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GIS-Based Method for Finding Optimal Ocean Energy Location: A Case Study of Terengganu State

S H B Shafiai[1], A Gohari[1], J G Zhou[2] and P N E B Nohuddin[3]

[1] Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia.
[2] School of Computing, Mathematics and Digital Technology, Manchester Metropolitan University, All Saints Building, All Saints, Manchester, M15 6BH, United Kingdom.
[3] Institute of Visual Informatics (IVI), Universiti Kebangsaan Malaysia, 43600 UKM, Bangi Selangor, Malaysia.

Abstract. Ocean energy is one of the most important renewable energy sources and it can highly contribute to the supply of the world's electricity demands. This paper presents a method of locating the highest potential sources of ocean energy by implementing Geographic Information System (GIS). The aim of this study was to find the optimal wave energy location in the coastal area of Terengganu state in Malaysia. The wave data for the years 2015-2017 have been collected. The GIS was adopted to prepare data for analysis and perform geostatistical analysis. The results showed the exact location of areas in the coastal area of Terengganu in which maximum energy from the ocean can be harvested. The proposed methodology can be applied in other coastal areas.

1. Introduction

Renewable energy, which often called clean or green energy, originates either from natural sources or processes that are constantly replenished. Gradually, conventional thermal power-generating sources are replacing with renewable energy sources especially in the power sector [1]. As mentioned in the report by the European Commission [2], oceans represent an abundant, huge, and predictable resource for renewable energy and can significantly contribute to supplying the world's electricity demands. Wave energy is a type of ocean-based renewable energy source that can be used to generate electricity by using wave power. The wave energy has long been considered one of the most promising renewable technologies [3]. According to The Economist website [4], the main advantage of wave energy against solar and wind sources is that it is more dependable than them because of wave power availability for up to 90 percent of the time, while their availability is about 20-30 percent of the time.

The efficient harvesting of ocean wave energy necessitates proposing the location of highest potential energy sources in coastal areas. Since the problem of finding the location of optimal energy sources is geo-spatial problem, GIS can be implemented effectively to solve the problem by providing different tools for spatial and geostatistical analysis. Some researchers have studied the potential of marine renewable energy sources in Southeast Asia. Nasir and Maulud [5] assessed the wave power potential in Malaysian territorial waters to develop a wave energy converter. They concluded that the most suitable area is in the waters of Terengganu and Sarawak. Also, the average potential energy that can be generated in Malaysian territorial waters is between 2.8kW/m to 8.6kW/m. Samrat et al., [6] investigated wave energy at different locations in Malaysia and concluded that Malaysia has excellent wave energy resource. Chong and Lam [7] presented the current status and future prospects of

renewable energy in Malaysia with particular focus on the ocean renewable energy. They compared different types of ocean renewable energy and identified Tidal current energy as a preferable option particularly in the Straits of Malacca. Belhamadia et al., [8] discussed the wind and solar energy potentials in Malaysia. Their result revealed that Mersing has the highest wind speed and the highest wind speed occurs during the northeast monsoon. Lin et al., [9] utilized satellite remote sensing technology and GIS technology, and simulated wave data to present the wave energy in the South China Sea. Their result stated that there is feasibility and viability for wave energy farming in the South China Sea. Purba et al., [10] developed four dynamic oceanographic, combining with technologies using GIS approach to find areas in Indonesia that are potential to produce energy from the ocean with different level. Malik [11] assessed potential renewable energy sources such as solar, wind, ocean, and biomass for Brunei. His result indicated that although there is potential for wave energy, but it may not be economically viable. Morim et al., [12] assessed the wave energy resources along the Southeast coast of Australia based on the 31-year hindcast. They have concluded that the most promising area for wave power exploitation was the central coast of New South Wales.
This research provides a GIS-based approach to find the exact location of optimal wave energy sources in the coastal area of Terengganu state in Peninsular Malaysia. Firstly, the required data such as wave information has been collected. Then, ArcGIS software, which is supplied by Environmental Systems Research Institute (ESRI), was used to make the collected data ready for analysis and perform geostatistical analysis to obtain the result.

2. Methodology
This study used ArcGIS Desktop 10.6.1 as a platform to analyse the geospatial data. The data in GIS can be categorized into spatial data and attribute tables. Spatial data can be represented by vector and raster data (grid data) structures. The vector format includes three types of data such as point, line (arc) and polygon, while data type in raster format is surface. In fact, raster data are made up of regular-spaced pixels and each pixel allocated by a single value or class. Attribute tables are made up of records and fields such that all records have the same fields and each field can store specific type of data.

2.1. Data preparation and geodatabase design
The required data were including the geographical location of the study area and observation points, and wave information such as wave height, and wave period for the years from 2015 to 2017. The area of this study was the coastal area of the Terengganu state in Peninsular Malaysia. Terengganu is located on the east side of Malaysia, which is illustrated in Figure 1, and it overlooks the South China Sea.

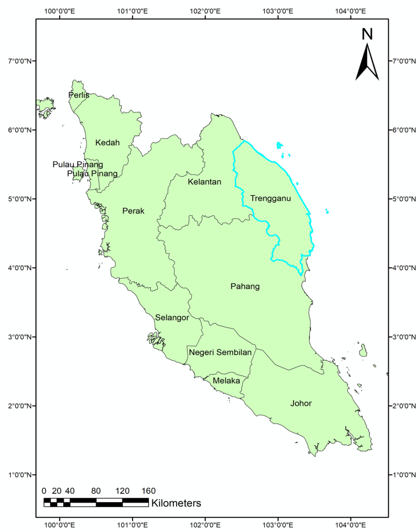

Figure 1. Location of the study area.

The observation points are points on the sea including information of wave height, and wave period for the years 2015, 2016 and 2017 which have been collected by National Hydraulic Research Institute of Malaysia (NAHRIM). The obtained data were in tabular format and needed to be georeferenced in ArcMap. For this purpose, the geographical coordinate system of them set to the World Geodetic System (WGS84), which is used by the Global Positioning System (GPS), for its reference coordinate system. The location of georeferenced observation points and the Terengganu state is shown in Figure 2. The observation points, Terengganu state and its coastal area, which covered by observation points, were saved in separate shapefiles in Arc Map as points and polygon respectively. In order to check the accuracy of the georeferenced data, they have been converted into the Keyhole Markup Language (KML) format which enables the representation of geographic features in applications such as Google Earth. Figure 3 illustrates the location of georeferenced data in Google Earth.

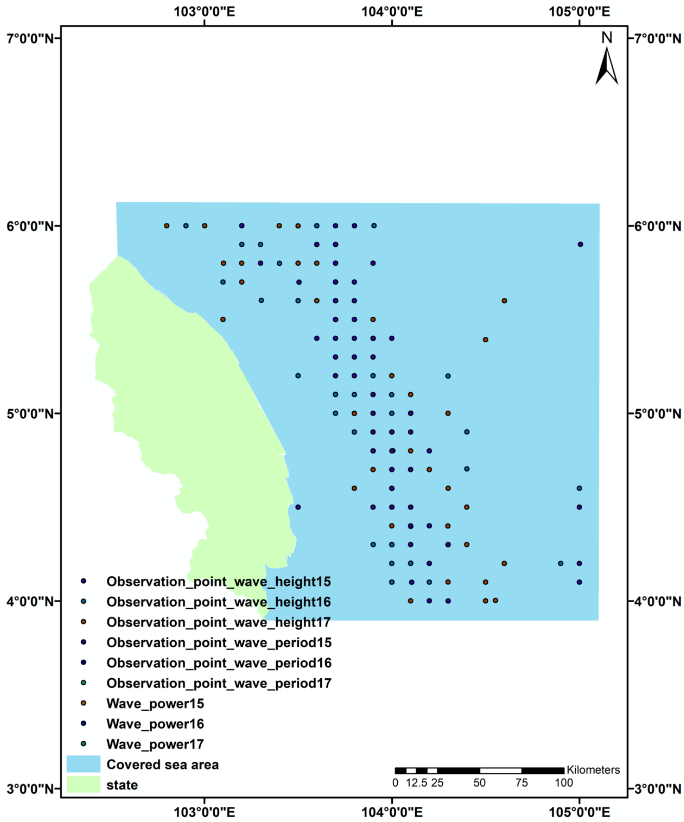

Figure 2. The georeferenced Terengganu state and observation points in Arc Map.

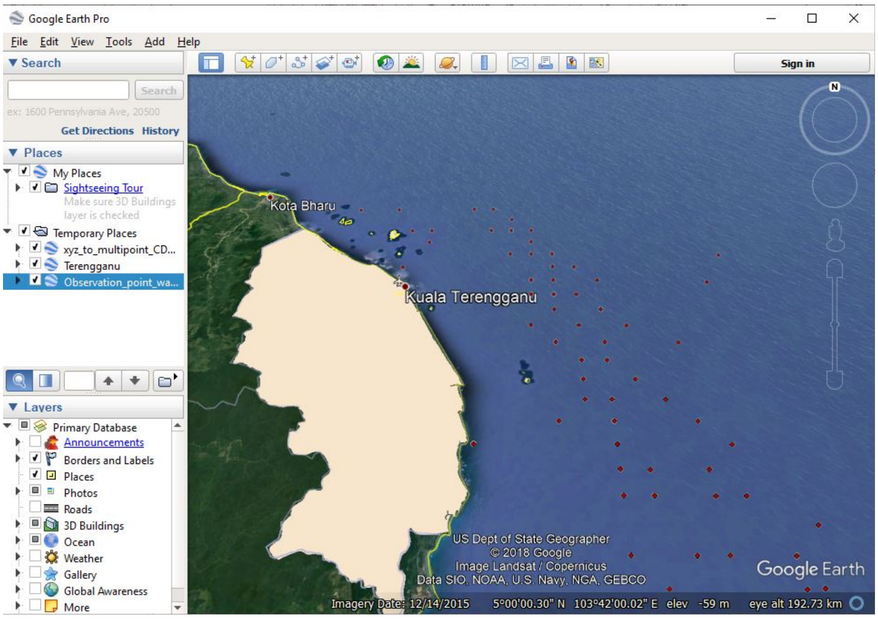

Figure 3. The location of the georeferenced study area and observation points in Google Earth.

An Arc GIS geodatabase is a collection of geographic datasets of various types held in a common file system folder and enable users to organize and store spatial databases, tables, and raster datasets. File geodatabase and personal geodatabase are two types of single user geodatabases. The file geodatabase has been designed in ArcCatalog including point feature classes such as wave period, wave height, and wave power for each year, and Terengganu state polygon feature class. The content of the designed geodatabse depicts in Table 1.

Table 1. The content of the designed geodatabase.

Feature class	Type
Wave height 2015-2017	point
Wave period 2015-2017	Point
Wave power 2015-2017	Point
Terengganu state	Polygon

2.2. Equations of wave power energy
Wave height and wave period are two effective parameters on the wave energy. The wave power energy equation originally derived from the general equation of wavetrain energy, E=ρgH^2, where ρ is the density of the water and H is the root mean square wave height (H^2 = a^2/2). The wave power energy, which is introduced by Cruz [13], is calculated by

$$E\left(\frac{kW}{m^2}\right) = c \times H^2 \times T \quad (1)$$

where c = constant given by ρg^2/4π (≈ 7.87 kW · m^{-3}· s^{-1}), H is the wave height (m), and T is the wave period (s).

3. Results
The result of this study is in two parts. The first part includes interpolation and reclassification of three years data of wave energy parameters. The second part of result constitute weighted overlay analysis of yearly-basis and 3 years of data of combined effective parameters (wave height, wave period, and wave power) on wave energy.

3.1 Interpolation and reclassification

Interpolation predicts values for cells in a raster from a limited number of sample data points. Inverse Distance Weighted (IDW) is one of the interpolation methods which estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight, it has in the averaging process. The reclassification enables reclassify or change cell values of a raster file to alternative values implementing a variety of methods. For this study, the scale for reclassification of interpolated data was considered as 1 to 9. The best phenomena condition for optimal energy location is rated 9, and the worst one is rated 1. Interpolation rasters and reclassification rasters related to wave height, wave period, and wave power of 3 years combined data (2015-2017) are illustrated in Figures 4, 5, and 6 respectively.

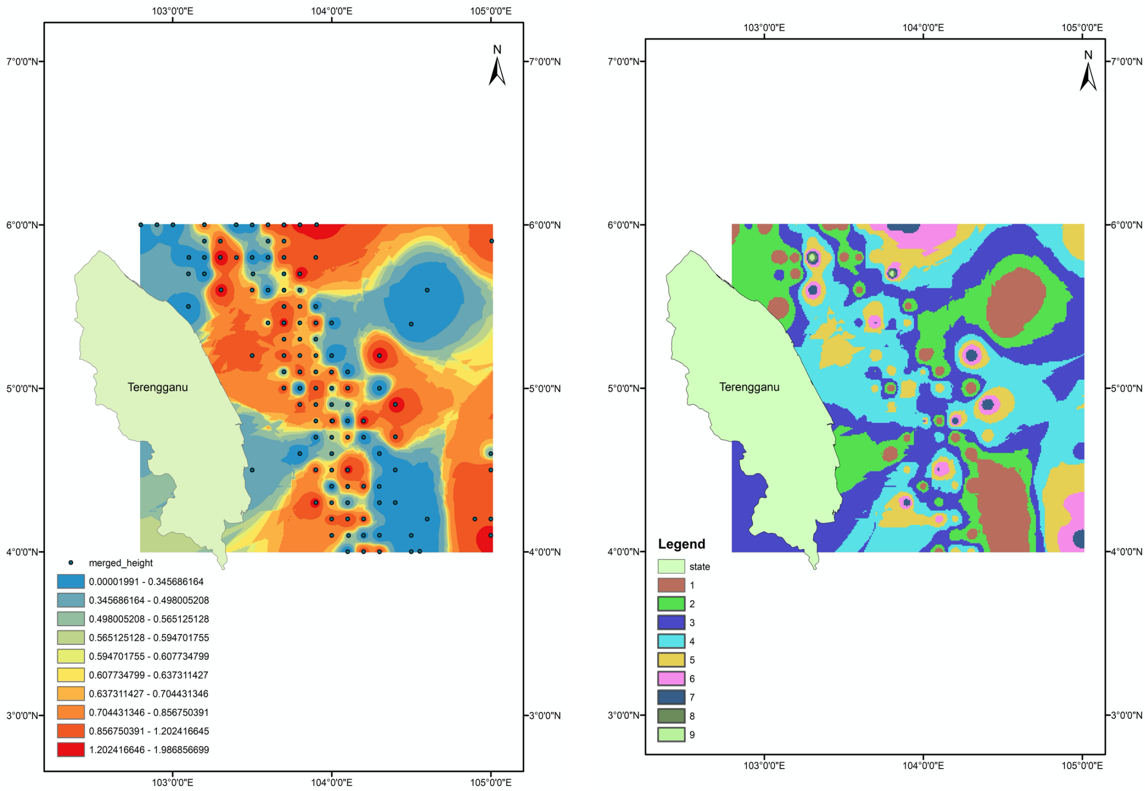

Figure 4. Interpolation of wave height (left) and its reclassification (right).

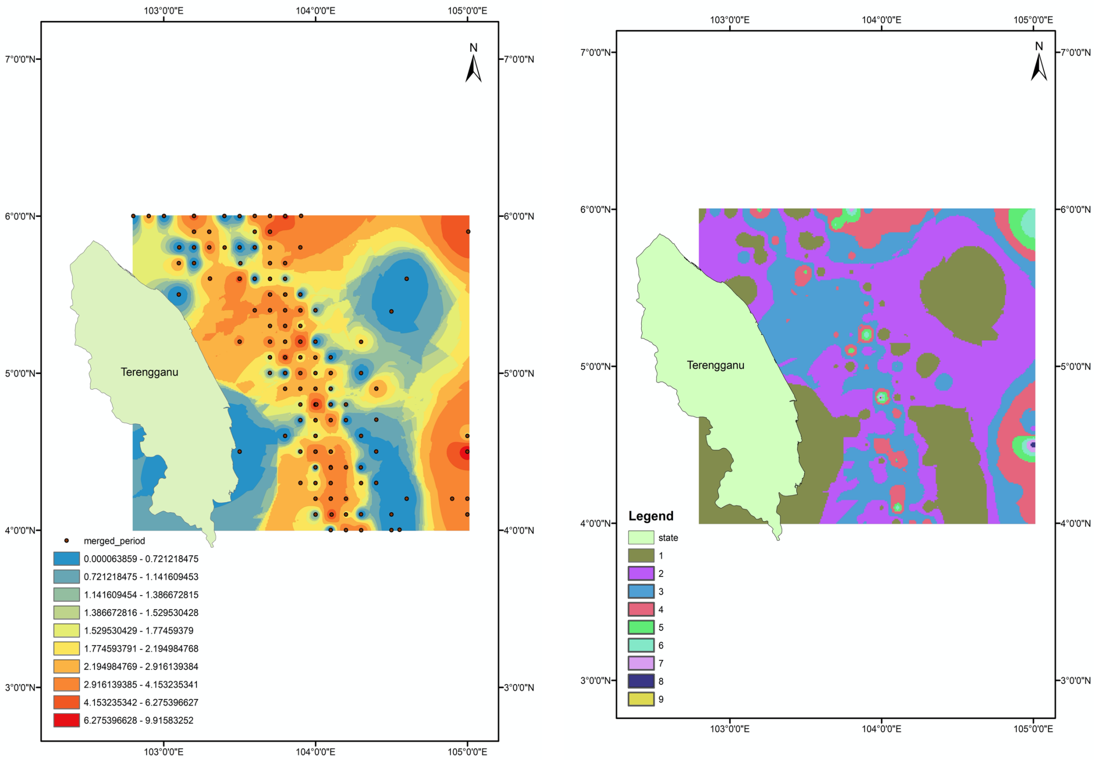

Figure 5. Interpolation of wave period (left) and its reclassification (right).

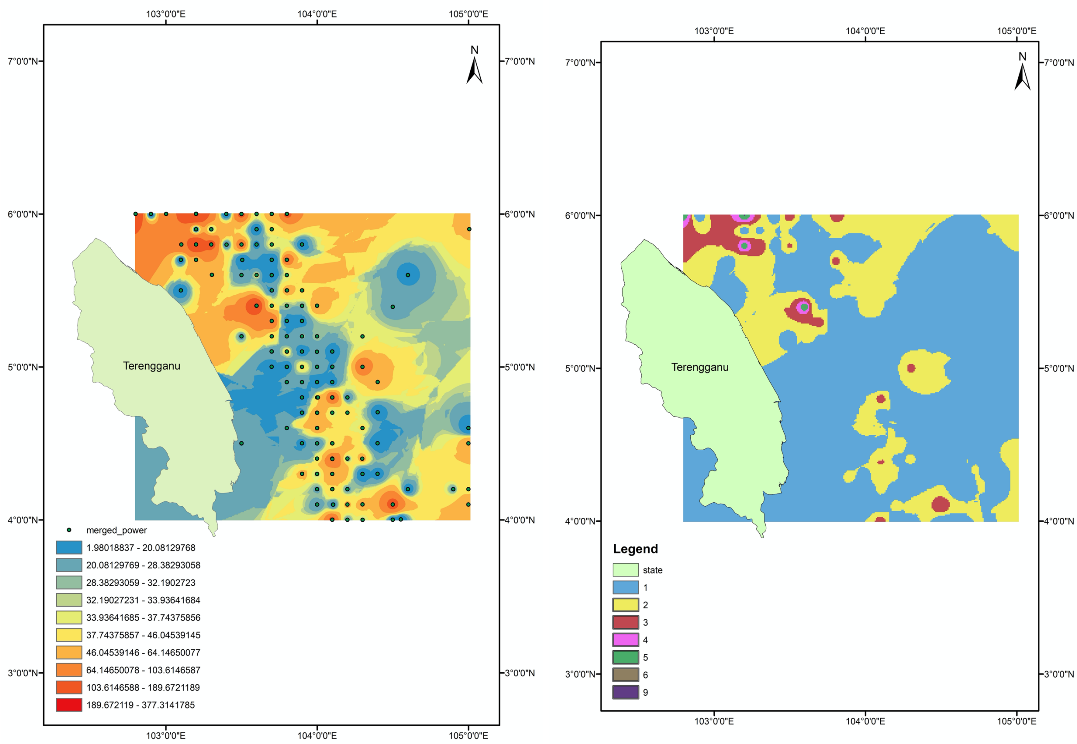

Figure 6. Interpolation of wave power (left) and its reclassification (right).

3.2 Weighted overlay analysis

Basically, Multicriteria problems can be solved by the weighted overlay analysis approach. Therefore, in this study, it was performed to obtain the result of yearly-basis and 3 years of data analysis of combined effective parameters (wave power, wave height, and wave period) on wave energy. For this purpose, shapefiles of effective parameters for each year merged into one shapefile. In addition, weights need to be assigned to each effective parameter of wave energy. Since the equation of wave power dependent in wave height and period, the assumed weight for the wave power, wave height, and wave period were considered as equal. These weights along with reclassified maps in Figures 4-6 input into raster calculator (map algebra) tool to execute a single map as the final result for each year. The yearly-basis results from 2015 to 2017 are shown in Figure 7. The results are shown in five classifications of a range of values and related colors, where the highest range of values (red color) represent the location of highest potential wave energy in the coastal area of Terengganu state for each year. The result indicates that the highest wave energy could be harvested in 2016 when compared with the years 2015 and 2017. Another result of this study was the location of optimal energy based on a combination of 3 years data which is depicted in Figure 8. In order to achieve this result, shapefiles of effective parameters for all three years merged into one shapefile. Then, the same procedure as yearly-basis analysis has been followed. In Figure 8, the coastal area highlighted in red color represents maximum wave energy, followed by blue, green, yellow, and grey. The map result in Figure 10 states that the optimal wave energy located in the coastal area between 5°0′0″N-103°0′0″E and 6°0′0″N-104°0′0″E.

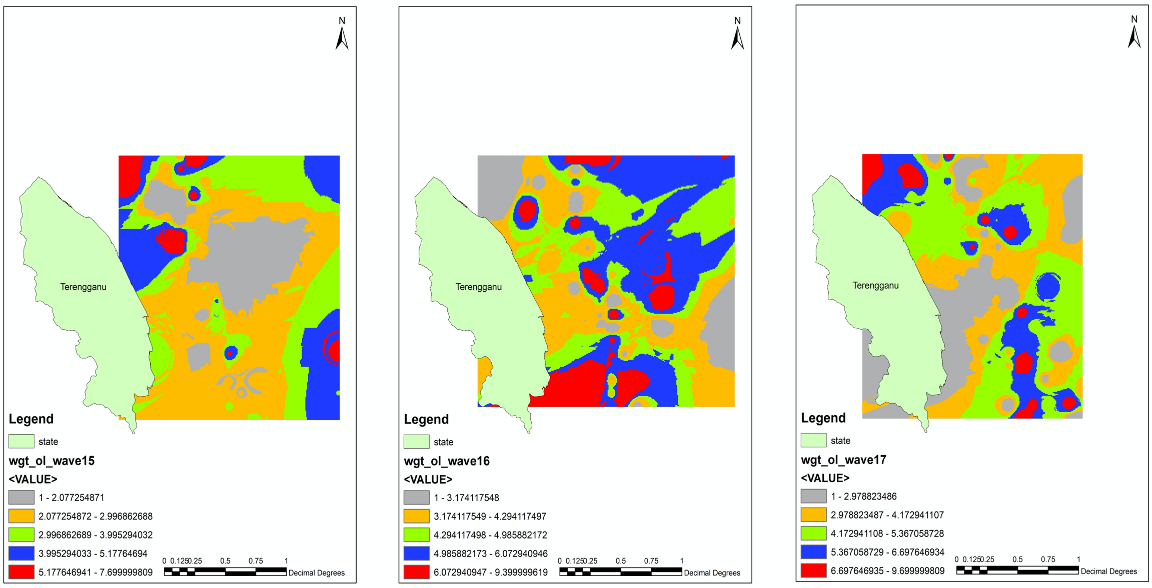

Figure 7. Yearly-basis result for 2015 (left), 2016 (middle), and 2017 (right).

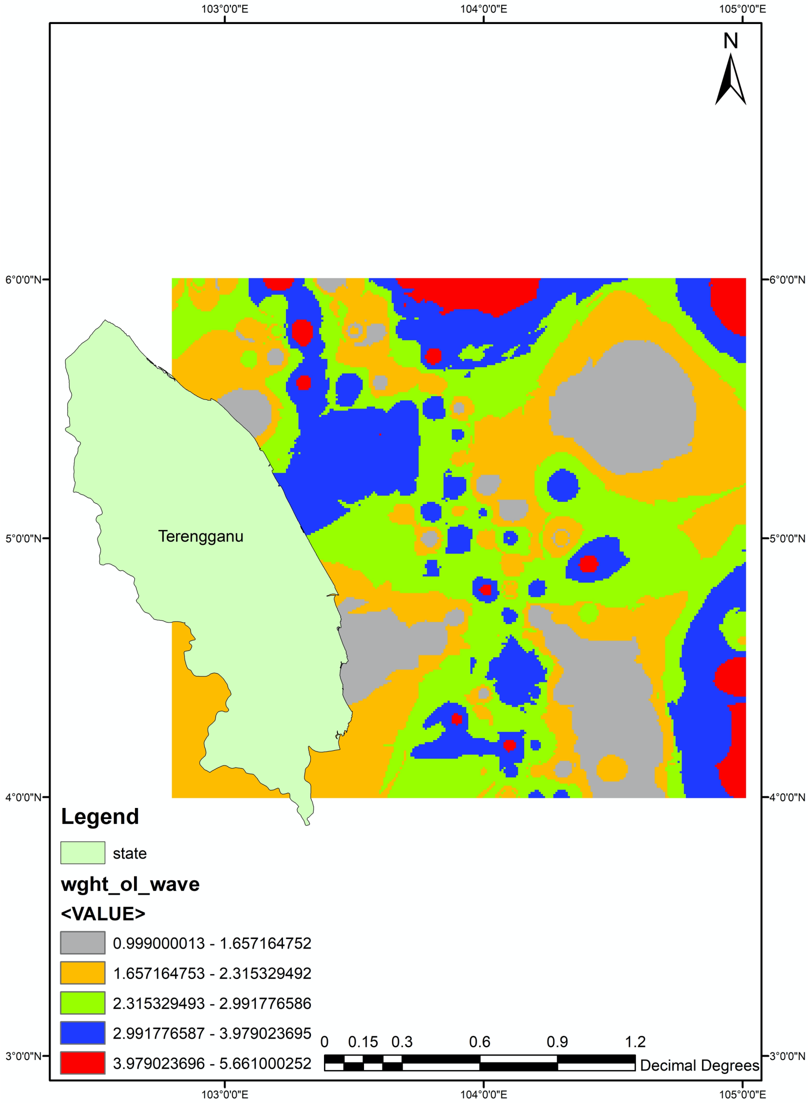

Figure 8. Raster representation of result based on three years combined data.

4 Conclusion

This paper presented the application of GIS in finding the location of optimal wave energy in the coastal area of Terengganu state in Peninsular Malaysia. The methods and tools were used in GIS environment were include geodatabase design, merge, Interpolation by using IDW method, reclassification, and weighted overlay analysis by implementing map algebra. The location of optimal energy was identified for each year and cumulative years. The coastal area of Terengganu state can be considered as highly potential wave energy. To develop this study, it is suggested that the bathymetry information of the sea also to be considered in analysis. Furthermore, it is recommended that expand this study by obtaining real-time data of wave from satellites in order to produce a live map of energy sources in the coastal areas.

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Nomenclature

Symbol	Description	Units
E	Wave power energy	Kw/m^2
ρ	Water density	Kg/m^3
g	gravity	m/s^2
H	Wave height	m
c	Constant	
T	Wave period	s