Malaysian Journal of Sustainable Environment
Vol.9.No.1 (2021) 55-76
doi: 10.24191/myse.v9i1.17292

THE MAPPING OF SALINITY LEVEL USING THE INVERSE DISTANCE WEIGHTED (IDW) INTERPOLATION METHOD ALONG THE COASTAL AREA OF PULAU TUBA, LANGKAWI

***Sharir Aizat Kamaruddin, Khairul Naim Abd.Aziz[1], Muhammad Akmal Roslani[1], Zamzila Erdawati Zainol[1], Aziani Ahmad[1], Mohd Idrus Shaari[1], Rosnani Nazri[1] & Jamil Tajam[1]**
***Corresponding author**
[1]Fakulti Sains Gunaan, Universiti Teknologi MARA, Cawangan Perlis, Kampus Arau, 02600, Arau, Perlis, Malaysia

shariraizat@uitm.edu.my, khairul87@uitm.edu.my, akmalroslani@uitm.edu.my, zamzila396@uitm.edu.my, aziani@uitm.edu.my, mohdidrus@uitm.edu.my, rosnani176@uitm.edu.my, jamiltajam@uitm.edu.my
Received: 14 June 2021
Accepted: 22 July 2021
Published: 31 March 2022

ABSTRACT

The purpose of this study is to investigate the accuracy of the Inverse Distance Weighted (IDW) interpolation method to estimate and map the surface water salinity along the coastal waters of Pulau Tuba, Langkawi. Sea surface salinity was recorded using a refractometer during two sampling activities that were carried out in November 2018. The Global Positioning System (GPS) was used to record the geo-location of each sampling point. IDW method was applied in data collection using ArcGIS Software. Statistical analyses such as correlation analysis, regression analysis, and error analysis were employed to assess the prediction of salinity values. The transformation of the spatial model to map was carried out later to assess the accuracy of the map. The study found that there is a strong positive correlation, r= .753 (p< .05) with the coefficient of determination of 56.80% between observed and predicted salinity values. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were calculated at

0.724466 and 0.921728, respectively. The accuracy of the map was found at 81.25%. The study also found that the salinity reading is polyhaline along the coastal water of Pulau Tuba. Overall, the study found that the IDW method has provided a tool to predict and map the surface salinity along the coastal waters of Pulau Tuba, Langkawi.

Keywords: *Inverse Distance Weighted, Pulau Tuba, Salinity, GIS, Interpolation*

INTRODUCTION

Seawater contains many ions and minerals that make it salty (Prusty & Farooq, 2020). About a litre (1000g) of seawater contains 35g of salt. The salt causes the seawater to become denser than the freshwater (Timmermans & Marshall, 2020). Salinity might vary with location especially in the surface area, however, the relative composition of seawater remained similar (Turhan et al., 2014). Some locations tend to be higher or lower in salinity level, but the ocean usually has salinity between 34 ppt and 36 ppt (Alam et al., 2020). Some locations experience higher salinity due to low rainfall and strong warm and dry wind that lead to the evaporation of saltwater (Uddin, 2014). When evaporation occurs, the salt that remains will increase the salinity level and water becomes denser (Ibrahim et al., 2020). High rainfall and the numerous rivers connected to the saltwater ecosystem may lead to a high salinity level (Sakai et al., 2021). Besides, the locations that have a higher number of rainfall events can result in the seawater becoming diluted (Pistocchi et al., 2020). The salinity level becomes lower because the higher amount of freshwater added to the seawater makes the seawater less dense. Furthermore, near land, the salinity is also observed to be low (Kaushal et al., 2021). There are numerous technologies or software that can be used to investigate the pattern of salinity.

A Geographic Information System (GIS) is a system created for capturing, visualizing, analyzing, managing, and interpreting many types of geographical data (Han, 2006). The spatial software process spatial data to solve many spatiotemporal problems. GIS is also a system that is used to evaluate the survey operating to expand the amount of information (Kamel Boulos & Geraghty, 2020). Users of different backgrounds used GIS to communicate, make analyses, distribute information, and solve complex problems around the world. By using the suitable technique, geo-location that has not been measured can still be interpolated depending on the physical characteristics of the area (Habib et al., 2020). One of the important tools that can be used by spatial analysts to investigate water quality is the spatial interpolation technique.

The application of the spatial interpolation technique has been recently used to map the concentration of water pollution and has started to gain popularity in Malaysia. Kriging is the most popular choice for interpolation according to several recent studies in the assessment of water quality (Capili et al., 2021; Li et al., 2019; Maliqi & Penev, 2019; McLeod et al., 2017). On the other hand, for the northern region of Malaysia, Kamaruddin et al., (2020) used the spline interpolation method to map the sea surface temperature in the coastal water of Pulau Tuba, Langkawi.

Kamaruddin et al., (2019) also used the spline interpolation method to estimate the sea surface salinity along the coastal area of Pulau Tuba. Kamaruddin et al., (2018) used the same techniques to map salinity over Sungai Merbok, Kedah. Another form of interpolation method is the Inverse Distance Weighted (IDW). This interpolation method determines cell values using a linear weight combination of a set of sample points (Tomaszewski, 2021). The weight is a function of inverse distance. IDW interpolation is mathematical that assumes a closer value and shares more similarity than the further value with its function and characteristics.

To date, there is a dearth of information on the applicability of the IDW interpolation method as a tool to map and estimate the surface water salinity. This problem leads to the investigation of the accuracy of the IDW method to predict and model the surface water salinity along coastal waters of Pulau Tuba, Langkawi. Hence, this study aims to investigate the accuracy of the IDW method to estimate and map the surface water salinity along the coastal waters of Pulau Tuba, Langkawi, Kedah. The specific objectives are (1) to investigate the correlation between the observed and estimated surface water salinity predicted by the IDW interpolation method, (2) to analyse the error between the observed and estimated surface water salinity predicted by the IDW interpolation method, and (3) to determine the accuracy of IDW to estimate and map the surface water salinity along coastal waters of Pulau Tuba, Langkawi, Kedah. The gap of this study lies in the lack of knowledge on the applicability of the IDW interpolation method to be used in predicting and mapping the sea surface salinity. The significance of this study is to help government and non-government bodies such as the Langkawi Development Authority (LADA), the Department of Environment (DOE Malaysia), and the Department of Fisheries (DOF Malaysia) to consider using the IDW interpolation method as a tool for monitoring, conserving, and planning the development of the coastal area of Pulau Tuba as a hub for socio-economic and biodiversity.

METHODOLOGY

Study Area Description

The study area is along the coastal area of Pulau Tuba, Langkawi. Pulau Tuba is located next to Pulau Dayang Bunting inside the archipelago of Pulau Langkawi. The economic activities of this island are fishing, farming, servicing, and operating tourism activities (Kamaruddin et al., 2020). There are numerous types of mangrove and plant species found at the straits of Pulau Tuba. However, the island is still considered moderately developed than Pulau Dayang Bunting and is known as the main island of Pulau Langkawi. Due to the rich biodiversity, environmental problems should be monitored and solved efficiently in Pulau Tuba. Figure 1 shows the map of Pulau Tuba, Langkawi, Kedah.

Sampling Activities

Sampling activities were conducted twice in November 2018. A total of 32 sampling points were pinpointed using Global Positioning System (GPS). A small boat was used for sampling activities. Sampling activities were carried out in the afternoon and during high tide. Sampling activities took about 2 hours and 45 minutes to be completed. The Niskin water sampler was lowered to 1 meter below the surface of the water. A refractometer was used to determine the reading of salinity. Reading of data was based on three trials to get an average reading per sampling point. All equipment used have been carefully calibrated by researchers and staff from the Marine Technology laboratory located at the Faculty of Applied Sciences, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600, Arau, Perlis, Malaysia. Figure 2 shows the sampling points established over the coastal area of Pulau Tuba.

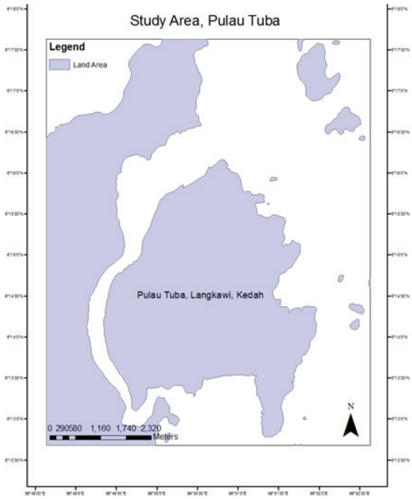

Figure 1. The map of Pulau Tuba, Langkawi Kedah

Source: Author

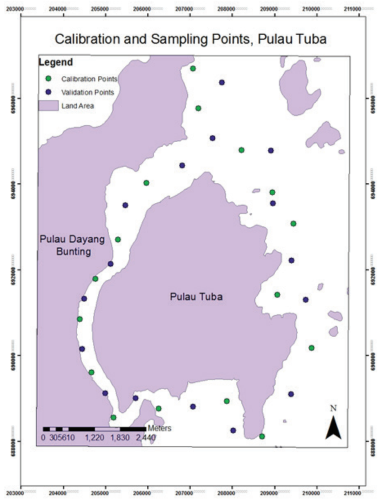

Figure 2. 32 sampling Points Established at the Coastal Area of Pulau Tuba

Source: Author

The Development of the Spatial Model

The method for the development of the spatial model is based on Kamaruddin et al (2019) and Kamaruddin et al (2020). Data from the first sampling activity were used for the development of the spatial model. Overall, data were derived from 16 sampling points. In this study, the 50:50 ratio for calibration: validation sampling points were adopted by Simpson & Wu (2014) where they found that the use of 40% to 50% of total samples had optimally improved the accuracy of the model in predicting the variability of data. The spatial software of ArcGIS was used for the development of the model. The setting of the interpolation analysis was at default. The data collected from the first sampling activity were called the calibration data. Estimation using the IDW interpolation method was conducted using the interpolation tool in spatial analyst function. Below is the formulae shown for the IDW method.

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

Where, V_i is the ith unknown value, n is the number of points taken to obtain the unknown value, V_j is the jth known value, dii is the distance between the ith unknown value and the jth known value and p is the power.

The Validation of the Spatial Model

The method for the validation of the spatial model is based on Kamaruddin et al (2019) and Kamaruddin et al (2020). Data from the second sampling activity were used to validate the developed spatial model. The data from the second activity is called the validation data. Statistical analyses such as correlation analysis, regression analysis, and error analysis were employed when comparing the observed and estimated value salinity. Here, the observed value is the raw data from the second sampling activity while the estimated value is based on the prediction made by the IDW method. Statistical analyses were carried out using Statistical Package for the Social Sciences (SPSS) software (Ver. 27.0) with the alpha = 0.05.

An Accuracy Assessment

The accuracy assessment map was carried out to determine the precision of the developed map. A comparison between the predicted and the observed pH readings was conducted. The study used the Overall Accuracy (OA) which reported the accuracy in the percentage form and the equation of OA as shown below:

$$Overall\ Accuracy\ (OA) = \frac{\text{Number of Correct Occurrences}}{\text{Total Occurrences}} \times 100\% \quad (2)$$

FINDINGS AND ANALYSIS

The calibration data have been successfully interpolated using the IDW interpolation method. The power parameter has been set up to 2 as it was the default value. In this study, the power parameter manipulates the significance of known points on the interpolated values of salinity based on the gap from the output point. The lower or minimal value of the power parameter will create a smooth surface. Figure 3 shows a raster image produced after executing the IDW method.

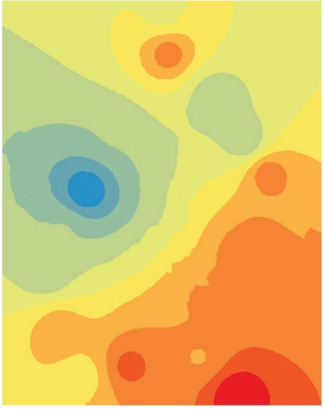

Figure 3. The Raster Image (automatically generated) of an Interpolated Sea Surface Salinity Produced using the IDW Method

Source: Author

The raster image shows the different colours that indicate different values of sea surface salinity estimated using the IDW method. Each colour represents ranges of estimated salinity values. Drastic layering colors can be observed on the bottom left and in the middle left of the raster image (Figure 3). Interpolation estimates the values for cells in a raster using a limited number of points. The colors produced from the raster image is based on the idea that spatially distributed objects are spatially correlated. The unknown values of salinity are estimated using the mathematical formula and interpolation type (in this case the IDW methods) that incorporate the value of nearby known points of salinity.

Estimation

Extract values to points is a tool used to extract the cell values of a raster on a set of point features and to record the values in the attribute table of an output feature class. In this study, a set of point features is based on the validation data. Table 1 shows the comparison between the observed and predicted values of salinity using the IDW method. Table 2 shows the data based on descriptive statistics for the observed and predicted values of salinity.

Table 1. Listing of the Observed Values and Predicted Values of Salinity (ppt) Estimated using the IDW Interpolation Method

Sampling points	Observed values	Predicted values
2	30.00	29.05
4	27.00	28.83
6	28.00	28.34
8	28.00	28.43
10	26.00	27.67
12	27.00	27.63
14	28.00	28.07
16	28.00	28.93
18	30.00	29.35
20	30.00	29.63
22	30.00	29.87
24	30.00	30.23
26	30.00	30.15
28	28.00	29.84
30	29.00	29.66
32	29.00	28.28

Source: Author

Table 2: The list of Data Based on Descriptive Statistics for the Observed Values and Predicted Values of Salinity (ppt) Estimated using the IDW Interpolation Method

	Observed values	Predicted values
N	16	16
Range	4.00	2.60
Minimum	26.00	27.63
Maximum	30.00	30.23
Sum	458.00	463.96
Mean	28.6250	28.9975
Std Deviation	1.31022	0.85941
Variance	1.717	0.739
Skewness	-0.413	-0.154
Kurtosis	-0.880	-1.257

Source: Author

Correlation Analysis

For this study, the correlation analysis was carried out to measure the strength of association between the observed and predicted values, and the direction of the relationship (Kumar & Chong, 2018). Table 3 shows the Pearson correlation analysis using the SPSS software (Ver. 27.0) with the alpha at .05. The observed value and the predicted value of salinity predicted using the IDW interpolation method were found to be positively correlated, $r(16) = .753$, $p < .05$.

Table 3. Pearson Correlation Analysis Executed using SPSS Software Found that the r= .753 (p< .05)

		Observed	Predicted
Observed	Pearson Correlation	1	.753**
	Sig. (2-tailed)		.001
	Sum of Squares and Cross-products	25.750	12.725
	Covariance	1.717	.848
	N	16	16
Predicted	Pearson Correlation	.753**	1
	Sig. (2-tailed)	.001	
	Sum of Squares and Cross-products	12.725	11.079
	Covariance	.848	.739
	N	16	16

**. Correlation is significant at the 0.01 level (2-tailed)

Source: Author

The study found that there is a strong positive correlation between the observed and predicted values of salinity. The study also notifies that the non-parametric test such as Kendall rank correlation coefficient and Spearman's rank correlation coefficient have resulted in moderate and strong positive correlation coefficients. Table 4 shows the result of the non-parametric test of Kendall's rank correlation coefficient and Spearman's rank correlation coefficient tabulated using Statistical Package for the Social Sciences (SPSS) software (Ver. 27.0).

Table 4. The Analysis of the Non-parametric Test of Kendall's Rank Correlation Coefficient, r= .577, (p< .05) and Spearman's Rank Correlation Coefficient r= .739, (p< .05)

			Observed	Predicted
Kendall's tau_b	Observed	Correlation Coefficient	1.000	.577**
		Sig. (2-tailed)	.	.004
		N	16	16
	Predicted	Correlation Coefficient	.577**	1.000
		Sig. (2-tailed)	.004	.
		N	16	16
Spearman's rho	Observed	Correlation Coefficient	1.000	.739**
		Sig. (2-tailed)	.	.001
		N	16	16
	Predicted	Correlation Coefficient	.739**	1.000
		Sig. (2-tailed)	.001	.
		N	16	16

**. Correlation is significant at the 0.01 level (2-tailed)

Source: Author

Regression Analysis

A simple linear regression analysis was used to predict the relationship between the observed and predicted values of salinity based on the regularized and tension spline methods at a 95% confidence level. The prediction value of salinity estimated by the IDW interpolation method did explain a significant amount of variance in the observed value of salinity, F (1,14) =18.378, p <0.001, R2= 0.568, R2adjusted= 0.537. The study also found that the regression coefficient (B= 0.498) indicated an increase in the predicted value of salinity corresponded to an increase in the observed value of 0.498. The simple linear regression equation was reported as observed value = 14.852 + 0.498 (predicted value).

Error Analysis

In the error analysis, Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were calculated at 0.724466 and 0.921728. In general, the lower the value of MAE and RMSE, the better a model can fit a dataset. MAE measures the mean magnitude of the errors in a set of estimations, without considering their direction (Chai & Draxler, 2014). RMSE is a measure of how spread out these residuals are in a system (Willmott & Matsuura, 2005).

The Transformation of the Spatial Model to Map

Next, the study considers the classification of data using the manual method with three classes. Since the minimum value and maximum value of the estimation have been recorded at 26.67041206 and 30.99976158 respectively, three classifications of salinity ranges were chosen: <27.00ppt; 27.00--28.99ppt; and > 29.00 ppt. The clustering of these ranges is important because salinity levels are dynamic across the spatial and temporal dimensions. The variations of salinity ranges are based on the effects of the tidal activities, seasonal, day/night-time, and anthropogenic activities. Figure 4 shows the classification statistics and the break values (%) performed to the spatial model.

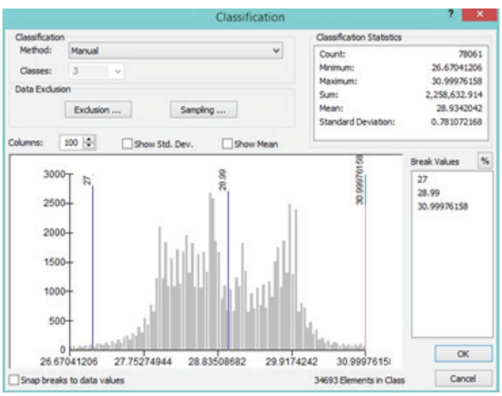

Figure 4. The information of the Classification Statistics and the Break Values (%) Executed to the Spatial Model Interpolated using the IDW Interpolation Method

Source: Author

Furthermore, the transformation process from a spatial model into a spatial map was carried out. Map elements have been inserted for better visualization and communication. Map elements such as title, scale bar, legend, and north arrow were added to the Map Layout using the Data Frame Properties. Figure 5 shows the map of salinity after inserting the map elements.

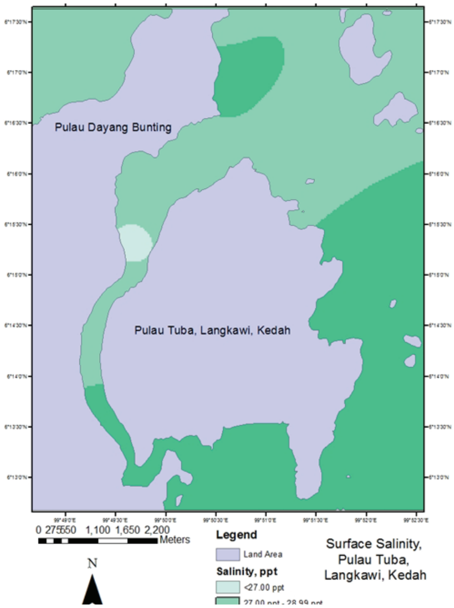

Figure 5. The Map Shows the Distribution of Sea Surface Salinity Generated using the IDW Interpolation Method

Source: Author

Based on the map produced, the Straits of Pulau Tuba (Selat Pulau Tuba) indicates a low reading of salinity level. The coastal water of Pulau Tuba and Pulau Dayang Bunting is covered with diverse mangrove and marine life that are a part of the brackish ecosystems. The lowest reading of salinity value can be observed in the middle of the straits due to numerous human activities and development. The Southern-East of the coastal water of Pulau Tuba indicates a high reading of salinity levels. This area is remarkably close to the open ocean where there is a mix of high and complex concentrations of ions and minerals called salt.

The Accuracy Assessment

Next, an accuracy assessment was conducted to assess the precision of the developed map. The study found that the accuracy of the map yield is 81.25%. The study found that IDW incorrectly estimated the value of salinity at Sampling points 10, 28, and 32. Incorrect estimations are calculated due to the spatial interpolation method that tend to underestimate the value of the spatial data. Underestimation and overestimation of data have been observed in numerous studies (Kamaruddin et al, 2019, Kamaruddin et al, 2020). Table 5 shows the correct occurrences of 16 sampling points.

Table 5. The Correct Occurrences of 16 Sampling Points where the Accuracy of the Map was Recorded at 81.25%

Sampling points	Observed values (ppt)	Predicted values (ppt)	Correct occurrences
2	> 29.00	> 29.00	YES
4	27.00--28.99	27.00--28.99	YES
6	27.00--28.99	27.00--28.99	YES
8	27.00--28.99	27.00--28.99	YES
10	<27.00	27.00--28.99	NO
12	27.00--28.99	27.00--28.99	YES
14	27.00--28.99	27.00--28.99	YES
16	27.00--28.99	27.00--28.99	YES
18	> 29.00	> 29.00	YES
20	> 29.00	> 29.00	YES
22	> 29.00	> 29.00	YES
24	> 29.00	> 29.00	YES
26	> 29.00	> 29.00	YES
28	27.00--28.99	> 29.00	NO
30	> 29.00	> 29.00	YES
32	> 29.00	27.00--28.99	NO
Correct Occurrences = (13/16) *100% = 81.25%			

Source: Author

DISCUSSION

There are several factors that have led to salinity changes. One of the factors is the characteristics of the landscape or geographical area. Based on the map, the salinity of Pulau Tuba is being affected by the mangrove ecosystem that flourishes along the straits of Pulau Tuba (Selat Pulau Tuba). Salinity in the estuarine ecosystem varies from 0.5ppt to 30 ppt. Montagna et al., (2013) stated that inside the estuary, salinity readings are referred to as oligohaline (0.5-5.0 ppt), mesohaline (5.0-18.0 ppt), or polyhaline (18.0 to 30.0 ppt). The salinity of the open ocean is about 35 ppt (Garcia, 2019). The salinity changes in the estuarine ecosystem have a great influence on the biodiversity of species since animals and plants that live here need to tolerate with the fluctuation of salt. Besides, vertical distribution of salinity can also be observed when comparing the surface zone and the deep zone (Yu, 2015). The surface water has less salinity level than deep water due to the density of ion and salt concentration.

Precipitation has a major influence on the salinity level, especially when it is influenced by the monsoon season where rainwater is added to the coastal water and estuarine ecosystems (Chen et al., 2019). This study was conducted in November 2018 where the forecast of heavy rainfall for Pulau Langkawi was between May to Mid-November 2018. There is a 50% chance of thunderstorms accompanied by heavy rainfall between April to October (Bhattacharya, 2021). The effects of surface runoff by the precipitation process can also lead to the rise and fall of salinity levels.

Another factor that may affect the salinity readings is anthropogenic activities (Velasco et al., 2018). Rapid agricultural activities that lead to fresh agriculture drainage into the coastal water and excessive use of fertilizer can cause degradation of salinity due to the addition of freshwater that decrease the salinity level (Montazar, 2021). However, this is not a major factor as the socioeconomic activities on the island is still low. However, paddy fields and small-scale agriculture sites can be found scattered along the island that could potentially add minerals or freshwater into the estuary or coastal waters.

Climate change can also influence the salinity level (Vineis et al., 2011). The increasing climate temperature due to global warming could increase the evaporation of saltwater and eventually reducing the ion and mineral content in the seawater (Zika et al., 2018). Catastrophic storms as a result of climate change can also influence the rapid surface runoff that may bring salt or freshwater into the sea. However, due to the lack of conclusive evidence and climate data for this area, the effects of climate change on the salinity of Pulau Tuba remain unknown.

The IDW interpolation method believes that the variable being mapped decreases the influence with distance from its sampled location (Watson & Philip, 1985). However, this method depends mainly on the inverse of the distance raised to mathematical power. Furthermore, one needs also to consider the influence of the point used for the calculation ((Philip & Watson, 1982). Some researchers recommended the variable search value or fixed search value criteria be considered to improve the accuracy of the model.

The findings of this study could influence government and non-governmental bodies to consider the IDW interpolation method for environmental mapping of salinity. Although the Kriging interpolation method has been a popular option to be used as an interpolating tool, Kriging requires a deeper understanding of the characteristics of the attribute data, and it can be erroneous. The finding of this study also revealed the distribution of salinity along the coastal area of Pulau Tuba. The map produced can be used by local people to identify an area for development such as sustainable aquaculture, marine culture, and tourism activities. Sustainable approaches of using coastal and estuarine ecosystems may protect the biodiversity of species and improve the livelihood of the residents and government revenues.

CONCLUSION AND RECOMMENDATION

The study concludes that the correlation between the observed values and predicted values based on IDW method estimation yield a significant strong positive correlation with $r= .753$ ($p< .05$). The coefficient of determination (R2) is recorded at 0.568 (56.80%). Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were calculated at 0.724466 and 0.921728, respectively. The spatial model was successfully transformed into a map that yielded an accuracy of 81.25%. Moderate reading of salinity level of the coastal area of Pulau Tuba was expected from the effects of the horizontal and vertical distribution of salinity where the surface water of Pulau Tuba exhibits an estuarine ecosystem. Anthropogenic activity and climate change are two important concerns that could affect the normal level of salinity required for flora and fauna to thrive in this area.

There are two major limitations of this study that could be addressed in future research. First, for the methodology section, the study was performed in November 2018, and the changes of salinity level were expected and affected by many environmental factors such as tidal activities. Water quality research is complex due to every parameter having a significant relationship to other water parameters. Secondly, the limitation of time also contributed to the limited number of sampling frequencies and the number of sampling points. The dearth of previous studies in the study area also pose a problem as there is a lack of baseline data for water salinity. However, this limitation has been analyzed and supported using literature and findings from other researchers.

The limitation of this study has opened the prospect for upcoming research in the study area. The study proposes that the sampling activities be conducted for a longer period to effectively develop a robust model. Furthermore, the effects of tidal activities, seasonal variation, and time of sampling activities should be addressed as well. Nonetheless, this study believes that IDW has potential and should be considered as a method for interpolating surface water salinity by spatial analysts. The map produced by this study can be used for sustainable social-economic development and effective biodiversity management of the coastal area of Pulau Tuba and nearby islands.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the generous assistance and support from the academic and non-academic staff for their contribution in this study and publication, especially to Ocean Research, Conservation and Advance (ORCA) (Research Interest Group, RIG), Integrative Natural Product Research (Research Interest Group, RIG), and the Faculty of Applied Sciences, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600

Arau, Perlis, Malaysia.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Alam, M. R., Sharmin, S., Islam, S. M., Alam, M. A., Ehiguese, F. O., Pattadar, S. N., & Shahjahan, M. (2020). Salinity intrusion affects early development of freshwater aquaculture species pabda, Ompok pabda. *Aquaculture Reports,* 18, 100476. https://doi.org/10.1016/j.aqrep.2020.100476

Bhattacharya, R. (2021). *Langkawi weather & climate.* Langkawi Insight. https://www.langkawi-insight.com/langkawi_0000e0.htm

Capili, N. I., Marilla, J. F., & Montes, K. (2021). Spatial variability model for water quality assessment of the physicochemical parameters and the water quality index of Laguna Lake and its tributaries. *Journal of Physics: Conference Series, 1803*(1), 012006. https://doi.org/10.1088/1742-6596/1803/1/012006

Chai, T., & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. *Geoscientific Model Development, 7*(3), 1247-1250. https://doi.org/10.5194/gmd-7-1247-2014

Chen, B., Qin, H., Chen, G., & Xue, H. (2019). Ocean salinity as a precursor of summer rainfall over the east Asian monsoon region. *Journal of Climate, 32*(17), 5659-5676. https://doi.org/10.1175/jcli-d-18-0756.1

Garcia, H. (2019). World ocean atlas 2009 citations. https://doi.org/10.5194/essd-2019-135-sc1

Habib, M., Alzubi, Y., Malkawi, A., & Awwad, M. (2020). Impact of interpolation techniques on the accuracy of large-scale digital elevation model. *Open Geosciences, 12*(1), 190-202. https://doi.org/10.1515/geo-2020-0012

Han, D. (2006). Integrating geographic information systems (GIS) into breast cancer epidemiologic research. https://doi.org/10.21236/ada457468

Ibrahim, H. D., Xue, P., & Eltahir, E. A. (2020). Multiple salinity equilibria and resilience of Persian/Arabian Gulf basin salinity to brine discharge. *Frontiers in Marine Science,* 7. https://doi.org/10.3389/fmars.2020.00573

Kamaruddin, S. A., Zainolabdin, S. N., Abd.Aziz, K. N., & Roslani, M. A. (2019). Comparative Study of Regularized and Tension Spline Interpolation Method to Map Surface-Water Salinity of Pulau Tuba, Langkawi, Kedah. *Multidisciplinary Informatics Journal, 2*(1), 91-97.

Kamaruddin, S. A., Abd Aziz, K. N., Roslani, M. A., Tajam, J., Zaınolabdın, S. N., & Mohd Razman, N. F. (2018). Mapping of salinity level using spline interpolation techniques over the water of Sungai Merbok, Kedah. *Malaysian Journal of Sustainable Environment, 5*(2), 114. https://doi.org/10.24191/myse.v5i2.5620

Kamaruddin, S. A., Rusli, H. H., Abd.Aziz, K. N., & Roslani, M. A. (2020). Characteristics and distribution of microplastics in surface sediment of Selat Pulau Tuba, Langkawi, Kedah. *Malaysian Journal of Sustainable Environment, 7*(2), 133. https://doi.org/10.24191/myse.v7i2.10269

Kamaruddin, S. A., Zainolabdin, S. N., Abd.Aziz, K. N., Roslani, M. A., Zohir, N. S., & Al-Bakri, N. Y. (2020). *A Comparative Study Of The Accuracy Of Regularized And Tension Spline Interpolation Methods To Map The Surface Water Temperature Of Pulau Tuba, Langkawi, Kedah.* Charting the Sustainable Future of ASEAN in Science and Technology, 285-295. https://doi.org/10.1007/978-981-15-3434-8_25

Kamel Boulos, M. N., & Geraghty, E. M. (2020). Geographical tracking and mapping of coronavirus disease COVID-19/severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2) epidemic and associated events around the world: How 21st century GIS technologies are supporting the global fight against outbreaks and epidemics. *International Journal of Health Geographics, 19*(1). https://doi.org/10.1186/s12942-020-00202-8

Kaushal, S., Likens, G., Mayer, P., Pace, M., Reimer, J., Maas, C., Galella, J., Utz, R., Duan, S., Kryger, J., Yaculak, A., Boger, W., Bailey, N., Haq, S., Wood, K., Wessel, B., Collison, D., & Aisin, B. (2021). Freshwater salinization syndrome: Emerging global problem and risk management. https://doi.org/10.5194/egusphere-egu21-16299

Kumar, S., & Chong, I. (2018). Correlation analysis to identify the effective data in machine learning: Prediction of depressive disorder and emotion states. I*nternational Journal of Environmental Research and Public Health, 15*(12), 2907. https://doi.org/10.3390/ijerph15122907

Li, H., Smith, C., Wang, L., Li, Z., Xiong, C., & Zhang, R. (2019). Combining spatial analysis and a drinking water quality index to evaluate monitoring data. *International Journal of Environmental Research and Public Health, 16*(3), 357. https://doi.org/10.3390/ijerph16030357

Maliqi, E., & Penev, P. (2019). Spatial representation of surface water monitoring and its assessment using geostatistical and non-geostatistical techniques in gis. *Geodesy and cartography, 45*(4), 177-189. https://doi.org/10.3846/gac.2019.8590

McLeod, L., Bharadwaj, L., Epp, T., & Waldner, C. (2017). Use of principal components analysis and Kriging to predict groundwater-sourced rural drinking water quality in Saskatchewan. *International Journal of Environmental Research and Public Health, 14*(9), 1065. https://doi.org/10.3390/ijerph14091065

Montagna, P. A., Palmer, T. A., & Beseres Pollack, J. (2013). *Hydrological changes and estuarine dynamics*. SpringerBriefs in Environmental Science. https://doi.org/10.1007/978-1-4614-5833-3

Montazar, A. (2021). *Salton sea and salinity.* Imperial County. Retrieved June 1, 2021, from https://ceimperial.ucanr.edu/Custom_Program275/

Salton_Sea_and_Salinity/

Philip, G. M., & Watson, D. F. (1982). A precise method for determining contoured surfaces. The APPEA Journal, 22(1), 205. https://doi.org/10.1071/aj81016

Pistocchi, A., Bleninger, T., Breyer, C., Caldera, U., Dorati, C., Ganora, D., Millán, M., Paton, C., Poullis, D., Herrero, F. S., Sapiano, M., Semiat, R., Sommariva, C., Yuece, S., & Zaragoza, G. (2020). *Can seawater desalination be a win-win fix to our water cycle?* Water Research, 182, 115906. https://doi.org/10.1016/j.watres.2020.115906

Prusty, P., & Farooq, S. (2020). *Seawater intrusion in the coastal aquifers of India - A review*. HydroResearch, 3, 61-74. https://doi.org/10.1016/j.hydres.2020.06.001

Sakai, T., Omori, K., Oo, A. N., & Zaw, Y. N. (2021). *Monitoring saline intrusion in the Ayeyarwady delta, Myanmar, using data from the Sentinel-2 satellite mission.* Paddy and Water Environment. https://doi.org/10.1007/s10333-020-00837-0

Simpson, G., & Wu, Y. (2014). Accuracy and effort of interpolation and sampling: Can GIS help lower Field costs? ISPRS *International Journal of Geo-Information, 3*(4), 1317-1333. https://doi.org/10.3390/ijgi3041317

Timmermans, M., & Marshall, J. (2020). undefined. *Journal of Geophysical Research: Oceans, 125*(4). https://doi.org/10.1029/2018jc014378

Tomaszewski, B. (2021). *Geographic information systems (GIS) for disaster management.* CRC Press.

Turhan, A., Kuscu, H., Ozmen, N., Sitki Serbeci, M., & Osman Demir, A. (2014). Effect of different concentrations of diluted seawater on yield and quality of lettuce. *Chilean journal of agricultural research, 74*(1), 111-116. https://doi.org/10.4067/s0718-58392014000100017

Uddin, S. (2014). Environmental impacts of desalination activities in the

Arabian Gulf. *International Journal of Environmental Science and Development*, 114-117. https://doi.org/10.7763/ijesd.2014.v5.461

Velasco, J., Gutiérrez-Cánovas, C., Botella-Cruz, M., Sánchez-Fernández, D., Arribas, P., Carbonell, J. A., Millán, A., & Pallarés, S. (2018). Effects of salinity changes on aquatic organisms in a multiple stressor context. Philosophical Transactions of the Royal Society B: Biological Sciences, 374(1764), 20180011. https://doi.org/10.1098/rstb.2018.0011

Vineis, P., Chan, Q., & Khan, A. (2011). Climate change impacts on water salinity and health. *Journal of Epidemiology and Global Health, 1*(1), 5. https://doi.org/10.1016/j.jegh.2011.09.001

Watson, D.F. and Philip, G.M. (1985) A Refinement of Inverse Distance Weighted Interpolation. Geoprocessing, 2, 315-327.

Willmott, C., & Matsuura, K. (2005). Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research,* 30, 79-82. https://doi.org/10.3354/cr030079

Yu, L. (2015). Sea-surface salinity fronts and associated salinity-minimum zones in the tropical ocean. *Journal of Geophysical Research: Oceans, 120*(6), 4205-4225. https://doi.org/10.1002/2015jc010790

Zika, J. D., Skliris, N., Blaker, A. T., Marsh, R., Nurser, A. J., & Josey, S. A. (2018). Improved estimates of water cycle change from ocean salinity: The key role of ocean warming. *Environmental Research Letters, 13*(7), 074036. https://doi.org/10.1088/1748-9326/aace42