

# Evaluating the Effectiveness of IDW Model in Developing Spatial Distribution Maps of Water Quality in the Soai Rap-Long Tau River



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**ABSTRACT:** Surface water quality of Can Gio mangrove forest, one of the world's biosphere reserves, plays important role for the regional ecosystem. However, there has been no assessment in water quality progression within the forest's core area. The Inverse Distance Weighting (IDW) method, which is a widely applied regression model, therefore has not been applied to evaluate its effectiveness in the study area. This study aims to assess the applicability of the IDW model in developing spatial distribution maps of surface water quality in the Soai Rap - Long Tau River system by collecting and analysing 25 water samples along a 70 km waterway. Monitored parameters include pH, BOD, COD, Total Phosphorus, Total Nitrogen, E-Coliform, Coliform, and Salinity. Results reveal that BOD and COD concentrations exceed national standards by 1.4 and 1.5 times, respectively, indicating organic pollution, while other parameters remain within acceptable limits, suggesting minimal microbial and agricultural contamination. In Soai Rap - Long Tau area, IDW-based spatial maps show higher pollution levels in densely populated, industrial, and transport-affected zones, confirming the influence of human activities on water quality. In the study area, statistical validation indicates that the IDW model performs well for most parameters, with correlation coefficients (R) above 0.5, especially for Salinity ( $R^2 = 0.84$ ), demonstrating strong model fit. For pH, although error metrics (MAE, MBE, and RMSE) indicate reasonable accuracy, the low R value suggests poor spatial correlation. The study recommends denser sampling for parameters like pH and further refinement of spatial models to improve prediction reliability. Overall, the IDW model proves useful for visualizing surface water quality patterns and identifying pollution hotspots in the Can Gio mangrove area.

**KEYWORDS:** Surface Water Quality, Interpolation Models, IDW, Human Impact, Mangrove Forest.

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## I. INTRODUCTION

Recognized by UNESCO on January 21, 2000, Can Gio mangrove forest is the first world biosphere reserve in Vietnam (UNESCO, 2000). The area is located southeast of Ho Chi Minh City, downstream of the Dong Nai - Saigon river system. The region has a total area of 70,445.34 hectares, population of more than 75,000 people, and density of 108 people per square kilometer in 2018. The area is surrounded by a dense water system, including large rivers such as Soai Rap, Long Tau, Dong Tranh, and Thi Vai. This river system supports a unique flooded ecosystem, supplying water for daily life and industrial use in the buffer zone, and facilitating waterway for large cargo ships.

Many studies have highlighted the pollution-capturing capacity and self-cleaning ability of forest ecosystems. A study in a mangrove forest in the Phetchaburi province of Thailand, which largely characterized by *Avicennia* plants,

has proven to increase dissolved oxygen (DO) by 32.39%, while reducing phosphate, ammonia, and nitrate by 88.23%, 73.77%, and 64.28%, respectively (Jitthaisong *et al.*, 2012). These ecosystems are also considerably valuable from both ecological and economic perspectives, especially in terms of carbon storage capacity (Xu *et al.*, 2024). In thirty years, human activities have put a lot of pressure on the mangrove forest system in Can Gio. Despite its important role in preserving the unique ecosystem and reducing pollution, industrialization and changes in land use have led to increased levels of heavy metals in the river sediments. Additionally, a rise in total organic carbon (TOC) and total nitrogen has been studied since the 1990s, which can be attributed to river point sources, atmospheric pollution, and erosion (Costa-Böddeker *et al.*, 2020). A study about risk assessment of metals in sediments of Soai Rap estuary of Saigon - Dong Nai River, has shown that Copper (Cu) and Lead (Pb) exceeded the national standard by 1.64 - 2.2 times and 1.34 - 1.44 times, respectively (Phuong *et al.*, 2018). An

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analysis of dioxin in forest sediment samples in Can Gio has been conducted and found that the sediment quality was good for benthic organisms, and the abnormal values were found at a depth of  $95 \pm 10$  cm, which may have been originated from defoliants sprayed during the Vietnam War (Hung *et al.*, 2021). The pollution load capacity of Can Gio mangrove forests is correspondingly reaching a precarious threshold. A study about the loading capacity of Ho Chi Minh City's coastal water resources has revealed that the area will no longer be able to manage the pollution load by the year 2030, including Total Suspended Solids (TSS), BOD,  $\text{PO}_4^{3-}$ , and Coliform (Tuan and Huy, 2021). Another research on evaluation of Saigon River water resources' quality applying quality indicators including COD,  $\text{BOD}_5$ , Ammonium ( $\text{NH}_4^+$ ), Nitrate ( $\text{NO}_3^-$ ) revealed a quality declining trend of the total area (Hong *et al.*, 2023).

Despite studies on the natural environmental quality in the Can Gio Biosphere Reserve indicating the declining pollution-capturing ability and the sediment environmental quality showing signs of pollution, there has been no in-depth study on the quality of surface water resources within the biosphere reserve, especially the core area of the Long Tau - Soai Rap River basin. Recent studies on surface water quality in the region have focused on the quality of coastal seawater in the estuary area (Thanh and Khanh, 2018; Tuan and Huy, 2021; Quach *et al.*, 2024) without specific assessment of the water quality progression from the populated residential and industrial areas (Phu My bridge, District 7, Ho Chi Minh City) to the estuary (the last section of Long Tau River).

Regarding spatial interpolation, many different interpolation methods are widely applied, such as Spline, Kriging or Inverse Distance Weighted method (IDW). The IDW is a popular interpolation application integrated into many GIS analysis programs such as ArcGIS, and QGIS. It is widely applied in environmental quality studies such as building radiation distribution maps (Roux *et al.*, 2023), nitrate distribution map for ground water (Ohlert *et al.*, 2023), surface water quality zoning map (Y *et al.*, 2021), and rainfall distribution estimation (Chen and Liu, 2012). For water quality, it showed its effectiveness by high correlation coefficient values in Tunisia (Khouni *et al.*, 2021), decent combination to other method in China (Yang *et al.*, 2020) or India (Talukdar *et al.*, 2023). In Vietnam, IDW was applied for zoning the Water Quality Index (WQI) at Sai Gon River, Binh Duong province in 2020 (To *et al.*, 2020), and Can Tho City in 2021 (Y *et al.*, 2021). Each interpolation method has its own disadvantages. The Spline interpolation mathematical function, for example, is ineffective if the interpolation value and distance become too large, and Kriging depends on the spatial distribution trend of the object expressed by the z value. The IDW method, therefore, has some disadvantages such as: the quality of the interpolation results may decline if the distribution of sample points is not uniform; empirical selection of interpolation parameters; the unsmoothing surface; sensitivity to outliers such as clustered or isolated points; no estimation of error; or the arbitrary weight assignment (Marc *et al.*, 2013; Li *et al.*, 2018; Khouni *et al.*, 2021). Consequently, this method needs special requirement of the dataset to be

effective (Ikechukwu *et al.*, 2017) such as the even distance between reference points, or limited outliers.

The method has proved to be effective for evenly and widely distributed substances such as pollutants, and to build quality zoning maps in natural environments (Yang *et al.*, 2020; To *et al.*, 2020; Khouni *et al.*, 2021; Y *et al.*, 2021). It, however, is considered to have limits when the environment has local changes such as the natural ecological environment in Can Gio with some concentrated human activities zones. So far, this model has not been applied to examine the environmental quality changes in the study area, Long Tau - Soai Rap River. For these arguments, this study was conducted to consider the probability of applying the IDW spatial interpolation method in developing surface water quality maps in the Can Gio area. For the best performance, the sample points in the study were carefully chose within an even distance to apply to the IDW model. Other results expected from interpolated maps are human impacts on water quality, specifically the Long Tau-Soai River area. Eight quality parameters including pH, BOD, COD, Total Phosphorus, Total Nitrogen, E-Coliform, Coliform, Salinity are involved in the analysis and evaluation.

## II. GEOLOGICAL BACKGROUND.

Can Gio, the only coastal district of Ho Chi Minh City, is located in the Southeast of the city, and about 50 km from the city center. The North is bordered by Soai Rap River; the South borders the East Sea. The West is separated from Long An and Tien Giang provinces by Soai Rap River. The Northeast is separated from Dong Nai province by Long Tau River. The Southeast is adjacent to Ba Ria-Vung Tau province by Thi Vai River. The area is presented in Figure 1.

The total area of Can Gio is about 704.45 km<sup>2</sup>, accounts for about 1/3 of the city, of which forestry land, river and canal comprise of 46.45% and 32% of the entire area, respectively. Particularly, mangrove areas account for 56.7% of the district, creating a unique mangrove ecosystem, which is mainly Mangrove, *Sonneratia*, *Avicennia*. The area is primarily used for farming rice, fruits, sedge, and salt production. With a coastline of nearly 20 km, the area is very potential for aquaculture, sea transportation, and sea wharf.

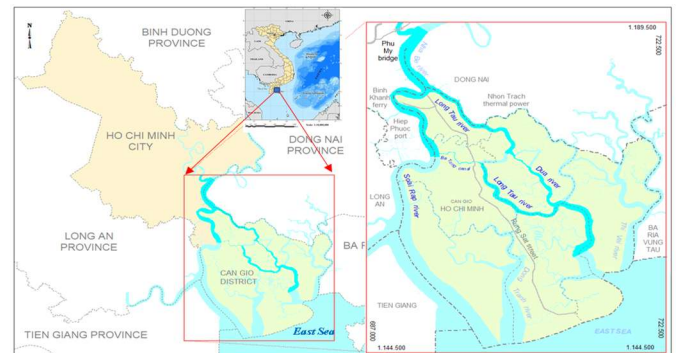


Figure 1. The study area at Can Gio district, Ho Chi Minh City. Source: Global Administrative Areas (GADM) 2018 and Vietnam OSM Becamap 2024)

The Can Gio mangrove forest holds a significant strategic position as it borders a rapidly urbanizing metropolis. This area

serves as a crucial waterway for transporting goods from the sea to the city's port. Recognized as a World Biosphere Reserve, the forest is vital for preserving a diverse and unique wetland ecosystem. However, the region faces considerable pressure from urbanization and industrial activities from surrounding rapidly developing areas, including Ho Chi Minh City, Long An, and Dong Nai provinces. Environmental quality of the area, additionally, has not yet been fully studied; especially the quality progression. Therefore, to establish a baseline for assessing human impacts this study evaluated changes in surface water quality within the forest's core. This assessment aims to provide insights into the interactions between urban development and environmental sustainability.

### III. METHODOLOGY

#### A. Data Collection

The water samples were taken in March 2024, from 7:30 a.m. to 5:30 p.m. Total length of the surveyed and sampled waterway is about 65 - 70 km, starting from the Phu My Bridge in District 7, going along Long Tau River to the waterfront, then returning towards Soai Rap River to the starting point. The distance among the sampling sites is indifferent for every sample, mostly ranging from 2.5 to 3km. The pathway and locations of the monitoring sites were predetermined using Google Earth application version 7.3.6.10201. The samples were taken in the middle of the river and from 10 to 20 cm depth. A total of 25 samples were collected and illustrated in Figure 2.

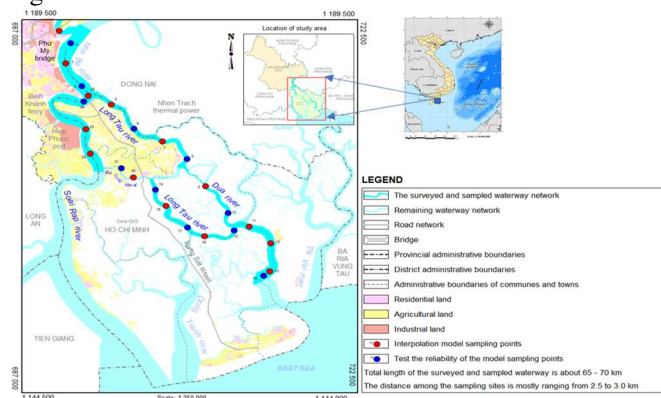


Figure 2. The sampling sites at Can Gio district (red and blue dots)

From the Figure 2, the dataset is randomly divided into two categories, including 14 red samples for running the interpolation model on QGIS application version 3.10.4. The other 11 blue samples were applied to test the reliability of the model.

#### B. Methodology

##### 1) Sample preservation and analysis

Samples were taken and preserved according to Vietnamese Standard TCVN 6663 - 3: 2016 (Vietnam Ministry of Science and Technology, 2016). They were preserved in a container at a temperature of less than 2°C, completely shielded from the sunlight, and transported to the laboratory on the same day. The quality parameters pH, BOD, COD, Total Phosphorus, Total Nitrogen, E-Coliform,

Coliform, Salinity were analyzed at the laboratory of Saigon University, in accordance with the regulations QCVN 08:2023/BTNMT: Regulations National technical standards on surface water quality (Vietnam Ministry of Natural Resources and Environment, 2023).

##### 2) GIS based map application

The study utilized base maps from the Ho Chi Minh City Geographic Information System database version 2024 on the Quantum Geographic Information System (QGIS) application (HCMCGIS Application Center, 2024). These base maps were sourced from Google, Carto, ESRI, and the OpenStreetMap database. These database systems are widely recognized for their effectiveness due to the large amount of information contributed by numerous users resulting in frequent updates (Ming *et al.*, 2013; Neis and Zielstra, 2014). In the study, this information was used to develop base maps for the study area and to evaluate population density and human production activities in relation to water resource quality.

##### 3) Inverse distance weighted (IDW) interpolation

Recognized as one of the spatial interpolation methods, IDW is widely applied in interpolating undefined points on the map, illustrated in Figure 3 for elevation points.

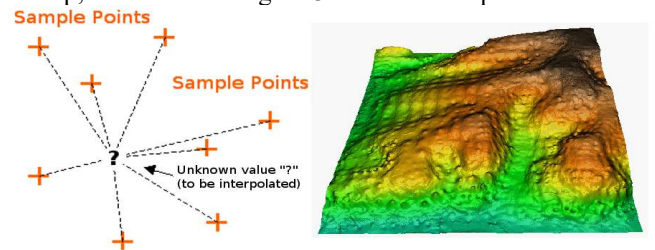


Figure 3. IDW interpolation based on weighted sample point distances (left) and IDW simulation for surface from elevation vector points (right) (Mitas and Mitasova, 1999).

In the IDW interpolation method, the points are weighted so that the influence of one point over another decreases with distance. An assigned weight of an undefined point will decrease if its distance with a defined point, which is a sampling site, increases. This can be explained that as the coefficient increases, the value of the unknown point approaches the value of the nearest observed point. Weights are assigned to a point according to the principle that the weights will decrease as the distance from the new point increases (Watson and Philip, 1985). The general formula of the method is as (1) (ESRI, 2004, 2024):

$$z(s_o) = \sum_{i=1}^N \lambda_i z(s_i) \quad (1)$$

where  $z(s_o)$  is the predicting value of a point  $s_o$ ;  $N$  is the number of the nearby defined points (sample points) that is involved to the calculation;  $\lambda_i$  is the assigned weights to every measured point, which are inversely proportional to distance;  $z(s_i)$  is the observed valued of the  $i^{th}$  point.

The assigned weight  $\lambda_i$  is calculated as followed (2):



$$\lambda_i = \frac{d_{i0}^{-p}}{\sum_{i=1}^n d_{i0}^{-p}} \text{ and } \sum_{i=1}^n \lambda_i = 1 \quad (2)$$

where  $\lambda_i$  is the weight coefficient of the  $i^{\text{th}}$  point,  $d_{i0}$  is the distance between the predicted point ( $s_0$ ) and the defined points ( $s_i$ ); and  $p$  is the power of the distance.

In Equation (2), the  $p$ -value represents the power parameter and is determined by minimizing the Root Mean Square Prediction Error (RMSPE), which is a statistical measure of the error in the estimated surface (Stuart, 1980). The computer application will attempt various powers to find the one that result in the lowest RMSPE, as shown in Figure 4 (left). The weight is inversely proportional to the distance raised to the power  $p$ . Consequently, as distance increases, weight declines rapidly. If  $p = 0$ , the distance does not decrease and since each weight will be equal the prediction will be the average of all measured values. As  $p$  increases, the weights of distant points decrease rapidly, illustrated in Figure 4 (right). If the  $p$ -value is too high, only a few surrounding points will affect the prediction. Therefore, the study applies the  $p$ -value of 2 to run the IDW interpolation model by QGIS application for all the sample sites.

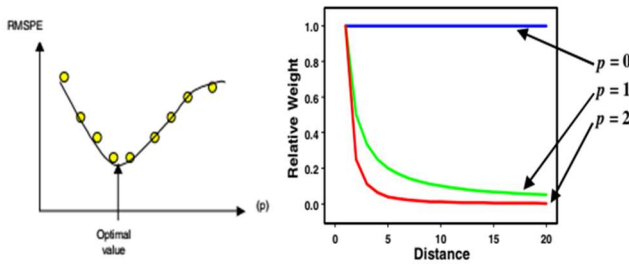


Figure 4. Illustration about  $p$  selection by RMSPE (left) and optimum  $p$  value (right) of IDW method (ESRI, 2004).

In this study, IDW analysis was performed by the QGIS program version 3.10.14-A Coruña. On the QGIS application, the IDW interpolation method was performed on the map layer of observation vector points (sample sites) and export the interpolated image by the structured line method.

#### 4) Reliability assessment

In order to test the reliability of the IDW model, some of the parameters are included and calculated. They are Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). The formula of the two parameters is presented in (3) and (4). Both of these error calculations are widely applied in many studies on evaluation models, including regression and interpolation simulations. RMSE has a value in the range from negative to positive infinity with a value of 0 being optimal for an absolutely accurate model. MAE has a value from 0 to positive infinity and is most optimal at the smallest value. Other assessment calculations are also included in the study, including correlation coefficient ( $R$ ), and Mean Bias Error (MBE), as in formula (5) and (6). The  $R$  value explains how much the model fit the observation and is ranging from +1 to -1. MBE is another parameter checking the average deviation between the two datasets. MBE values close to 0 are best, while negative values indicate

underestimation, and positive values indicate overestimation (Wang and Lu, 2018; Chicco *et al.*, 2021; Hodson, 2022).

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^n |p_i - o_i| \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (p_i - o_i)^2} \quad (4)$$

$$R = \frac{\sum_{i=1}^n (p_i - \bar{p})(o_i - \bar{o})}{\sqrt{\sum_{i=1}^n (p_i - \bar{p})^2} \sqrt{\sum_{i=1}^n (o_i - \bar{o})^2}} \quad (5)$$

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^n (p_i - o_i) \quad (6)$$

where  $p_i$  is the predicted value of a site  $i$  when applying the IDW model;  $o_i$  is an observed value of a site  $i$ ;  $n$  is the number of the sites.

## IV. RESULTS AND DISCUSSION

### A. Statistical Description of the Observed Values

During the process of sampling and analysing samples, three parameters were not applied for the interpolation model because of very low detected value, including:

#### 1. E. Coli

Escherichia coli, commonly known as E. coli, is a type of gram-negative bacterium found in the digestive tracts of humans and animals. This bacterium plays a significant role in promoting digestive health. The presence of E. coli in outdoor environments can indicate microbiological pollution, such as the improper disposal of animal carcasses or untreated human and animal waste released into the environment. Therefore, the very low level of E. coli in water samples indicates that the water in the research area is free from microbial contamination and can be safely used for domestic purposes.

#### 2. Total Phosphor and Total Nitrogen

The very low value of Total Nitrogen and Phosphorus is similar to the study in 2022 about the coastal seawater quality in Can Gio in the period 2019-2021, with total Phosphor and Nitrogen concentration being quite low (Thai *et al.*, 2022). Together with on-site observations, it can be predicted that there is insignificant risk of contamination from chemical fertilizers or farm waste.

The remaining parameters including pH, BOD<sub>5</sub>, COD, Coliform and Salinity of the total 25 samples in comparison with National Quality Standard, type B (Vietnam Ministry of Natural Resources and Environment, 2023) are statistically described in Table 1.

Based on the current regulations for surface water quality, the average quality is classified as type B, suitable for industrial and agricultural purposes after undertaking proper treatment measures (Vietnam Ministry of Natural Resources and Environment, 2023). However, the quality of the water samples does not meet the standards for BOD and COD indicators, with mean values exceeding the B-type standard by 14.28 and 36.96 times, respectively. Because the

two indicators BOD and COD show the level of oxygen consumption of microorganisms in water in the presence of nutrients as food, the higher the consumption level, the more nutrients microorganisms consume. Therefore, these indicators are considered signs of organic substances in the water (Sawyer *et al.*, 2003; Sharma and Dahiya, 2023). Further evidence is therefore needed to determine whether these organic substances are pollutants, as the sampled area

is a mangrove forest. Specifically, Coliform levels are within the acceptable range for type B water quality, but do not meet the standards for type A water quality. Consequently, it can be concluded that the water in the study area is of good quality but shows signs of organic pollution due to higher BOD and COD values than the standards.

Table 1. Statistical description of the quality parameters

|                  | Unit   | Min   | Max   | Mean   | StD    | Low CI 95% | High CI 95% | Quality standard |
|------------------|--------|-------|-------|--------|--------|------------|-------------|------------------|
| pH               |        | 6.39  | 7.74  | 7.13   | 0.33   | 7.00       | 7.27        | 6.5-8.5          |
| BOD <sub>5</sub> | (mg/l) | 7.00  | 121   | 71.40  | 34.60  | 57.12      | 85.68       | ≤ 6              |
| COD              | (mg/l) | 312   | 696   | 511.68 | 103.40 | 469.00     | 554.36      | ≤ 15             |
| Coliform         | (CFU)  | 1,400 | 3,300 | 2,356  | 557.58 | 2,125.84   | 2,586.16    | ≤ 5,000          |
| Salinity         | (‰)    | 10    | 26.00 | 16.80  | 5.38   | 14.58      | 19.02       |                  |

CI = Confident Interval; StD = Standard Deviation

**B. Water Quality Interpolation**

Out of the eight monitoring parameters, five were included in the quality progressive map, including pH, BOD<sub>5</sub>, COD, Coliform, and Salinity. Three parameters, including E. Coli, Total Phosphorus, and Total Nitrogen, were not applied for assessing the changes. These three

parameters were tested to have very low measurement values, and significantly below the allowable standards. As a result, generating assessment maps to determine pollution levels for these parameters is unnecessary.

The spatial progression of the area is presented in Figures 5 to 9. The interpolation maps reveal several findings as follows:

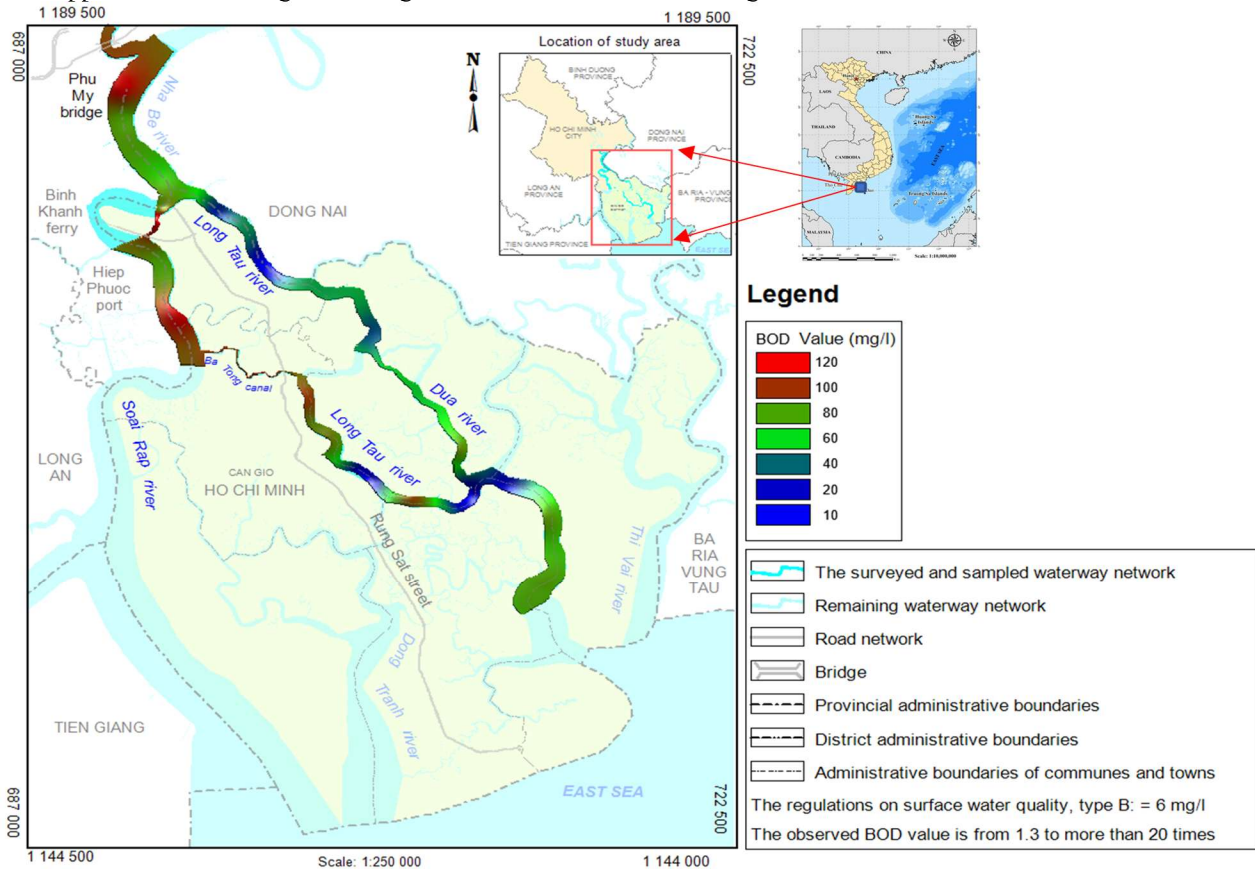


Figure 5. Water quality interpolation for BOD value (mg/l)

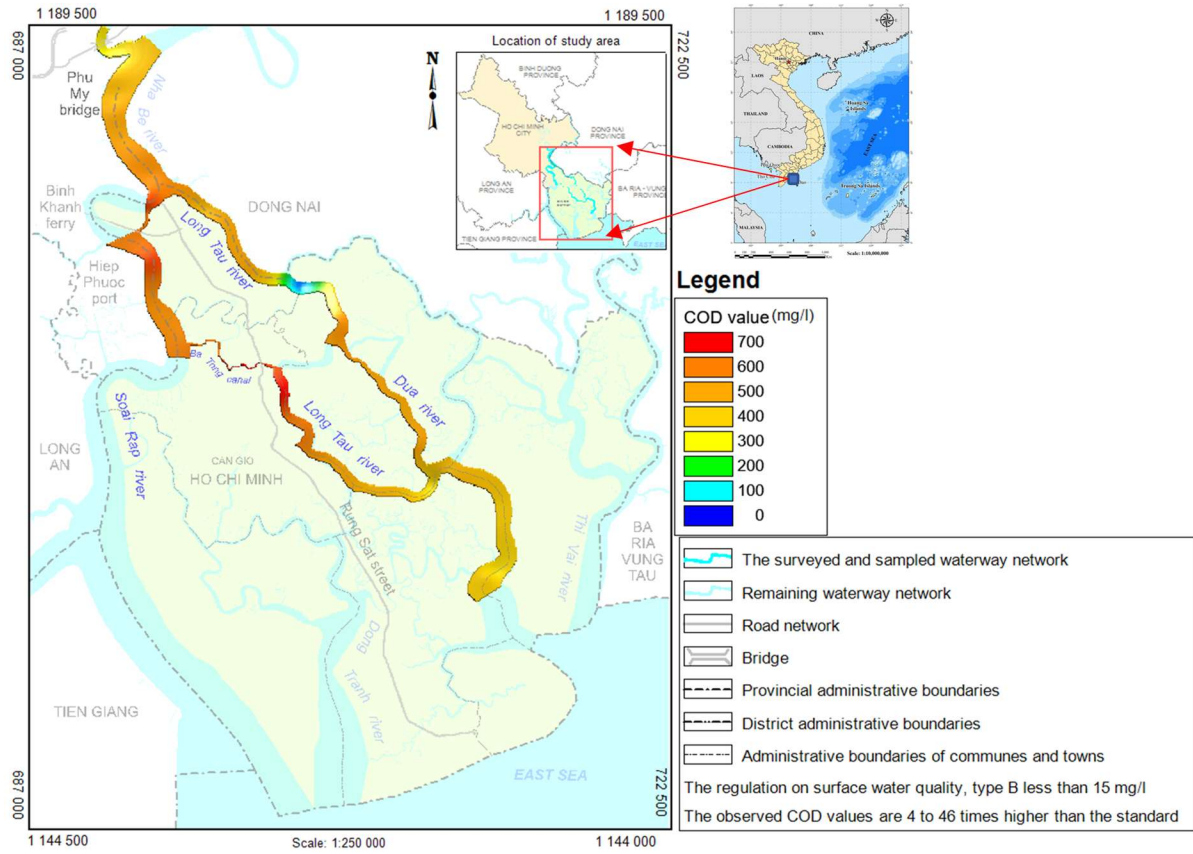


Figure 6. Water quality interpolation for COD value (mg/l)

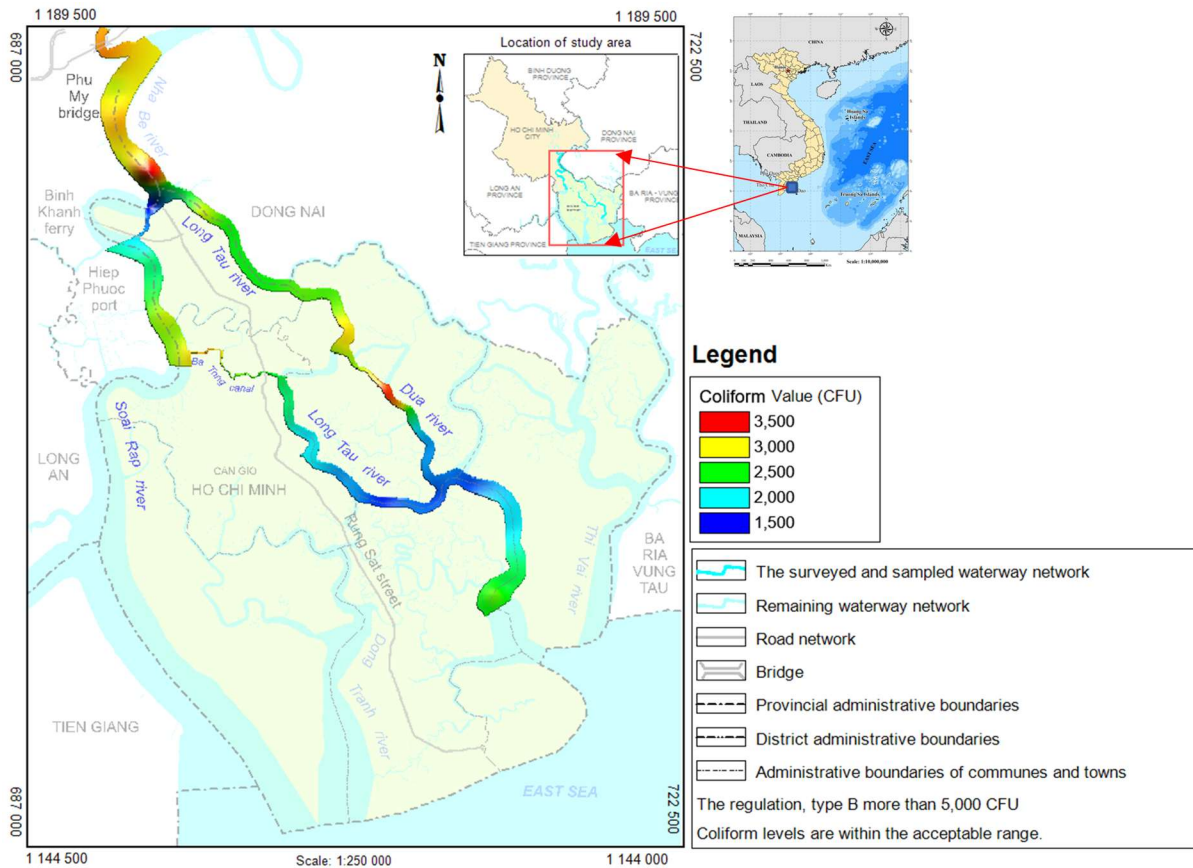


Figure 7. Water quality interpolation for Coliform value (CFU)



1) BOD, COD, and Coliform

This is a group of parameters which higher values indicate worsen environmental quality. Figures 5, 6, and 7 depict elevated values primarily concentrated in industrial and residential areas, including those surrounding the Soai Rap River section, Hiep Phuoc industrial park, Hiep Phuoc 5 Industrial Park, and Nhon Trach thermal power plant.

The maps clearly indicate that human activities have significantly impacted the quality of surface water. Additionally, the estuary area has experienced increased pollution as the values of monitored parameters have risen. The heightened pollution in the estuary area can be attributed to heavy waterway transportation, as well as active aquaculture and fishing activities in the region.

When compared with the regulations on surface water quality, type B, the observed BOD value is from 1.3 to more than 20 times, and COD values are 4 to 46 times higher than the standard. Coliform values, on the contrary, are 0.3 to 0.6 times lower than the standard.

2) pH and Salinity

In Figure 8, it is evident that the pH value gradually increases when moving from the mainland to the seaport. Particularly at waterway intersections between tributary rivers, pH values tend to reach their highest levels. Therefore, more detailed assessments are required to investigate the changes in pH resulting from navigation and human production activities.

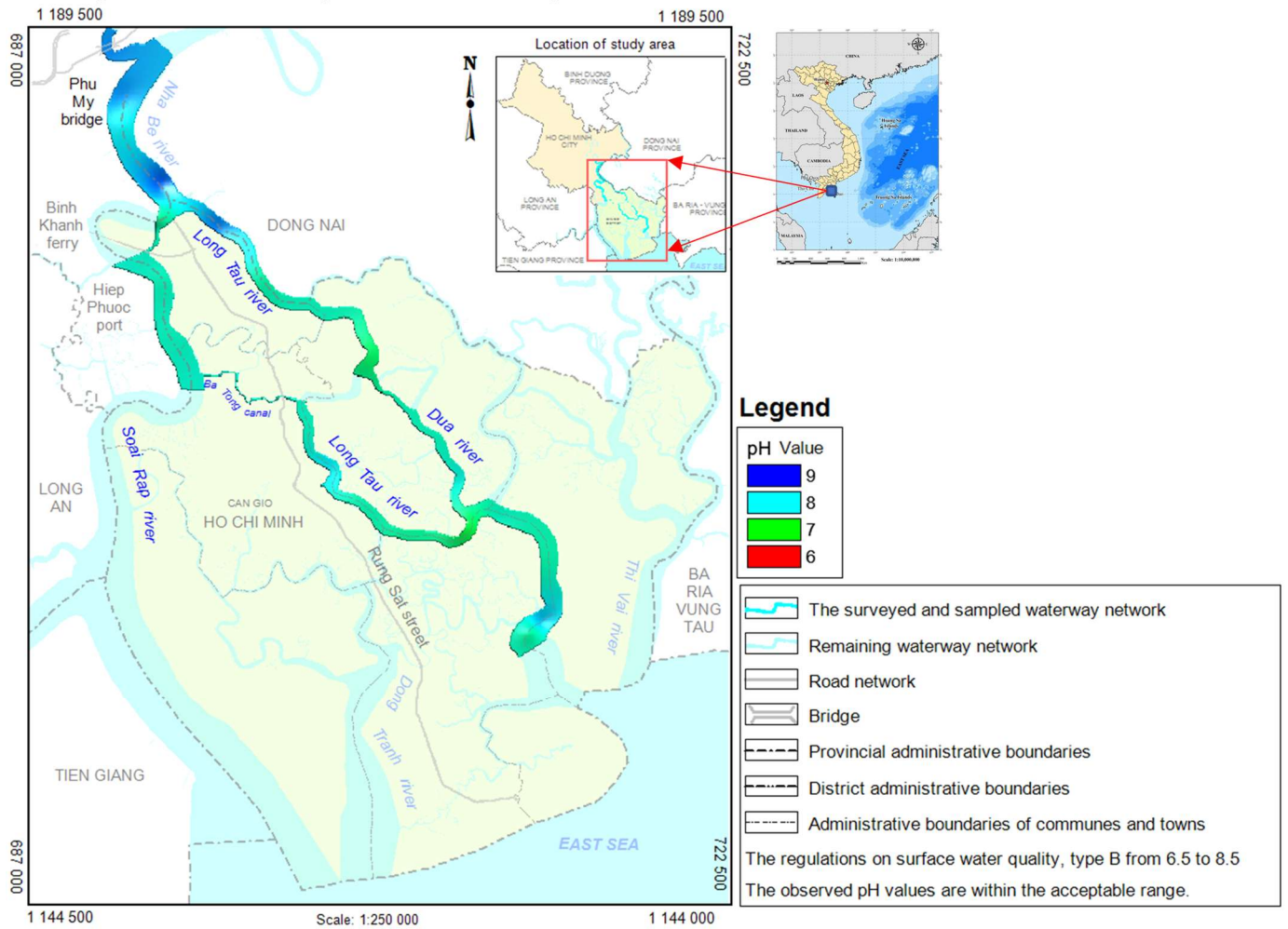


Figure 8. Water quality interpolation for pH value

The national regulation specifies that the salinity of water used for domestic purposes must be less than 250 mg/L (2.5 ppt) (Vietnam Ministry of Health, 2018). Among the 25 samples collected, the average concentration was about 16.8 ppt, ranging from 14.5 to 19 ppt on average. Figure 9 illustrates that the salinity of the study area increases closer to Can Gio seaport, with the lowest salinity

occurring in samples within the inner city. The first sample (Phu My Bridge) showed the lowest value of 10 ppt, which is four times higher than the standard. Therefore, it can be concluded that saline invasion in the Saigon - Soai Rap - Long Tau River area is rapidly developing, particularly during the dry season in 2024.

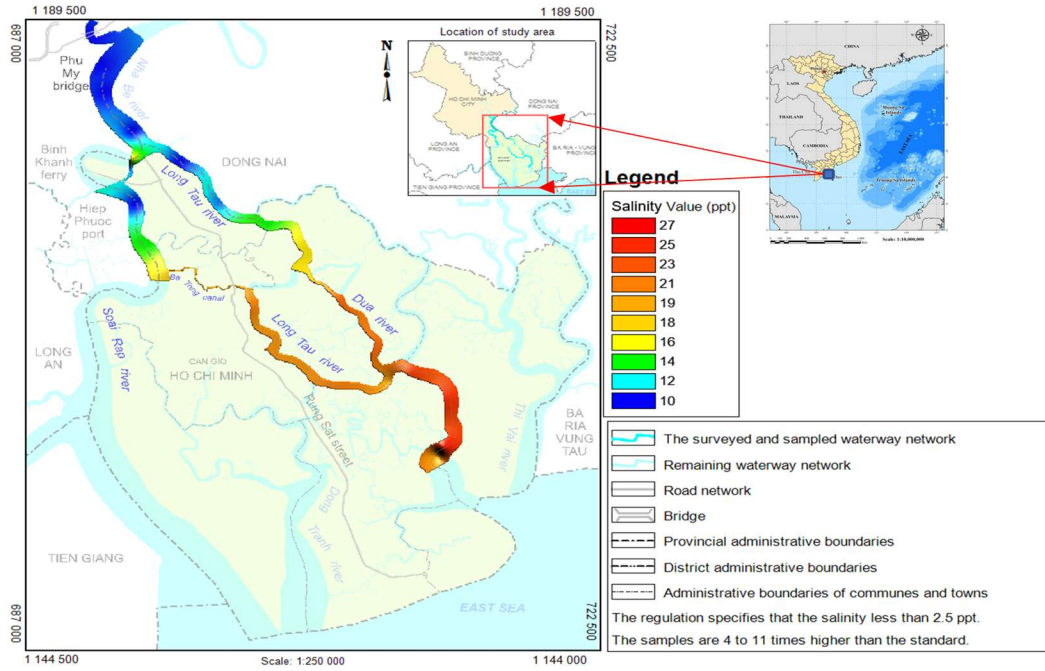


Figure 9. Water quality interpolation for Salinity value (%)

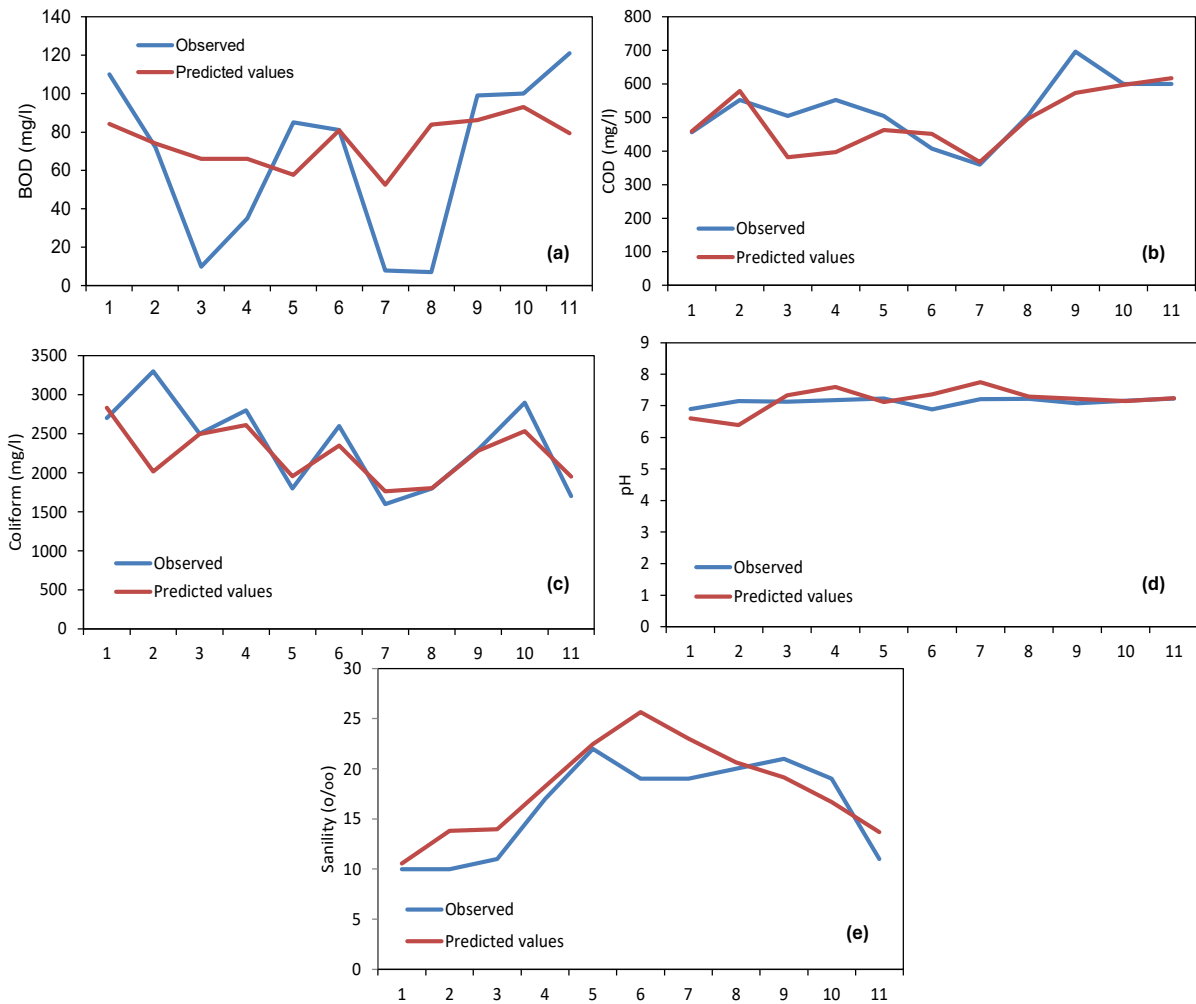


Figure 10. The differences between observed (blue) and predicted values (red): (a) BOD, (b) COD, (c) Coliform, (d) pH, (e) Salinity.



C. Model Evaluation

1) Deviation between observed and modelled datasets

The differences between the monitored and predicted values are graphed in Figure 10. It can be seen that most of the progressive trends of the observed and predicted values are almost following the same pattern, except for BOD.

2) Evaluation of reliability

Normality inspection of the errors was conducted by SPSS application version 16.0. The results are presented in Figure 11. From the Figure, the errors are distributed evenly along the normality lines for all the parameters. Therefore, the model can be described to be significant and accordingly applied for testing the power and reliability. The results of these testing parameters are presented in Table 2, which underlined numbers indicating good to

fairly good fitness of the model. The model for BOD demonstrates good MBE and coefficient R, but its MAE and RMSE are quite high, indicating significant errors between the observed and predicted values. COD and Coliform show good correlation, with R values of 0.72 and 0.66 respectively. However, further attention is needed as the RMSE value for these two parameters is also relatively high, signifying a substantial deviation between the observed and actual values. The pH values have very good mean error values, including MAE, MBE, and RMSE. Nevertheless, it shows relatively low correlation with an R value of 0.29. The IDW model has been found to be the best at adapting to salinity based on good validation values, especially the highest R value of more than 0.8.

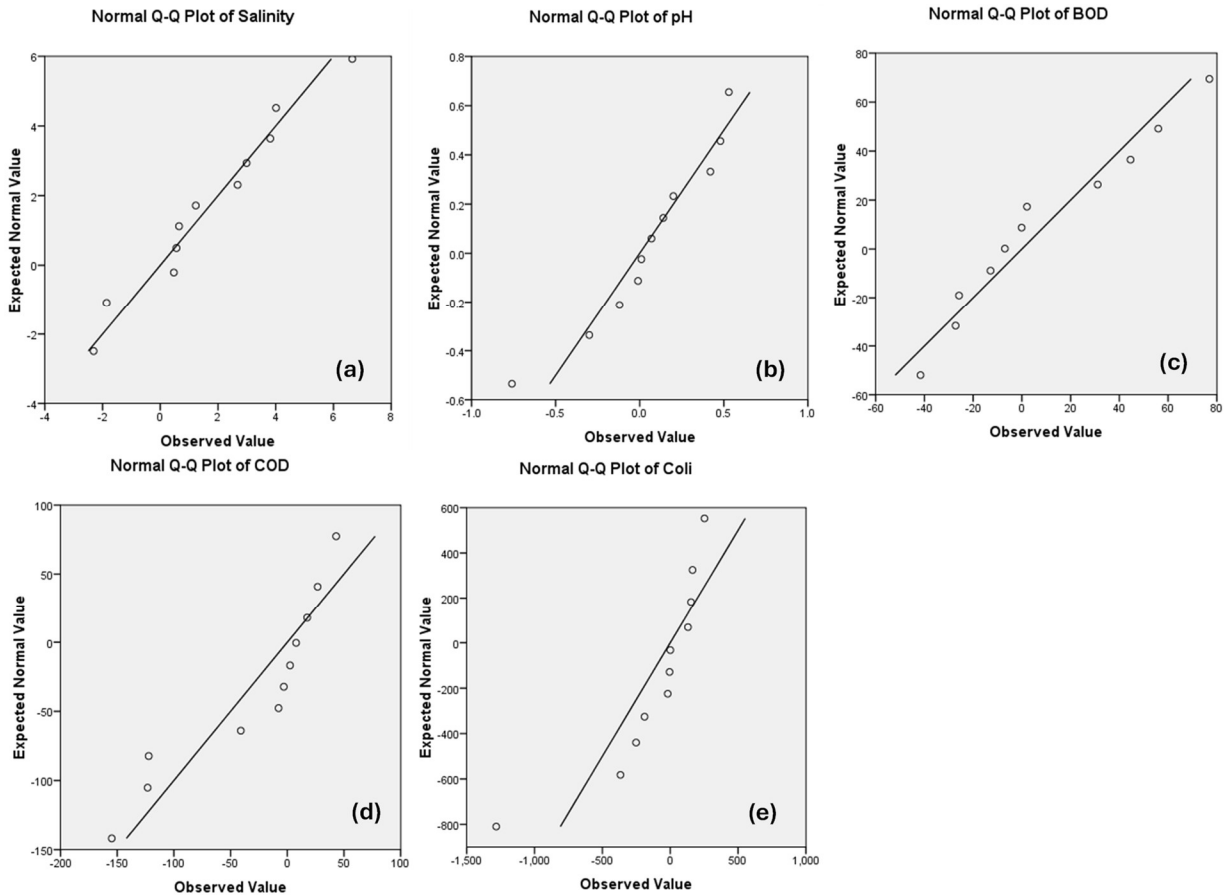


Figure 11. Normal Q-Q plot of the errors: (a) Salinity, (b) pH, (c) BOD, (d) COD, (e) Coliform.

Table 2. Model evaluation results

|             | <b>BOD</b>  | <b>COD</b>  | <b>Coliform</b> | <b>pH</b>   | <b>Salinity</b> |
|-------------|-------------|-------------|-----------------|-------------|-----------------|
| <b>MAE</b>  | 29.57       | 49.97       | 255.90          | <u>0.28</u> | <u>2.47</u>     |
| <b>MBE</b>  | <u>8.74</u> | -32.20      | -128.44         | <u>0.06</u> | <u>1.71</u>     |
| <b>RMSE</b> | 37.37       | 73.10       | 427.46          | <u>0.36</u> | <u>3.05</u>     |
| <b>R</b>    | <u>0.53</u> | <u>0.72</u> | <u>0.66</u>     | 0.29        | <u>0.84</u>     |

## V. DISCUSSION

This study evaluated the water quality in the Soai Rap - Long Tau River system within the Can Gio mangrove forest area, Vietnam. Overall, most monitored parameters indicated that the water quality meets type B of the national standard. However, elevated concentrations of BOD and COD suggest signs of organic pollution. These findings highlight the need for more detailed assessments regarding the concentration and sources of organic substances in mangrove water bodies to accurately characterize the pollution.

Spatial distribution maps of key water quality parameters: BOD, COD, Coliform, pH, and Salinity were generated using the Inverse Distance Weighting (IDW) interpolation method. For BOD, COD, and Coliform, higher concentrations were found in areas with dense population, industrial activities, port operations, and waterway transport. This pattern indicates strong anthropogenic influences on surface water quality in the region. The spatial distribution of pH was notably irregular, with peak values located at confluences of river branches. This suggests that localized factors such as aquaculture or navigation may be affecting pH levels, warranting more targeted investigations. Meanwhile, salinity exhibited a clear inland-to-coastal increasing trend, with signs of saline intrusion during the dry season.

Model validation revealed that the IDW interpolation lacked smoothness, especially for BOD and Coliform, although the modeled and observed trends remained generally consistent. These observations are consistent with previous findings in other countries such as Tunisia, China, and India (Yang *et al.*, 2020; Khouni *et al.*, 2021; Talukdar *et al.*, 2023), and in Vietnamese studies (To *et al.*, 2020; Y *et al.*, 2021), which also noted variability in model accuracy depending on the pollutant and region.

The correlation coefficient ( $R^2$ ) values for most parameters, except pH, ranged from 0.5 to 0.84, indicating acceptable performance of the IDW model for mapping spatial variation in water quality. However, the error metrics (MAE, MBE, RMSE) showed significant fluctuations, suggesting limitations in prediction accuracy and model robustness. Among the parameters, salinity showed the strongest model performance, with optimal error indicators and the highest  $R^2$  value (0.84).

For the pH parameter, although MAE, RMSE, and MBE values were reasonable, the correlation coefficient was the lowest, indicating a poor fit between observed and modelled values. Furthermore, pH displayed unique spatial behaviour clustered and inconsistent compared to other parameters which may be a result of its sensitivity to external influences and the nature of IDW. Therefore, applying alternative interpolation techniques, such as Kriging or spline methods, may yield better performance for pH mapping in future studies.

The results also reinforce existing concerns about organic pollution in the core zones of the mangrove

reserve. These findings align with previous studies reporting decreasing pollution load capacity (Tuan and Huy, 2021) and ecological degradation (Hong *et al.*, 2023; Costa-Böddeker *et al.*, 2020).

It is important to acknowledge the study's limitation in terms of sampling density, with only 25 points covering a 65-70 km river section (approximately 2.5-3.0 km between sites). Despite this, the interpolated maps captured meaningful spatial trends. To improve the model's effectiveness, future research should increase the sampling frequency and extend the study area to cover adjacent rivers, such as Long Tau and Dong Tranh. Additionally, pre-processing the dataset to exclude unsuitable variables prior to interpolation is recommended to enhance model precision and reliability.

## VI. CONCLUSION

This study assessed water quality in the Soai Rap - Long Tau River, Can Gio mangrove area, showing generally good conditions under type B standards. However, BOD and COD values exceeded permissible limits, indicating signs of organic pollution. Spatial interpolation using the IDW method revealed higher pollution in densely populated and industrial zones. Salinity increased from inland to sea, with signs of saline intrusion during the dry season. pH showed uneven distribution, with high values at river junctions, likely influenced by aquaculture and navigation. Model evaluation showed that while IDW worked well for most parameters ( $R^2 = 0.5-0.84$ ), it was less effective for pH. Despite some limitations in smoothness and sample spacing (25 sites over ~70 km), the IDW model still produced meaningful spatial trends. Future work should increase sampling density and explore alternative interpolation methods, especially for pH. Overall, IDW is a suitable approach for spatial water quality assessment, supporting earlier findings of environmental degradation in the area.

## AUTHOR CONTRIBUTIONS

**Thu Thi Minh Nguyen:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing, Project administration. **Ngan Truong Nguyen:** Software, Data curation. Formal analysis, Validation. **Doan Quang Tri:** Visualization, Supervision, Writing – review & editing, Writing – original draft, Literature review, Writing – review & editing.

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