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Sustainable Management of the Coastal Water pH of Pulau Tuba Using the Inverse Distance Weighted (IDW) Method

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ABSTRACT

Ocean acidification can be managed and monitored effectively through the application of spatial interpolation methods. The purpose of this study is to evaluate the precision of the Inverse Distance Weighted (IDW) interpolation method to estimate and map the coastal water pH for the sustainability of Pulau Tuba, Langkawi, Kedah. About 30 sampling points have been set up during two sampling activities in November 2018. The pH meter has been calibrated and lowered to 1 meter below the water surface to measure the reading of pH. The development of the spatial model was developed using the spatial analyst tool available in ArcGIS Software. Several types of statistical analyses were carried out to compare the observed and predicted value of pH. such as correlation analysis, regression analysis, and error analysis. Accuracy assessment was conducted later after the transformation of a spatial model into a surface map. The study found that the IDW interpolation method successfully interpolated the pH readings. The result showed that there is a strong positive correlation between the observed and predicted values. For error analysis, Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were recorded at 0.033 and 0.044, respectively. After the transformation of the spatial model to the surface map, the accuracy of the map is recorded at 81.25%. The study also outlines the sustainable mechanisms and opportunities for the government to implement in combatting the ocean acidification processes. The map produced can be used for social and economic development and the protection of biodiversity for the coastal water of Pulau Tuba.

Keywords: *Accuracy, Interpolation, Inverse Distance Weighted, pH, Pulau Tuba*

INTRODUCTION

By 2025, coastal eutrophication is expected to rise to 20% due to inefficient or poor management of pollution and eutrophication processes (Racine et al., 2021). Sustainable development, especially in eliminating pollution that includes plastics, surface runoff and untreated sewage that came from the land can be reduced if the government takes necessary action to counter them at the early phase (Edokpayi et al., 2017). A sustainable process in making sure these pollutants do not seriously affect the valuable marine resources which could become worse when ineffective climate change plans are

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put into action (Ferronato & Torretta, 2019). Ocean acidification has become a major issue discussed in many governments and new policies are making their way to reduce it (Billé et al., 2013).

A sustainable approach should be implemented by making the right policy and monitoring plan (Purvis et al., 2018). Before any plan being applied to reduce and monitor the effects and impacts of the ocean acidification process, managing the hot spot location of the potential of pH upsurges should be carried out first. However, getting baseline data of ocean acidification phenomena could become problematic when there is a lack of tools to be used to visualize and communicate successfully between the current pollution status and the public. Government can use the Geographical Information System (GIS) to manage geospatial data related to ocean acidification. Besides, numerous location-based data are being transformed into valuable geospatial information that can be used for the decision-making process (Sui, 2014). Environmental accident, environmental, pollution management and land-use planning can benefit from the relevant management team that used GIS (Miller, 1999). One way of managing and monitoring the ocean acidification process is by using spatial interpolation methods (Agostini et al., 2018).

Spatial interpolation has become a tool for predicting unknown values from unknown locations in the study area using known values (Kamaruddin et al., 2021). The technique has several advantages such as high accuracy, being low cost, and being able to save time for sampling activities (Kamaruddin et al., 2018). However, choosing the right interpolator to interpolate the attribute data required an assessment of accuracy (Kamaruddin et al., 2020a). To date, there is less research focused on interpolating sea surface pH, especially in remote areas, and highly subjected to pollution. Besides being cost, energy and time effective, the spatial interpolation method can be used as an effective plan for sustainable management of marine resources. Marine resources such as fish in the ocean are sensitive to pH changes. At the surface, changes in pH have a significant effect on the biodiversity of phytoplankton and zooplankton.

Sea surface pH can be predicted using many tools or modelling techniques for a sustainable approach toward healthy coastal and estuarine ecosystems (Kamaruddin et al., 2021). However, in the coastal area and mangrove ecosystem, modelling pH can be difficult as many factors could contribute to the fluctuation of pH readings. Furthermore, due to increasing concern about the impact of global warming, studying the distribution of pH in the coastal and mangrove ecosystems is significant especially at the location of high biodiversity of species (McNicholl et al., 2020). The pH at the surface water is important to be monitored especially when involving delicate species such as plankton (Spisla et al., 2021).

The Inverse Distance Weighted (IDW) interpolation method can be used to manage the hot spot location of probable pollution events and as a guideline for implementing suitable sustainability monitoring and managing of marine resources potentially affected by the ocean acidification activity. The IDW interpolation method used weight distance as the key to predict or estimate valuable geospatial information. The government might be able to obtain images of the ocean acidification process that occur in a location where the biodiversity is high and significantly important to be sustained.

One location that has high biodiversity species that combined the coastal and mangrove ecosystem is Pulau Tuba, Langkawi, Kedah. To date, there has been a lack of baseline information on the distribution of pH in this location. Besides, there has been no information on the accuracy of the IDW method to be used as an interpolator to map the surface pH. The purpose of this study is to assess the accuracy of the Inverse Distance Weighted (IDW) to estimate and map the coastal water pH of Pulau Tuba, Langkawi, Kedah. In achieving the aim of the study, several specific objectives are developed: (1) to determine the correlation between the observed and estimated reading of pH, (2) to determine the error of the estimation between the observed and estimated reading of pH, and (3) to assess the accuracy of the prediction map produced using IDW methods. Overall, the gap to be filled by this research is the unknown accuracy of the IDW method to estimate and map the distribution of pH. The study is significantly important for environmental and biodiversity protection and sustainable management and development of socio-economic activities that would benefit residents and local governments.

METHODOLOGY

Description of Study Area

Pulau Tuba is in the southeast of the main island of Pulau Langkawi, Kedah. The island is situated next to Pulau Dayang Bunting. The island has many biodiversity species that flourish from the coastal, marine, and mangrove ecosystems. The socio-economic activities by the locals are farming, fishing and operating tourism activities (Kamaruddin et al., 2020b). Pollution can be expected from non-point sources from Pulau Langkawi, however, point source pollution directly from the islands is considered minimal (Kamaruddin et al., 2019). Since the island is close in proximity to the main island of Pulau Langkawi, its' meteorological, oceanography and hydrography are similar to Pulau Langkawi.

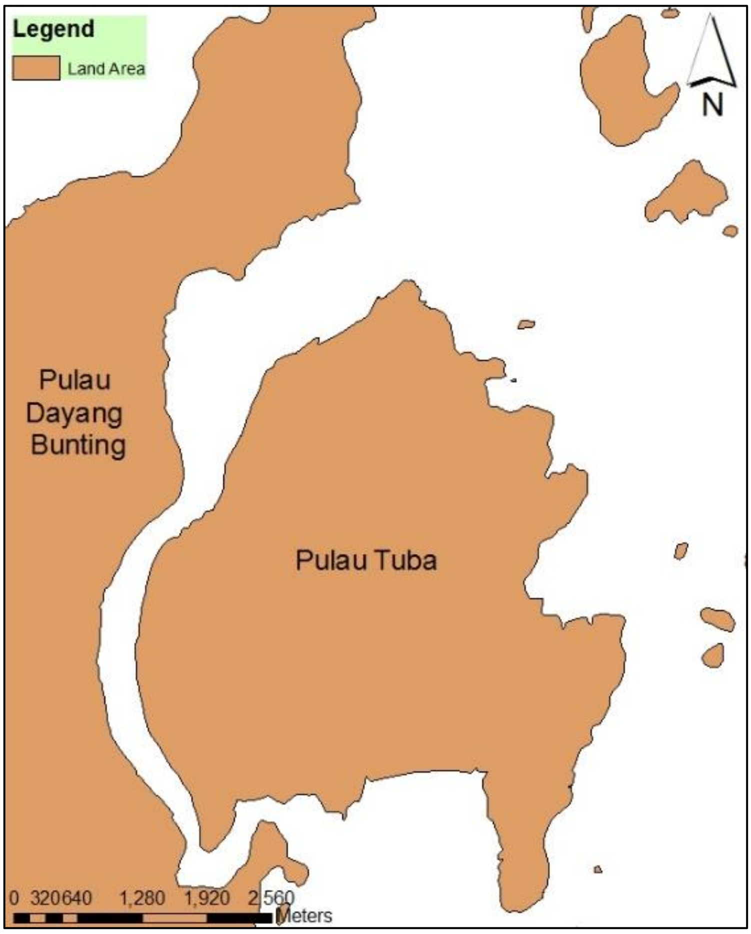

Figure 1: Pulau Tuba is Located Next to Pulau Dayang Bunting

Sampling Activities and Design

Sampling activities were carried out in November 2018. Two sampling activities were carried out as the data from the first sampling activity was used for calibration of the model and in the second sampling activity, the data was used for validation purposes. In this paper, the data for each of the sampling activities will be called calibration and validation data. A total of 30 sampling points has been established using the Global Positioning System (GPS) and the reading of pH was recorded using the pH meter. Calibration of both instruments is particularly important to avoid the issue of accuracy. A boat is used with minimal speed for sampling activities. The sampling activities started in the early morning and ended in the late afternoon. All data were sampled only during high tide and 1 meter below the surface using the marker marked on rope and cable as the pH meter entered the surface water. Sampling was carried out randomly and continuously. The data collected were based on the mean reading of three trials.

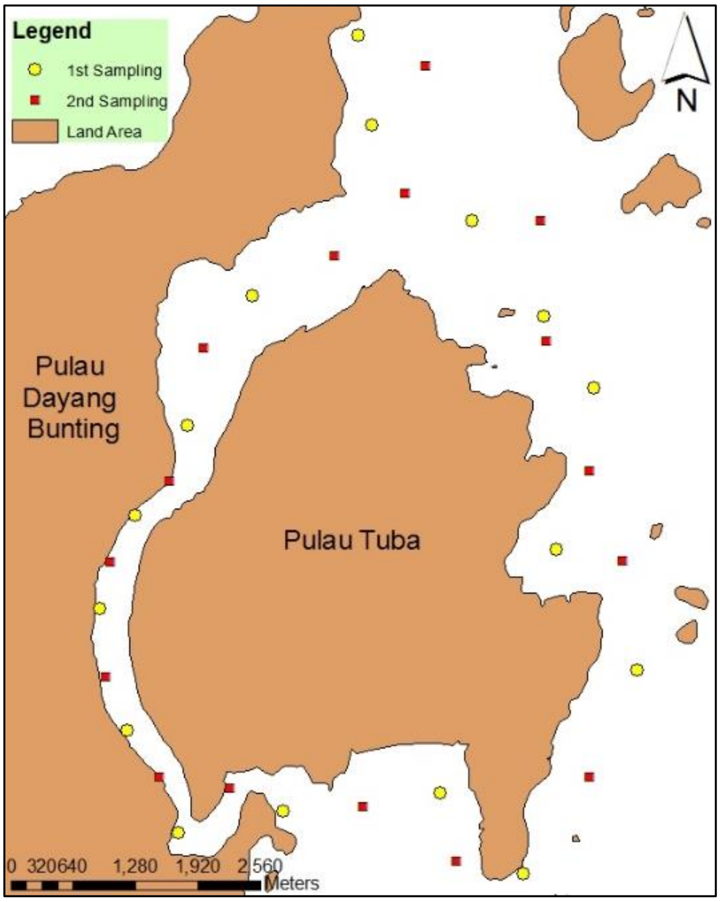

Figure 2: Sampling Points Over the Coastal Water of Pulau Tuba

Development of a Spatial Model

Calibration data were used for the development of the surface interpolation model using the IDW interpolation method. Calibration data were based on the data from the first sampling activities. According to Watson and Philip (1985), the IDW interpolation method used a weight distance average. In this research, the power option was maintained at 2 as this is the default set by systems. The output cell size, search radius, and input barrier polyline features remained unchanged as this is optional only. A total number of 16 sampling points was entered using the data entry tool. Below is shown the formulae for the IDW method.

$$V_i = \frac{\sum_{j=1}^{n} \frac{1}{d_{ij}^{\,p}} V_j}{\sum_{j=1}^{n} \frac{1}{d_{ij}^{\,p}}}$$

Where, V_i is the i^{th} unknown value, n is the number of points taken to obtain the unknown value, V_j is the j^{th} known value, d_{ii} is the distance between the i^{th} unknown value and the j^{th} known value and p is the power.

Validating of a Spatial Model

After an interpolation model was produced, the validation set was employed for comparative assessments. The validation set was based on the second sampling activity. Correlation analysis, regression analysis and error analysis were used to compare the observed and predicted values. SPSS software was used for statistical analyses with an alpha set at .05.

The Transformation of a Spatial Model to a Surface Map

In this section, the determination of the number of classes and ranges of pH were analyzed manually using the Classification tools. The maximum and minimum values were used as baseline data to set the class. Next, the transformation from a spatial model to a spatial map was done by inserting map elements such as scale bars, legend, title and north arrow for better visualization and communication.

Assessment of the Accuracy of the Map

The accuracy of the map was determined using the overall accuracy formula. The number of correct occurrences was counted and divided by the total number of sampling points. Correct occurrences criteria were based on the correct prediction of the estimated value to the observed value. Since water parameter dynamically changes and are affected spatially and temporally, the observed and predicted data were transformed to the class ranges. As the value of accuracy was subjective, the research draws the line at 75% as the threshold value. The equation of Overall Accuracy (OA) is shown below:

Overall Accuracy (OA)= (Number of Correct Occurrences)/ (Total Occurrences) ×100%

RESULTS AND DISCUSSIONS

The prediction levels of pH were successfully estimated using the IDW interpolation method. The prediction pH reading is listed in Table 1. A raw raster image was also produced as this was the output interpolated surface raster. Figure 3 shows the output raster developed using the IDW interpolation method. The research found that the data were clustered according to a range set by the ArcMap and each colour represents a set of classes.

Table 1: List of the Observed Value (validation set) and Predicted Values (estimation from the IDW interpolation method) According to Sampling Points

Sampling Points	Observed	Predicted
2	7.98	7.99
4	7.95	7.97
6	7.97	7.98
8	7.91	7.95
10	7.96	7.93
12	7.92	7.91
14	7.86	7.88
16	7.78	7.81
18	7.70	7.76
20	7.94	7.83
22	7.96	7.90
24	7.96	7.91
26	7.93	7.93
28	7.94	7.96
30	7.96	7.96
32	7.92	7.99

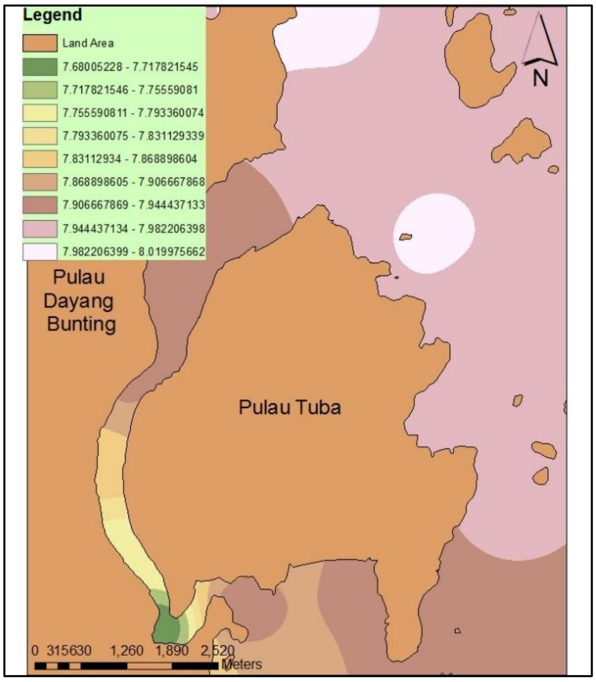

Figure 3: The Surface Interpolation of pH Level Developed Automatically by the Spatial Analyst Tool Without Classification of pH Ranges

The correlation analysis reveals that there is a positive correlation between observed and predicted values. Correlation analysis was used to determine the relationship between the observed and predicted values of pH estimated using the IDW interpolation method in the form of strength and magnitude. In this study, the observed and predicted values were found to be positively correlated, r (14) = .80, p < .05. Table 2 shows the result of the Pearson product-moment correlation coefficient analysis.

Table 2: The Pearson Product-moment Correlation Coefficient Analysis Measuring the Association between the Observed Value (Obs) and the Predicted Value (Pre)

		Obs	**Pre**
Obs	Pearson Correlation	1	.800**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	.086	.061
	Covariance	.006	.004
	N	16	16
Pre	Pearson Correlation	.800**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	.061	.068
	Covariance	.004	.005
	N	16	16
**. Correlation is significant at the 0.01 level (2-tailed).			

A simple linear regression analysis was used to predict the relationship between the observed and predicted values of pH based on the IDW interpolation method at the 95% confidence level. The prediction value of pH estimated by the IDW interpolation method did explain a significant amount of variance in the observed value of pH, F (1,14) =24.834, p <.05, R^2= .639, R^2 adjusted= .614. Table 3 shows the Analysis of Variance (ANOVA) for the regression analysis.

Table 3: The Analysis of Variance (ANOVA) Indicated the Significant F Value at 24.834.

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	.055	1	.055	24.834	.000[a]
	Residual	.031	14	.002		
	Total	.086	15			

a. Predictors: (Constant), Pre

b. Dependent Variable: Obs

The regression coefficient (b= .897) indicated that an increase in the predicted value of pH corresponded to an increase in the observed value of .897. The simple linear regression equation was reported as *observed value = .811 + .897 (predicted value)*. The prediction variable is statistically significant (p< .05), however, the constant variable was found to be not significant (p> .05) Table 4 shows the unstandardized and standardized coefficients table for the regression analysis.

Table 4: The Coefficient Table Shows the Constant and Predicted Coefficient at .811 and .897, respectively.

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.811	1.426		.569	.578
	Pre	.897	.180	.800	4.983	.000

a. Dependent Variable: Obs

For error analysis, Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were recorded at .033 and .044, respectively. Even though these analyses were used for comparing models, they were important to be reported. MAE and RMSE are important to indicate how far the predicted values are distanced from the observed values. The MAE analysis indicates that there was a 0.0033 average absolute error of the differences between the observed and predicted values. The value of 0.044 for RMSE, indicates that there was a 0.044 difference between predicted and corresponding observed values where each of the errors were squared and then averaged over the sample.

Classification of value was determined using the classification tool. The classification was made through three classes using the manual method. The classes were at <7.79, 7.79-7.90, and >7.90. Figure 4 shows the classification statistics where the maximum and minimum values were recorded between 7.68 to 8.02. Map elements were finally inserted to help in the visualization and communication of the map. Figure 5 shows the map of the surface water of pH for the coastal water of Pulau Tuba after the classification of pH ranges was done.

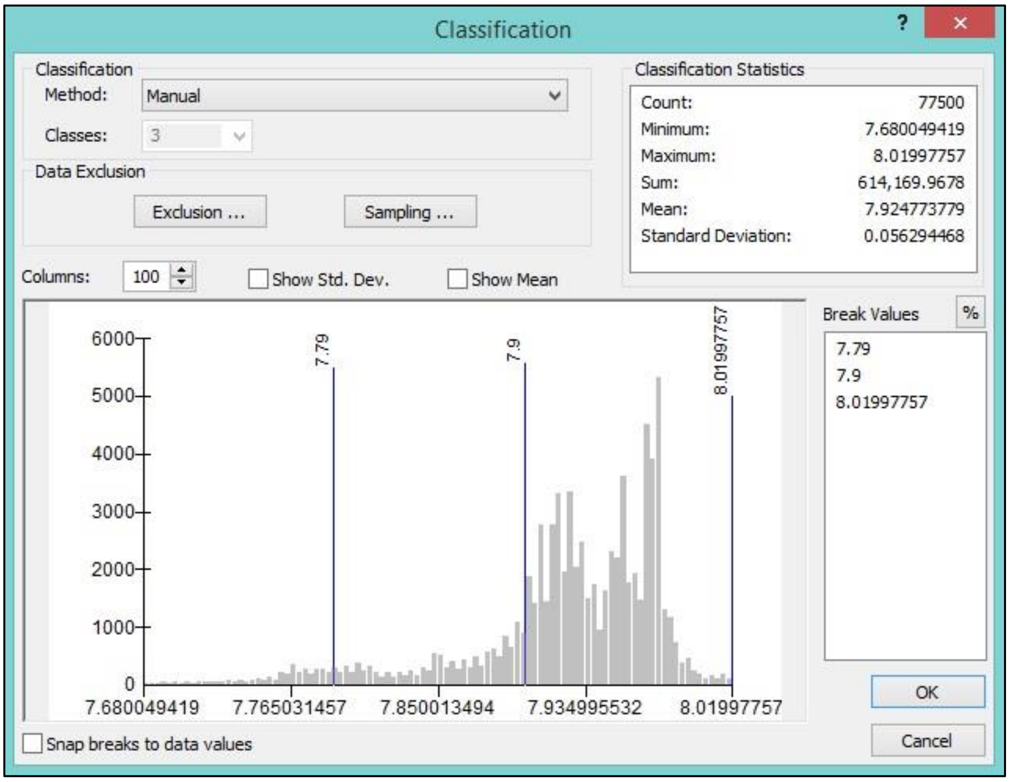

Figure 4: Classification Window Shows the Maximum and Minimum Values Were Recorded Between 7.68 to 8.02.

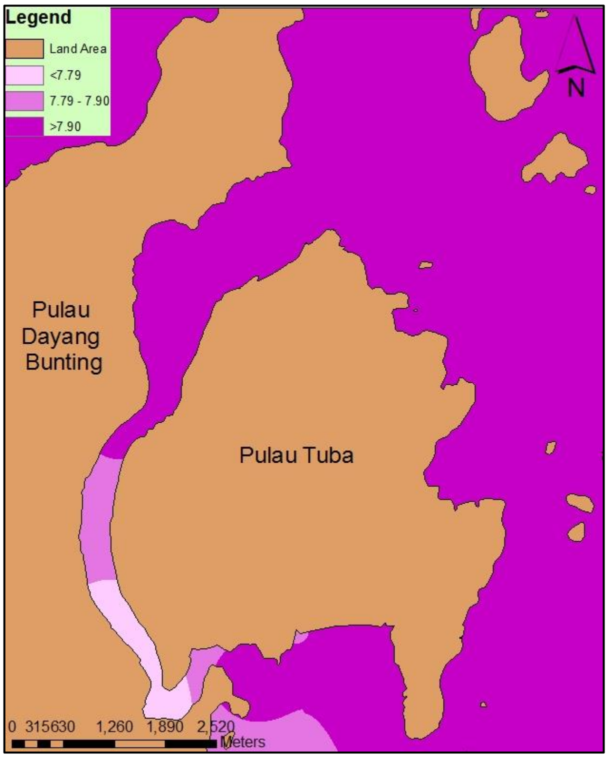

Figure 5: The Map of the Surface Water of Pulau Tuba, Langkawi, Kedah

The map shows that Pulau Tuba exhibits a basic environment. Seawater usually has a pH range of more than 8.2. The inner interior of the strait of Pulau Tuba has a low pH reading. This location has a dense mangrove ecosystem and the water in this area is considered brackish. The high alkalinity of the brackish water is due to the effects of dissolved calcium of shell and offshore coral. The soil in the mangrove area can also contribute to the low pH value of water due to the presence of acidic clay and sulphur reducing bacteria (Ng & Morgany, 2002). They also observed that some mangrove parts in Malaysia exhibit acidic brackish water due to the aeration of sulphates, forming sulphuric acids. The interior part of Pulau Tuba is also covered with a dense mangrove ecosystem. The lowering of pH in water in this area also could be a result of the decomposition of organic matter and humic acid water (Sammut et al., 1995). The estuarine ecosystem is important as the area is critical natural habitat (Carle, Benson, & Reinhardt, 2020) has significant economic value (Liu et al., 2020), performs environmental services (Carstensen et al., 2019) and acts as protective buffers (Pavoni et al., 2021). Anthropogenic activities would affect the natural balance of the estuarine ecosystem (Hillman et al., 2020) and impose increased pressure on vital natural resources (Serrao-Neumann et al., 2019). Furthermore, the threat to the coastal and mangrove ecosystem can be because of spill or dumping of fertilizers (Deegan, 2002); untreated sewage (Kelly et al., 2011); wastewater discharges from industrial facilities (Preisner et al., 2020); falling sediment (Eidam et al., 2021); and surface runoff from impervious surfaces (Rodrigues & Fidélis, 2021). However, since Pulau Tuba is less developed compared to the main island of Pulau Langkawi, these effects are considered minimal to the mangrove and coastal areas along the strait of Pulau Tuba.

One of the concerns of the pH readings in the coastal, estuarine and saltwater ecosystems is the effect of ocean acidification. Ocean acidification can cause the animals living in the coastal and mangrove ecosystems to be in difficulty to form shells and skeletons (Niemi et al., 2021). Besides, ocean acidification can also affect socioeconomic activities (Conway et al., 2017) and the marine food chain (Jin et al., 2020).

The accuracy assessment was carried out later. Table 5 shows the correct occurrences for 16 sampling points. Incorrect occurrences occur at sampling points 16, 20 and 22. The incorrect occurrences predicted by the IDW interpolation method were because of the underestimation and overestimation of the pH readings. The research found that the accuracy of the map was recorded at 81.25%.

Table 5: The Correct (/) and Incorrect (X) Occurrences Based on the Observed and Predicted Values Constructed by the IDW Interpolation Method

Sampling Points	Observed	Predicted	Correct
2	>7.90	>7.90	/
4	>7.90	>7.90	/
6	>7.90	>7.90	/
8	>7.90	>7.90	/
10	>7.90	>7.90	/
12	>7.90	>7.90	/
14	7.79-7.90	7.79-7.90	/
16	<7.79	7.79-7.90	X
18	<7.79	<7.79	/
20	>7.90	7.79-7.9	X
22	>7.90	7.79-7.9	X
24	>7.90	>7.90	/
26	>7.90	>7.90	/
28	>7.90	>7.90	/
30	>7.90	>7.90	/
32	>7.90	>7.90	/
Overall Accuracy (OA) = (13/16) *100% = 81.25%			

Several mechanisms can be considered to sustain the pH of the coastal ecosystems (Strong et al., 2014). Firstly, the government should minimize the eutrophication process as the result of rapid anthropogenic activities as this process leads to increased carbon dioxide concentrations. Secondly, the government should supervise the number of chemicals brought by the riverine system of surface runoff that can affect the coastal carbonate chemistry. Government should also monitor and manage the coastal upwelling because some regions have evidenced the effects of intensity upwelling processes to raise the pH level coupling with anthropogenic climate change. These indications can be used to monitor any anthropogenic activities that could harm the biodiversity and ecology around the coastal water of Pulau Tuba.

Strong et al. (2014) also highlighted several opportunities for action in strategically managing the ocean acidification process which is by setting up the programme for monitoring the ocean acidification processes, forming a new interstate task force to facilitate multitasker solution, a coordinated regional network of monitoring stations, launching public education programs, increasing global research and monitoring of ocean acidification processes, effective coastal zone management, improving policy and plan to observe the impact of permitting actions on ocean acidification and updating the marine genetic diversity at hot spot locations. This plan can be count as a piece of baseline information to be used by government and non-government bodies to monitor the pH level at the coastal waters of Pulau Tuba, Kedah.

There are two major limitations of this study that could be addressed in future research. Firstly, for the methodology part, the study was conducted during November and changes in pH level is expected and affected by the monsoon season, tidal activities and time of sampling activities. Water quality research is complex, due to every parameter having a significant correlation to other water parameters. Secondly, the time constraints contribute to the limited number of sampling frequencies and sampling points. The lack of the previous study in the study area also posed a challenge for this study because there was no baseline data for water pH. However, this limitation has been well analyzed and supported using literature and findings from other researchers.

The limitation of this study has created an opportunity for future study in this area of research. The study recommended that the sampling activities be carried out for a longer period so that a robust model could be developed effectively. Furthermore, the effects of tidal activities, seasonal variations and time of sampling activities should be addressed as well.

CONCLUSIONS AND RECOMMENDATIONS

The study concludes that the IDW interpolation method can estimate the surface water pH. The method is able in predicting the variability of surface water pH as it produces high correlation, high coefficient of determination and low values of mean absolute error and root mean square error. The transformation of spatial models into the map also contributes to high overall accuracy. The study has also addressed the role of government and non-government bodies to consider opportunities for action in strategically managing the pH level in the coastal water of Pulau Tuba. Furthermore, the mechanism to sustain the limit of the sea surface pH can be considered before approving or permitting any development that could harm the coastal carbonate chemistry over the coastal water of Pulau Tuba. Finally, the outcome of this study can be used by the concerned agencies for baselines data and help to monitor and sustain the coastal and marine water of Pulau Tuba, Langkawi, Kedah effectively. The developed map can also be used for entrepreneurs in deciding on aquaculture or mariculture sites as pH has a crucial effect on fish growth and development.

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