated by the differential heating of the earth, and as they blow over large areas of ocean, part of the wind energy is converted to water waves. The amount of energy transferred, and the size of the resulting waves, depends on the wind speed, the length of time for which the wind blows, and the distance over which it blows, (the 'fetch'). In oceanic areas, wind energy is transferred to wave energy and concentrated at each stage in the conversion process, so that original uniformly distributed solar radiation power levels of typically ~ 100 W/m2 of earth surface can be converted to waves with locally concentrated power levels in the order of 10 to 50 kW per meter of wave crest length, (the standard form of measurement) in ocean zones where relative high wave energy occurs. Within or close-to the wave generation area, storm waves known as the 'seas', exhibit a very irregular pattern, and continue to travel in the direction of their formation, even after the wind change direction or subside. In deep water, waves can travel out of the storm areas (wind fields) with a minimal loss of energy, and progressively becoming regular, smooth waves or a 'swell', which can persist for great distances (i.e., tens of thousands of kilometers) from the origin.

Consequently, coasts with exposure to the prevailing wind direction towards the coast and longfetches tend to have the most energetic wave climates—e.g. the Northwest coasts of North America, South West coast of South America, Europe, Africa, Australia and New Zealand. The global wave power potential has been estimated to be 86-87 kWh/year (which is equivalent to an installed power generation capacity of 1 to 10 million MW), which is of the same order of magnitude as world electrical energy consumption in the 1970's (Isaacs and Seymour, 1973; WEC, 1993). Figure 2-1 below shows that the highest wave climates, with annual average power levels between 20 to 70 kW/m or higher, are found in the temperate zones (30 to 60 degrees north and south latitude) where strong storms occur. However, significant wave climates are still found within ± 30º latitude where regular trade winds blow; the lower power levels being compensated by the smaller wave power variability.

3.2 Lake Malawi meteorology

Lake Malawi (or Nyasa) lies at 475 meters (1,600 feet) of altitude in the Rift Valley; along its shores, there are beaches, which in the afternoon are cooled by breezes and the lake is surrounded by mountains (World Climate Guide, 2021). The wind and therefore the wave regime of Lake Malawi are influenced by a number of meteorological features. Lake Malawi lies far enough south of the equator to experience.

marked seasonal variations in wind, temperature and precipitation (Eccles, 1974). It is to a large extent delimited by geological faults, particularly to the north and on the eastern coast. As a result, these shores are steep and depths in excess of 200m are found close inshore. At the southern extremely and along the southern half of the west coast the shoreline is more gently shelving (Eccles, 1974). Lake Malawi experiences Mwera winds which blow with maximum speed of up to 50km/h.

3.3 Numerical Weather Prediction (NWP)

According to the UK Meteorological Office (British weather bureau), numerical weather prediction concentrates upon two problems: “diagnosing the current state of the atmosphere and numerically modelling of how the atmosphere will evolve with time”. Observations of weather conditions are input into the NWP model and are representative of the current state of the atmosphere. From these observations weather forecasts are made. Forecasts are continually updated with observations and satellite input.

Satellite imagery is employed to observe meteorological variables such as wind speed and direction, cloud height and cloud amount, surface temperature, sea ice cover, vegetation cover, precipitation, etc. Forecast of wave conditions can be derived from predicted wind fields which are derived from forecast atmospheric conditions. A few examples of wind- and wave forecast models of the following organizations can be found on their respective websites: Buoyweather.com, Oceanweather.com, Stormsurf.com and NOAA NCEP.

3.4 Wave characteristics and parameters relevant to water wave power (CEM, 2002) basic wave mechanics

Since this investigation deals with wave power in deep water and intermediate water depth where linear wave theory describes wave parameters sufficiently accurate, the linear wave theory was used to define the parameters relevant to wave power below. Linear (or Airy) wave theory describes deep water waves as simple sinusoidal waves. The part of the wave profile with the maximum elevation above the still water level (SWL) is called the wave crest and the part of the wave profile with the lowest depression is the wave trough. The distance from the SWL to the crest or the trough is the amplitude of the wave and the wave height (H) is defined as the total distance from the trough to the crest. The wavelength (L) of a regular wave at any depth is the horizontal distance between successive points of equal amplitude and phase for example from crest to crest or trough to trough.

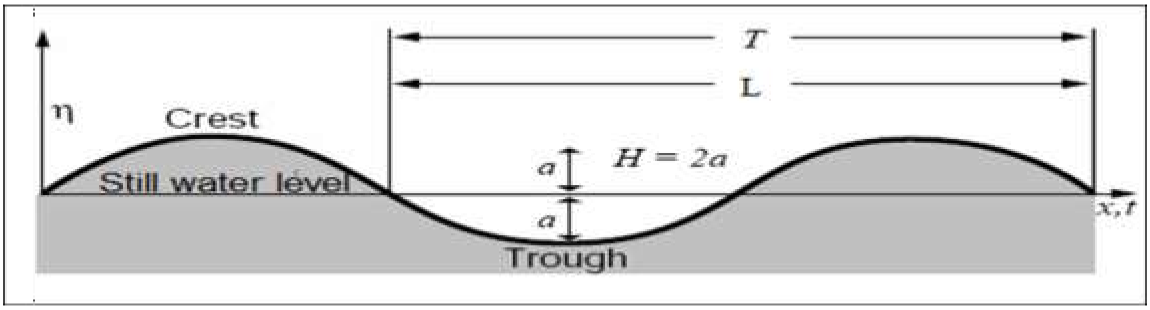

Figure 2. A Simple Sinusoidal Wave
(WMO, 1998)

3.5 Wave Height Analysis: Significant and Maximum Wave Heights

The significant wave height, Hsig is the mean of the highest third of the waves, and represents well the average height of the highest waves in a wave group. The analyzed wave height of Nkhatabay in the year 2019 for the month of December had the highest mean significant wave height of 0.4m. The results from the recorded heights at Nkhatabay station depicted a pattern that showed greatest wave heights in months of June and July. This is probably because of the prevalence of Mwera winds which blow over the lake during these months hence influencing a rise in wave heights.

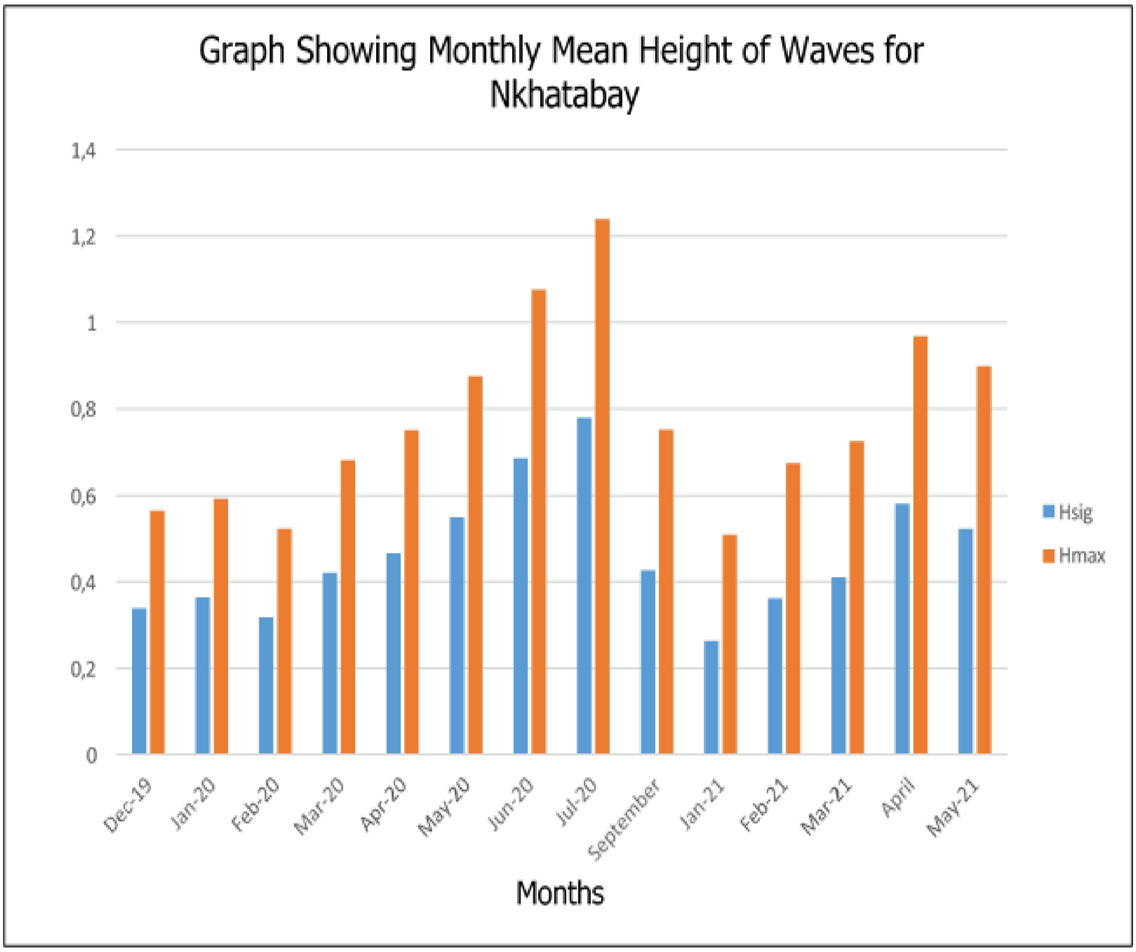

Figure 3. Showing monthly mean height of waves for Nkhatabay

There is a relationship between Significant wave height and time taken for a wave to take place. This was shown by a correlation test done on R. Wave data for December, 2019 produced a P-value less than 2.2 e -16 with a correlation coefficient of 0.55. Figure 2.1 below shows the relationship that exists between Significant wave height and the time taken for a particular wave to take place. It was observed that longer waves with larger significant wave heights required a larger amount of time to complete. For example, a wave with Hsignificant value of 0.2m required 2s to complete while a wave of Hsignificant value of 0.4m took over 2.5s to complete.

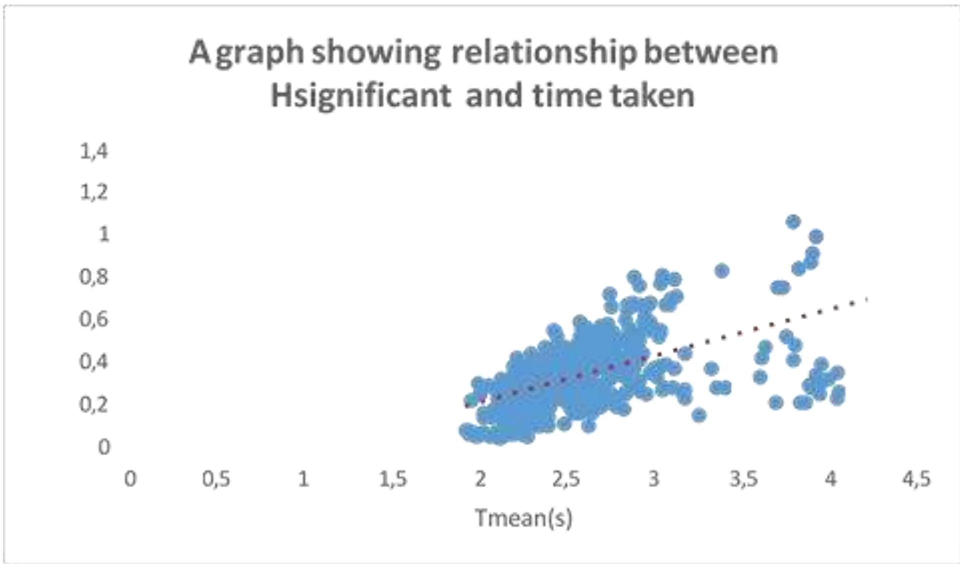

Figure 4. A graph showing a relationship between significant wave height and time taken

3.6 Wave probability distribution

The variation of waves is often described using Weibull density function. It is a statistical tool which is widely accepted for evaluation of wave probabilities and considered a standard approach. Probability plotting was used to calculate both Weibull parameters. Figure 2.0 Shows the Weibull Probability Density Function (WPDF) and the Weibull Cumulative Density Function. It is observed that the probability of having the highest density of waves is at 0.55. Another method is to determine frequency of occurrence using frequency distribution functions like Weibull distribution, Rayleigh distribution, chi squared distribution, generalized normal, log normal-distribution, three-parameter log-normal, gamma distribution, inverse Gaussian distribution, kappa, wake by, normal two variable distributions, as well as hybrid distribution.

Researches have shown that Weibull function fits the wave probability distribution more accurately compared to others. As waves change regularly, frequency distribution of waves based on time series data can be calculated. Exact probability density function describing the wave data is difficult to find. Weibull distribution is a two-parameter function characterized by scale parameter a (m) and shape parameter b (dimensionless).

Shape parameter b and scale parameter a, can be calculated using many methods as shown by previous researches. Graphical method (GM) which is also called Probability plotting, Method of moments (MOM), Standard deviation method (STDM), Maximum likelihood method (MLM), Power density method (PDM), Modified maximum likelihood method (MMLM), Equivalent energy method (EEM) are widely used (Parajuli, 2016). In literature about wave energy, these methods are compared several times however results and recommendations of the previous studies are different from each other. For this reason, according to the results of the studies, it might be concluded that suitability of the method may vary with the sample data size, sample data distribution, sample data format and goodness of fit tests. After performing a probability plotting, estimated parameter values of the available wave data produced a shape parameter of 5.426 and a scale parameter of 3.147 m which were derived from significant wave height values. Figure 5 below is a graph showing recorded significant wave height distribution at Nkhatabay.

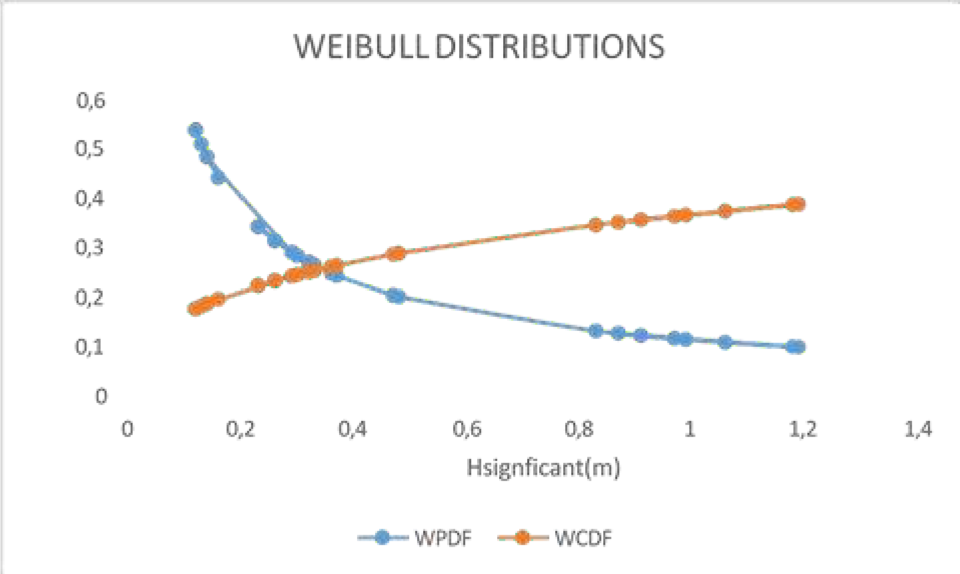

Figure 5. A graph showing recorded significant wave height distribution at Nkhatabay

3.7 Wave power (wave energy flux) calculation procedure

The wave power procedure used in this study is similar to that as defined in the thesis of (Geustyn, 1985). Measured wave data generally consist of wave parameters such as Significant wave height, time period and the wave direction. Wave power is measured in Watt/m or kWatt/m. Wave power potential of less than 5 kW/m is considered unfeasible to tap. Because of the high density of water (800) times more than air, sea waves have the highest energy density among the other renewable energy sources. Studies from University of Edinburgh have shown that over 81 percent of wave power can be converted into electricity. Using available data, statistical means of Significant wave height, wave time-period were calculated on Microsoft Excel and equation 2 was applied to estimate the power output of Nkhatabay. Analysis of available wave data presented the following statistical values in the table below.

Table 1. A table showing variables obtained from analysis of wave data

Variable	Value
Estimated Power Output (Annually)	202 Kw/m
Mean Significant Wave Height	0.468m
Mean Time Period	2.834s
Hsignificant Standard Deviation	0.31896

Using equation 2, calculations were made using mean values that were found and it was observed that power of about 202 KW/m per year could be generated at Nkhatabay. The graph below shows the relationship that exists between Significant wave height and power output. There is a direct relationship as increased values of Significant wave height portrayed increased values of power output. The analyzed data for the month of December, 2019 showed the highest value of Power output of 5900 W/m for a significant wave height value of 1.2m.

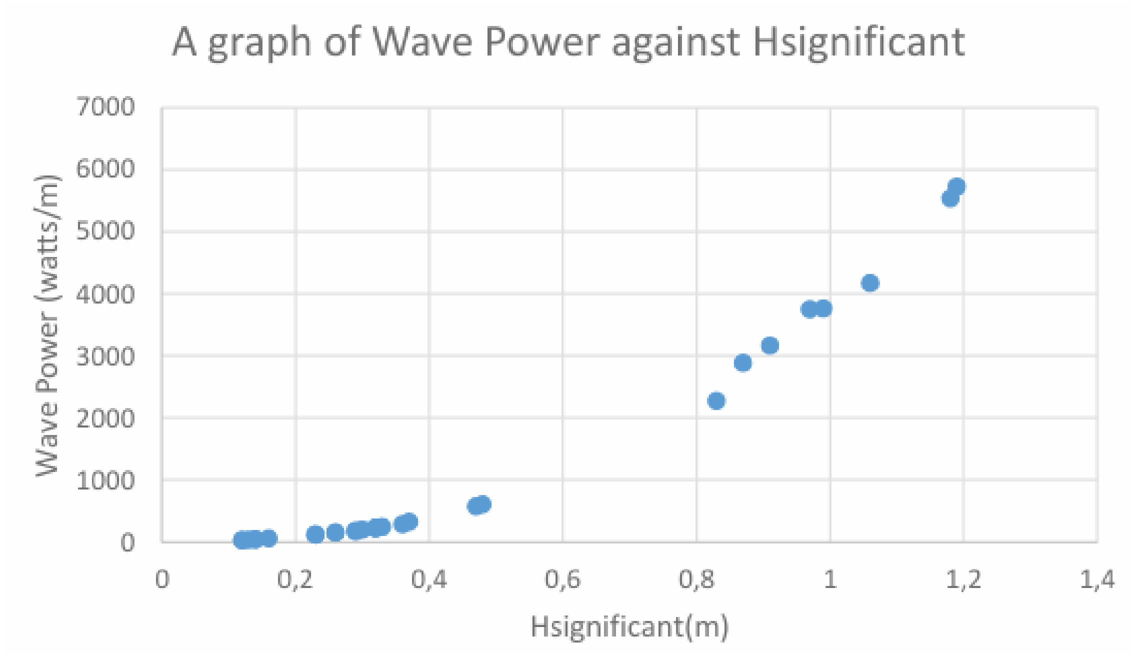

Figure 6. A graph showing a relationship between wave power and significant wave height at Nkhatabay

4. Conclusion

This paper provided a detailed wave resource analysis of a Nkhatabay station, a site in Lake Malawi, with regard to statistical analysis of water waves based on recorded wave data from the test site. This study has significant importance for wave energy converter development in Nkhatabay, on the survivability assessment of wave energy converters. A distribution methodology is proposed in this paper to model the significant wave height. A sound fit to the wave data from Nkhatabay recording station resulted from the distribution model. This proposed the distribution method can describe the characteristics of the significant wave height with a great accuracy at the site and it will give more reliable results on wave energy source estimation at the test site and wave energy converter performance. The most outcomes of the study can be summarized as follows: [1] Waves intensify over the Lake in June and June due to prevalence of Mwera winds which interact with water to form waves with greatest wave heights. [2] The average significant wave height for Nkhatabay wave data was found 0.467m and standard deviation was 0.319 and this was used to estimate the Wave Power potential of Nkhatabay using equation 2. [3] The wave power output was found that using a standard wave turbine at a depth of 5m in the lake, it can harness an average wave power of 202kW/m per year. This is relatively small for electricity production from wave power. It is safe to conclude that the potential for wave power generation in Nkhatabay is relatively small for large scale generation of wave electricity. However, can be considered for small scale applications. [4] After analysis of available data, it was discovered that there is a wave power potential of 202 kW/m per year for the period wave data was recorded.

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Author Contribution

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Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The author declare no conflict of interest.

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