Evaluation of the Performance of Spline Interpolation Method in Mapping and Estimating the Total Suspended Solids over the Coastal Water of Pulau Tuba, Kedah

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Abstract. The purpose of this paper is to evaluate the performance of the spline interpolation method in predicting and mapping the concentration of Total Suspended Solids (TSS) in the surface water of Pulau Tuba, Kedah. Thirty sampling points were set up and geolocated using the Geographic Positioning System (GPS). Gravimetric analyses were used to determine the TSS level. Fifty percent of the total sampling points were randomly chosen for developing spatial models using regularised and tension spline methods. The research found that the tension spline methods outperform the regularised spline method. The Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Error Percentage (MAPE) were reported at 351.641, 18.752, 15.81, and 21.51%, respectively. This study's findings are critical in the domains of spatial statistics and interpolation for creating a precise map of water properties.

1. Introduction

Environment monitoring describes the processes and activities which involve testing the water quality to ensure a healthy ecosystem. Poor water quality may cause detrimental effects on humans and other living organisms [1]. Water quality monitoring can help the researcher determine, predict, and learn natural processes in the surroundings and investigate human impacts on an ecosystem [2]. Total Suspended Solids (TSS) are one of the water quality parameters that have become a significant concern in Malaysia [3]. There is inadequate information on the TSS values, especially over the coastal water zones such as Pulau Tuba and Langkawi.

This study highlights two problems. The first problem is the lack of knowledge on the accuracy of the spline interpolation method to estimate the distribution of TSS on the surface water of Pulau Tuba, Kedah. The second problem is the unknown spatial distribution of TSS on the surface water of Pulau Tuba, Kedah. Both problems are essential to address as high estimation accuracy is required to reduce the prediction error. A high level of TSS could contribute to a significant loss in social-economic sectors and marine biodiversity.
This study aims to evaluate the performance of spline interpolation methods in estimating and mapping the concentration of TSS over the coastal water of Pulau Tuba, Kedah. This study is significant in spatial statistics, which focuses on the health of the marine and coastal zone environment. This study also provides data on the variability of TSS over the coastal water of Pulau Tuba, Kedah. The government or the non-government bodies can use the information in this study to monitor the concentration of TSS, manage strategic plans and policies to combat water pollution, and for administrating sustainability steps following the United Nations Sustainable Development Goals (SDGs), especially in SDG 14- Life Below Water that benefits the tourism and economic players and drivers at Pulau Langkawi, Kedah.

2. Literature Review
TSS can be defined as dry weight solids or suspended particles in water that can be trapped by a filter [4]. The process uses a filtered system and is popular in many industries [5]. Most of the common suspended solids are bacteria [6], clay [7], gravel sand, and silt [8]. The concentration of total suspended solids may increase due to increased erosion and runoff across rivers and streams, human pollution, algae, and sediment disruption [9]. This, in turn, may affect human and environmental health. High TSS in water may decrease the dissolved oxygen and increase the water temperature [10]. Suspended solids have also been blamed for damaging the fish gills and their visibility underwater [11]. High suspended particle also causes the marine and freshwater plant to get insufficient sunlight [12]. Due to this concern, an approach using spatial interpolation techniques can be used to monitor TSS in the aquatic ecosystem. Currently, the applicability of the spatial interpolation method to predict the variability of TSS is found to be insufficient.

Spatial interpolation is a process that uses known values to predict or estimate values at different points [13]. Spline interpolation methods have been used for predicting pollution. There are two approaches to spatial interpolation, namely deterministic and stochastic approaches. Stochastic approaches are more popular among users compared to the deterministic approaches. Spline is an example of a deterministic approach. Due to this method being less popular, its potential to predict water quality conditions is limited. In this study, TSS data and spline interpolation method were integrated to produce an accurate map of TSS at the coastal water of Pulau Tuba, Langkawi.

3. Methodology
3.1. Study Area
Pulau Tuba is in the southeast of the main island of Pulau Langkawi. The island is situated next to the famous Pulau Dayang Bunting. The main human activities are agriculture, water transportation, and tourism. Marine culture activities can be found along the strait of Pulau Tuba. The cluster of the residential areas can be found over the island and the coastal regions. Mangrove, which houses a variety of marine flora and fauna, can also be found in the inner part of the island. Figure 1 shows the location of the study area.
3.2. Sampling Frequency and Design
The sampling activities were carried out at noon during the months of November – December 2018. The sampling activities commenced at 11.30 am and ended at 4.00 pm. A total of 30 sampling points were visited using a small tourist boat. The locations of each sampling point were geolocated using the Global Positioning System (GPS). The samples were collected using the Niskin Water Sampler, 1 meter below the surface depth, and immediately brought to the Marine Technology laboratory at the Faculty of Applied Sciences, Universiti Teknologi MARA, Perlis Branch, Arau Campus for the assessment of the concentration of TSS.

3.2.1. Determination of the Concentration of TSS. Assessment of the concentration of TSS was conducted using the standard gravimetric analyses APHA 2540 of Standard Methods for the Examination of Water and Wastewater, 23rd Edition. The data was reported in the unit of mg/L.

3.2.2. Sample analyses. The filtering apparatus was assembled and placed in a small volume of reagent-grade water. The larger particle was sheared using a magnetic stirrer to obtain a more uniform (homogenous) particle size. The sample was dried for one hour in an oven from 103°C to 105°C, then cooled in a desiccator to balance the temperature and weight. The drying, cooling, desiccating, and weighting cycle was repeated until a constant weight was obtained or the weight change was less than 4% of the previous weight or 0.5 mg. At least 10% of all the samples were analysed in duplicate.

3.2.3. TSS Calculation. The concentration of TSS was reported as mg/L or as mg/L TSS as in equation (1). Samples yield residue mass < 2.5 mg or >200 mg were identified and reported as “estimate” because the mass exceeded the analysis criteria.
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\[ \text{mg total suspended solids/L} = \frac{(A - B) \times 1000}{\text{sample volume, mL}} \]  
(1)

Where:
\[ A = \text{weight of filter + dried residue, mg} \]
\[ B = \text{weight of filter} \]

3.3. Development of Interpolation Model

50% of sampling points were randomly chosen to develop the spatial interpolation models, while the other 50% were used to evaluate the developed spatial models [14]. Two methods, namely the regularized and tension spline methods, were used in this study. The weightage value was decided at 0.1, while the number of sampling points was set at 15. Spatial analysis software, namely ArcMap, ArcCatalog, and ArcView, was used to develop the model and map. The mathematical equations of splines equation, tension spline model, and regularized spline model used were provided as follows [14]:

3.3.1. Splines Equation

\[ S(x, y) = T(x, y) + \sum_{j=1}^{N} \lambda_j R(r_j) \]  
(2)

Where:
\[ J = 1, 2, \ldots, N \]
\[ N = \text{Number of points} \]
\[ \lambda_j = \text{Coefficients found by the solution of a system of linear equations.} \]
\[ r_j = \text{Distance from the point (x, y) to the j}\text{th point.} \]

3.3.2. Tension Spline Method

\[ T(x, y) = a_1 \]  
(3)

Where:
\[ a_1 = \text{coefficients found by the solution of a system of linear equations.} \]

And,
\[ R(r) = \frac{1}{2\pi} \left[ 1 n \left( \frac{r \varphi}{2} \right) + c + K_o \left( r \varphi \right) \right] \]  
(4)

Where:
\[ \varphi^2 = \text{Weight parameter} \]
\[ K_o = \text{Modified Bessel function} \]
\[ C = \text{constant equal to 0.0577215} \]

3.3.3. Regularized Spline Method

\[ T(x, y) = a_1 + a_2 x + a_3 y \]  
(5)

Where:
\[ a_1 = \text{coefficient found by the solution of a system of linear equation} \]

And,
\[ R(r) = \frac{1}{2\pi} \left\{ \frac{r^2}{4} \left[ 1 n \left( \frac{r}{2\pi} \right) + c - 1 \right] + r^2 \left[ K_o \left( \frac{r}{\tau} \right) + c + 1 n \left( \frac{r}{2\pi} \right) \right] \right\} \]  
(6)

Where:
\[ r = \text{Distance between the point and the sample} \]
\[ \tau^2 = \text{Weight parameter} \]
\[ K_v = \text{Modified Bessel function.} \]

3.4. **Statistical Analyses**
The descriptive statistics, correlation analyses, regression analyses, normality tests, paired-sample T-test, and Error analyses were conducted using the Statistical Product and Service Solutions (SPSS). The alpha value was set at 0.05.

3.5. **Comparison of Methods**
A comparative assessment of models and methods was carried out using the error metric and forecasting accuracy techniques. Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Error Percentage (MAPE) were used to compare the developed spatial models. The accurate model posed minimal prediction error and was chosen based on these statistical analyses.

3.6. **Transformation of Spatial Model into Map**
The spatial model was transformed into a map by inserting map elements such as the North arrow, legend, scale unit, title, and grid. Legend was classified using classify tool available in the ArcMap software manually.

3.7. **Map Accuracy Assessment**
The accuracy of the developed map was assessed by evaluating the correct occurrences using the range of the concentration of TSS. This accuracy was reported in percentage (%). The map accuracy was only measured for the model or methods that produced the slightest prediction error.

4. **Result and Discussion**

4.1. **Production of Spatial Model**
Spatial models developed using the regularized and tension spline methods were successfully generated. Figure 2 and Figure 3 show the spatial models developed by both methods.
Figure 2. The spatial model developed using the regularized spline method

Figure 3. The spatial model was developed using the tension spline method
4.2. Prediction by Spline Interpolation Methods

Predictions were made for 15 sampling points. The study found that ten and five sampling points had overestimated and underestimated the concentration of total suspended solids correspondingly when using the regularized method. On the other hand, when using the tension method, eight and seven sampling points were found to overestimate and underestimate the concentration of total suspended solids, respectively. Table 1 shows the measured and predicted concentration of total suspended solids using the regularized and tension spline methods.

Table 1. Prediction by spatial interpolation method

| Sampling Points | Measured TSS (mg/L) | Regularized Method (mg/L) | Tension Method (mg/L) |
|-----------------|---------------------|---------------------------|-----------------------|
| SP002TSS        | 69.500              | 79.440                    | 83.195                |
| SP004TSS        | 65.100              | 101.626                   | 89.893                |
| SP006TSS        | 82.860              | 83.879                    | 88.629                |
| SP008TSS        | 102.400             | 117.067                   | 94.981                |
| SP010TSS        | 110.600             | 65.696                    | 76.048                |
| SP012TSS        | 83.500              | 106.848                   | 104.812               |
| SP014TSS        | 30.000              | 46.412                    | 45.318                |
| SP016TSS        | 90.000              | 91.937                    | 90.341                |
| SP018TSS        | 93.400              | 73.753                    | 72.985                |
| SP020TSS        | 80.000              | 93.765                    | 93.235                |
| SP022TSS        | 62.200              | 99.583                    | 96.929                |
| SP024TSS        | 110.000             | 108.742                   | 101.821               |
| SP026TSS        | 102.300             | 96.249                    | 97.926                |
| SP028TSS        | 85.000              | 62.402                    | 62.567                |
| SP030TSS        | 105.500             | 140.364                   | 94.822                |

4.3. Descriptive Statistics

In the descriptive statistics, the study found that the data for the mean and median had close reading between the measured and predicted concentration of TSS using the tension spline method. Thus, the tension spline method produced a slight variance and range compared to the regularized method. Moreover, the study found that both methods had the prediction values with moderate skewed as the range was between -1 and – 0.5 or between 0.5 and 1. For kurtosis, the prediction made by the tension spline was greater than +1, indicating that the distribution was too peak. However, for the regularized spline method, the study found that the kurtosis value was close to zero, indicating that the response pattern was considered to follow a normal distribution. Table 2 shows the descriptive statistics generated for both methods.

Table 2. Descriptive statistics

|               | Measured TSS | Regularized Method | Tension Method |
|---------------|--------------|--------------------|----------------|
| N             | 15           | 15                 | 15             |
| Mean          | 84.8240      | 91.1842            | 86.2334        |
| Std. Error of Mean | 5.61066    | 6.10713            | 4.13881        |
| Median        | 85.0000      | 93.7652            | 90.3410        |
4.4. Normality Test

The normality tests were carried out later. The study found that data of TSS prediction using the regularized method follow the normal distribution. This situation did not occur when predicting using the tension spline method. Table 3 shows the normality test for both methods using the Kolmogorov-Smirnov and Shapiro-Wilk tests.

|                  | Kolmogorov-Smirnov | Shapiro-Wilk |
|------------------|---------------------|--------------|
|                  | Statistic | df | Sig. | Statistic | df | Sig. |
| Measured TSS     | .145      | 15 | 0.200 * | 0.916      | 15 | 0.165  |
| Regularized Method | .113      | 15 | 0.200 * | 0.988      | 15 | 0.998  |
| Tension Method   | .226      | 15 | 0.038 | 0.873      | 15 | 0.038  |

4.5. Correlation Analyses

A Pearson product-moment correlation coefficient was computed to assess the relationship between the actual value and predicted value estimated using both methods. Overall, estimation of the concentration of TSS by using both methods produced a strong and positive correlation. Correlation between the actual and predicted value of TSS estimated using the regularized spline interpolation method indicates a statistically significant difference between the two variables, \( r = 0.475, n = 15, p = 0.037 \). On the other hand, the correlation between the actual and predicted value of TSS estimated using the tension spline interpolation method indicates a statistically significant difference between the two variables, \( r = 0.509, n = 15, p = 0.026 \). Specifically, the results suggest that an increased value of the actual concentration of TSS correlated with the increased value of the predicted concentration for both methods. Table 4 shows the correlation between the actual and predicted values.
### Table 4. Correlation analyses

|                      | Regularized Method | Tension Method |
|----------------------|--------------------|----------------|
| Pearson Correlation  | 0.475*             | 0.509*         |
| Sig. (1-tailed)      | 0.037              | 0.026          |
| Sum of Squares and Cross-products | 3414.414          | 2481.553       |
| Covariance           | 243.887            | 177.254        |
| N                    | 15                 | 15             |

### 4.6. Regression Analyses

A simple linear regression analysis was used to predict the relationship between the observed and predicted values of TSS based on the regularized and tension spline methods at a 95% confidence level. The prediction value of TSS estimated by the regularized spline method did not explain a significant amount of variance in the observed value of TSS, $F(1,14) = 3.778$, $p= 0.074$, $R^2 = 0.225$, $R^2_{\text{adjusted}} = 0.166$. On the other hand, the prediction value of TSS estimated by the tension spline method did explain a significant amount of variance in the observed value of TSS, $F(1,14) = 4.543$, $p= 0.053$, $R^2 = 0.259$, $R^2_{\text{adjusted}} = 0.202$. Table 5 shows the result of the F test, while Table 6 shows the result of the F test for both methods.

### Table 5. F-test

| Model     | Sum of square | df | Mean Square | F    | Sig  |
|-----------|---------------|----|-------------|------|------|
| 1 Regression | 1488.465     | 1  | 1488.465    | 3.778| 0.074|
|           | Residual      | 5122.220 | 13 | 394.017    |      |      |
|           | Model         | 6610.685 | 14 |            |      |      |
| 2 Regression | 1711.898     | 1  | 1711.898    | 4.543| 0.053|
|           | Residual      | 4898.787 | 13 | 376.830    |      |      |
|           | Model         | 6610.685 | 14 |            |      |      |

### Table 6. Coefficient and t-statistics

| Model     | Unstandardized coefficients | Standardized coefficients |
|-----------|-----------------------------|--------------------------|
|           | B   | Std. Error | Beta | t   | Sig  |
| 1 Constant Reg. Method | 45.074 | 21.084 | 2.138 | 0.052 |
|         | 0.436 | 0.224 | 0.475 | 1.944 | 0.074 |
| 2 Constant Ten. Method | 25.366 | 28.357 | 0.893 | 0.388 |
|         | 0.690 | 0.324 | 0.509 | 2.131 | 0.053 |

### 4.7. Paired Sample T-test

A paired-samples t-test was conducted to compare TSS concentration in actual values and predicted values estimated using regularized interpolation method condition. There was no statistically significant difference in the scores' actual value (M= 84.8240, SD= 21.72997) and predicted value estimated using
regularized spline method (M = 91.1842, SD = 23.6528) condition; t (14) = -1.056, p = 0.309. Similarly, a paired-samples t-test was conducted to compare the concentration of TSS in actual value and predicted value estimated using the tension interpolation method condition. There was no statistically significant difference in the scores' actual value (M = 84.8240, SD = 21.72997) and predicted value estimated using regularized spline method (M = 86.2334, SD = 16.02952) condition; t (14) = 0.282, p = 0.782. The result indicates that the mean difference between the two variables is zero for both methods. This finding is important as the measured and predicted values should be intricately linked. The finding also reveals that Pair 2 had a larger significance value than Pair 1. Table 7 shows the results for paired samples tests for Pair 1 (actual vs. predicted value produced by regularized spline interpolation method) and Pair 2 (actual vs. predicted value produced by tension spline interpolation method) for TSS.

| Mean  | Std. dev. | Std Error Mean | t     | df  | Sig (2-tailed) |
|-------|-----------|----------------|-------|-----|----------------|
| Pair 1| 6.360     | 23.321         | -     | 14  | 0.309          |
| Pair 2| 1.409     | 19.355         | -0.282| 14  | 0.782          |

4.8. Error Analyses
In the error analyses, the TSS prediction by the tension spline method had lower errors than the regularized method. Mapping using both methods indicates reasonable forecasting as the data was within the 20%-50% range. However, the value of 21.51% was close to the range of 10%-20%, indicating good forecasting. Table 8 shows the error analyses conducted.

|                        | Regularized Method | Tension Method |
|------------------------|--------------------|----------------|
| Mean Squared Error (MSE)| 548.068            | 351.641        |
| Root Mean Squared Error (RMSE)| 23.41            | 18.752        |
| Mean Absolute Error (MAE)| 18.95             | 15.81          |
| Mean Absolute Percentage Error (MAPE)| 25.09%  | 21.51%        |

4.9. Production of Map
Map elements were inserted into the map for better visualization and communication of TSS variability in the study area. The range for the concentration of TSS was set to (<25 mg/L), (25-50 mg/L), (50-150 mg/L), (150-300 mg/L), and (>300 mg/L). However, since the minimum value was calculated at 39.83 and the maximum value was calculated at 181.58, the classification of the range of TSS was set at three classes which were (< 50 mg/L), (50-150 mg/L), (150-300 mg/L). Figure 4 shows the map of TSS developed using the tension spline method.
The inner part of the strait had a low concentration of TSS because this area had fewer human activities than other locations. A high concentration of TSS can result from anthropogenic activities [14].

4.10. Maps Accuracy Assessment

The accuracy of the map was determined by calculating the correct occurrence between the measured and predicted value (tension method). The study found that the accuracy of the developed map is 100%. Only station SP014TSS had the range of < 50mg/L, while most of the sampling points had the TSS value of 50-150 mg/L. Table 9 shows the correct occurrences for all sampling points.

Table 9. Maps accuracy assessment

| Sampling Points | Measured TSS (mg/L) | Correct occurrences (/) | Predicted (mg/L) |
|-----------------|---------------------|-------------------------|-----------------|
| SP002TSS        | (50-150)            | /                       | (50-150)        |
| SP004TSS        | (50-150)            | /                       | (50-150)        |
| SP006TSS        | (50-150)            | /                       | (50-150)        |
| SP008TSS        | (50-150)            | /                       | (50-150)        |
| SP010TSS        | (50-150)            | /                       | (50-150)        |
| SP012TSS        | (50-150)            | /                       | (50-150)        |
| SP014TSS        | (<50)               | /                       | (<50)           |
| SP016TSS        | (50-150)            | /                       | (50-150)        |
| SP018TSS        | (50-150)            | /                       | (50-150)        |

Figure 4. Map of TSS for Pulau Tuba

The inner part of the strait had a low concentration of TSS because this area had fewer human activities than other locations. A high concentration of TSS can result from anthropogenic activities [14].
4.11. The Implication of the Findings

Previous studies have highlighted that many academicians and researchers have used the spline interpolation method to observe data distribution. Spline has been used to predict air, land, or water pollution. The spline interpolation method had also previously been used to map the surface water temperature [15] and water salinity [17] over the coastal water of Pulau Tuba, Langkawi [15]. Apart from that, the spline interpolation method had also been used to map the surface salinity over the coastal water of Sungai Merbok, Kedah [16]. The finding of this research sheds light on the applicability of the spline interpolation technique in mapping the concentration of TSS over the coastal water of Pulau Tuba. The map can be used in site selection analyses to support the development of this area as sustainable agriculture, marine culture, and tourism hotspot.

5. Conclusion

The study concludes that the tension spline method outperforms the regularized spline method. The finding of this study may assist the government or the non-government bodies in monitoring the concentration of TSS and administrating sustainability steps following the United Nations Sustainable Development Goals (SDGs), especially in SDG 14 -Life Below Water that benefits the tourism and economic players and drivers at Pulau Langkawi, Kedah.

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| SP020TSS | (50-150) / (50-150) |
| SP022TSS | (50-150) / (50-150) |
| SP024TSS | (50-150) / (50-150) |
| SP026TSS | (50-150) / (50-150) |
| SP028TSS | (50-150) / (50-150) |
| SP030TSS | (50-150) / (50-150) |
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