Water quality assessment of main rivers and canals in Ben Tre Province, Mekong Delta Vietnam

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Abstract. Ben Tre, a Mekong Delta Province has dense canal networks with about 6,000km in total extension. There are more than 60 canals having over 50m of width. The river system plays the important role of Ben Tre Province, providing water for agriculture, drainage, navigation, fisheries and restoration in local area. Data for 44 sites from the main rivers and canals of Ben Tre were collected in April and October from 2015 to 2016 to analyze for pH, total suspended solid (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), amoni (NH₄⁺), phosphate (PO₄³⁻), and coliform. Then data were used for calculation and mapping. The ArcGIS 9.3 software, Inverse Distance Weighting (IDW) interpolation, and hydrologic variables in April and October from 2015 to 2016 were applied to build the maps of water quality for the Ben Tre. This result indicated that the water quality of many sites from the main rivers and canals of Ben Tre in April and October from 2015 to 2016 were polluted with TSS values at 75–304 mg/L, BOD₅ from 7.0–25.0 mg/L; and coliform from 1.1x10³ to 2.3x10⁵ MPN/100 mL. Additionally, the results classified water quality of Ben Tre at 5 classes, as described by The Vietnam Environmental Protection Agency, good quality for water supply (1); use for water supply required appropriate treatment (2); usage for water use for irrigation (3); water use for navigation (4); and, heavy pollution (5). Last but not least, the wastewater control solutions for Ben Tre are also suggested. There were some the prior projects for environmental pollution control these have been implemented to improve the water quality for main river and canals in Ben Tre Province.

1. Introduction
Ben Tre Province is nestled between two main branches of the Mekong’s largest tributary, which divergences to create a fertile agricultural region and beautiful coastline (figure 1) [1]. Ben Tre Province has dense canal networks with about 6,000 km in total extension. There are more than 60 canals having over 50 m of width. The river system plays the important role of Ben Tre Province, providing water for agriculture, drainage, navigation, fisheries and restoration in local area [1].

The surface water pollution in Ben Tre has reached alarming levels in many inland canals and rivers these run through townships. The analytical results of water quality in Ben Tre showed that TSS, BOD₅, Oil and Coliform parameters were found as exceed the National Technical Regulation for Surface Water Quality of levels A1 and A2 [2,3]. The process of socio-economic development and the promotion of industrialization and modernization in addition to bringing about certain socio-economic achievements were also gradually changing the quality of the environment in Ben Tre. Water pollution in Ben Tre Province has been more complicated and caused serious environmental problems in residential areas and public places such as BOD: 10 – 21 mg/L, COD: 18 – 36 mg/L, DO: 2.73 – 3.79 mg/L.
mg/L [2].

Figure 1. Map of sampling sites.

In order to improve the water quality assessment for the rivers and canals of Ben Tre, the water quality parameters of pH, TSS, DO, BOD₅, COD, NH₄⁺, PO₄³⁻, and coliform was described. Moreover, the ArcGIS 9.3 software, Inverse Distance Weighting (IDW) interpolation, and hydrologic variables in April and September of 2015 and 2016 were applied to build the maps of water quality assessment for Ben Tre Province. The objectives of this research were to: (1) Evaluate the properties of water quality for the main rivers and canals in Ben Tre; and, (2) Apply the GIS system for building the maps of water quality for Ben Tre.

2. Methods

2.1. Study sites and sample collection

Based on the characteristics of natural conditions and socio-economic development, 44 sampling sites for Ben Tre were suggested and representative for a sampling program (figure 1). The samples were collected according to methods presented in the Operational Guide (3rd Ed.), UN Environment Programme [4]. The water samples of various physiochemical parameters were taken in April and October from 2015 to 2016. Locations at each site were sampled in the middle of the canals with depth layer at 30-40 cm from water surface. Water samples were collected using 2 liter plastic containers and preserved at 2°C [4].

2.2. Physical and chemical analysis

The water samples were analyzed for aquatic environmental parameters (pH, total suspended solid – TSS, dissolve oxygen – DO, biological oxygen demand – BOD₅, chemical oxygen demand – COD, ammonia – NH₄⁺, phosphate – PO₄³⁻, and coliform) using standard methods recommended APHA-AWWA-WEF, 1998 [5].
2.3. Calculation of water quality index (WQI)

The WQI for building the forecast maps was calculated from Vietnam Environment Administration [6]. The WQI was based on 6 parameters pH, TSS, DO, BOD$_5$, COD, NH$_4^+$, PO$_4^{3-}$, and coliform. The classification of water quality for usage purposes was presented in Table 1.

| No. | Ranking WQI | Usage Purposes | Color Indicators |
|-----|-------------|----------------|------------------|
| 1   | 91 – 100    | Good quality for water supply | Blue             |
| 2   | 76 – 90     | Use for water supply required appropriate treatment | Green            |
| 3   | 51 – 75     | Water use for irrigation | Yellow          |
| 4   | 26 – 50     | Water use for navigation | Orange          |
| 5   | 0 – 25      | Heavy pollution | Red             |

2.4. Mapping building procedures

IDW interpolation function was used the measured values surrounding the prediction location in belows [7]:

$$\lambda_i = \frac{\sum_{j=1}^{G} \lambda_j / D_{ij}^p}{\sum_{j=1}^{G} 1 / D_{ij}}$$

Where $\lambda_i$ was the property at location $i$; $\lambda_j$ was the property at location $j$; $D_{ij}$ was the distance from $i$ to $j$; $G$ was the number of sampled locations; and $p$ was the inverse-distance weighting power.

Weights were proportional to the inverse distance raised to the power value $p$ [8]. The characteristics of the interpolated surface can also be controlled by limiting the input points used in the calculation of each output cell. Limiting the number of input points considered can improve processing speeds [9,10].

3. Results and discussion

3.1. Characteristics of water quality

The results of water quality analysis for the main river and canals of Ben Tre were presented Table 2. The analyzed results in many sites exceeded the National Technical Regulation for Surface Water Quality of levels A1 (good quality for water supply) and A2 (good quality for protection of aquatic communities), especially values of TSS, BOD$_5$, COD and coliform [11].

| Sites | pH   | TSS (mg/L) | DO (mg/L) | BOD$_5$ (mg/L) | COD (mg/L) | NH$_4^+$ (mg/L) | PO$_4^{3-}$ (mg/L) | Coliform (MPN/100mL) |
|-------|------|------------|-----------|----------------|------------|-----------------|---------------------|---------------------|
| NM01  | 6.7-7.6 | 53–127   | 5.0-6.4  | 5.0-9.0     | 7.0-9.0   | 0.02-0.10       | 0.03-0.05         | 1100-2400          |
| NM02  | 7.0-7.6 | 63–115   | 4.6-6.4  | 3.0-5.0     | 7.0-8.0   | 0.02-0.06       | 0.01-0.05         | 1200-4300          |
| NM03  | 6.1-7.8 | 59-163   | 5.8-6.6  | 4.0-6.0     | 9.0-12.0  | 0.02-0.18       | 0.01-0.06         | 900-2100           |
| NM04  | 7.0-7.6 | 45-141   | 2.7-6.2  | 4.0-11.0    | 9.0-19.0  | 0.12-0.23       | 0.01-0.10         | 1500-4600          |
| NM05  | 6.8-7.4 | 77-109   | 4.9-5.8  | 5.0-6.0     | 11.0-12.0 | 0.04-0.78       | 0.04-0.07         | 1000-9300          |
| NM06  | 6.9-7.6 | 42-152   | 4.4-5.8  | 5.0-6.0     | 11.0-12.0 | 0.04-0.78       | 0.01-0.07         | 1600-9300          |
| NM07  | 7.0-7.7 | 107-269  | 5.1-6.1  | 3.0-7.0     | 5.0-13.0  | 0.02-0.14       | 0.03-0.08         | 1200-7000          |
| NM08  | 7.0-7.9 | 112-304  | 5.1-7.1  | 4.0-7.0     | 7.0-12.0  | 0.00-0.10       | 0.01-0.08         | 700-6000           |
Generally, the results of aquatic environmental variables at 44 sites sampled from 2015 to 2016 showed that the water quality from many sites was polluted highly. The analysed results showed that the water quality at towns and industrial parks were heavily polluted usually [12].

3.2. Water quality index (WQI) and mapping

The values of WQI calculation at 44 sites for main rivers and canals at Ben Tre Province were presented in table 3. The results classified water quality at 5 classes, as described by The Vietnam Environmental Protection Agency, good quality for water supply (1); use for water supply required appropriate treatment (2); usage for water use for irrigation (3); water use for navigation (4); and, heavy pollution (5).
Table 3. Classification of water quality based on WQI values for main rivers and canals at Ben Tre Province in April and October, 2015 – 2016.

| Sites | April 2015 | Usage Purposes | October 2015 | Usage Purposes | April 2016 | Usage Purposes | October 2016 | Usage Purposes |
|-------|------------|----------------|--------------|----------------|------------|----------------|--------------|----------------|
| NM01  | 99         | Good quality for water supply | 99 | Good quality for water supply | 97 | Good quality for water supply | 97 | Good quality for water supply |
| NM02  | 91         | Good quality for water supply | 99 | Good quality for water supply | 96 | Good quality for water supply | 96 | Good quality for water supply |
| NM03  | 95         | Good quality for water supply | 98 | Good quality for water supply | 97 | Good quality for water supply | 97 | Good quality for water supply |
| NM04  | 100        | Good quality for water supply | 77 | Good quality for water supply | 79 | Good quality for water supply | 79 | Good quality for water supply |
| NM05  | 93         | Good quality for water supply | 95 | Good quality for water supply | 93 | Good quality for water supply | 95 | Good quality for water supply |
| NM06  | 51         | Water use for irrigation | 94 | Good quality for water supply | 93 | Good quality for water supply | 92 | Good quality for water supply |
| NM07  | 100        | Good quality for water supply | 96 | Good quality for water supply | 93 | Good quality for water supply | 73 | Water use for irrigation |
| NM08  | 98         | Good quality for water supply | 97 | Good quality for water supply | 92 | Good quality for water supply | 77 | Water supply required appropriate treatment |
| NM09  | 97         | Good quality for water supply | 96 | Good quality for water supply | 96 | Good quality for water supply | 97 | Good quality for water supply |
| NM10  | 98         | Good quality for water supply | 92 | Good quality for water supply | 85 | Water supply required appropriate treatment | 90 | Good quality for water supply |
| NM11  | 94         | Good quality for water supply | 98 | Good quality for water supply | 93 | Good quality for water supply | 91 | Good quality for water supply |
| NM12  | 98         | Good quality for water supply | 95 | Good quality for water supply | 95 | Good quality for water supply | 97 | Good quality for water supply |
| NM13  | 100        | Good quality for water supply | 91 | Good quality for water supply | 91 | Good quality for water supply | 95 | Good quality for water supply |
| NM14  | 86         | Water supply required appropriate treatment | 93 | Good quality for water supply | 85 | Good quality for water supply | 82 | Good quality for water supply |
| NM15  | 99         | Good quality for water supply | 94 | Good quality for water supply | 92 | Good quality for water supply | 54 | Water use for irrigation |
| NM16  | 96         | Good quality for water supply | 90 | Water supply required appropriate treatment | 87 | Water supply required appropriate treatment | 81 | Water supply required appropriate treatment |
| NM17  | 97         | Good quality for water supply | 96 | Good quality for water supply | 89 | Good quality for water supply | 53 | Water use for irrigation |
| NM18  | 60         | Water use for irrigation | 78 | Water supply required appropriate treatment | 93 | Good quality for water supply | 86 | Water supply required appropriate treatment |
| NM19  | 90         | Water supply required appropriate treatment | 59 | Water use for irrigation | 70 | Water use for irrigation | 8 | Heavy pollution |
| NM20  | 9          | Heavy pollution | 9 | Heavy pollution | 9 | Heavy pollution | 9 | Heavy pollution |
| NM21  | 95         | Good quality for water supply | 9 | Heavy pollution | 9 | Heavy pollution | 9 | Heavy pollution |
| Code  | Rating | Quality                                     | Pollutants | Treatment | Use                  |
|-------|--------|---------------------------------------------|------------|-----------|----------------------|
| NM22  | 93     | Good quality for water supply               | 9          | Heavy     | 9                    |
| NM23  | 94     | Good quality for water supply               | 9          | Heavy     | 8                    |
| NM24  | 81     | Water supply required appropriate treatment | 8          | Heavy     | 5                    |
| NM25  | 87     | Water supply required appropriate treatment | 8          | Heavy     | 8                    |
| NM26  | 95     | Good quality for water supply               | 9          | Heavy     | 63                   |
| NM27  | 93     | Good quality for water supply               | 92         | Good      | 72                   |
| NM28  | 91     | Good quality for water supply               | 89         | Water     | 88                   |
| NM29  | 91     | Good quality for water supply               | 9          | Heavy     | 86                   |
| NM30  | 94     | Good quality for water supply               | 78         | Water     | 87                   |
| NM31  | 93     | Good quality for water supply               | 98         | Good      | 9                    |
| NM32  | 95     | Good quality for water supply               | 95         | Good      | 94                   |
| NM33  | 96     | Good quality for water supply               | 8          | Heavy     | 7                    |
| NM34  | 47     | Water use for navigation                    | 46         | Water     | 46                   |
| NM35  | 46     | Water use for navigation                    | 8          | Heavy     | 46                   |
| NM36  | 82     | Water supply required appropriate treatment | 9          | Heavy     | 9                    |
| NM44  | 97     | Good quality for water supply               | 87         | Water     | 8                   |
| NM45  | 92     | Good quality for water supply               | 92         | Water     | 84                   |
| NM46  | 98     | Good quality for water supply               | 89         | Water     | 87                   |
| NM47  | 90     | Water use for irrigation                    | 74         | Water     | 66                   |
| NM48  | 91     | Good quality for water supply               | 80         | Water     | 86                   |

The ratings range from 0 to 99. A rating of 90 or above indicates good quality for water supply, while a rating below 50 indicates heavy pollution. The use of water includes water supply, irrigation, and navigation.
The maps of water quality of the main rivers and canals in Ben Tre at April and October from 2015 to 2016 were presented in figure 2. These results were suitable with the characteristics of socio-economic development in the Ben Tre Province. The wastewater from industrial parks and urban areas of Ben Tre Province is causing pollution in many areas [12].
Figure 2. Maps of water quality of the main rivers and canals in Ben Tre. April 2015 (a), October 2015 (b), April 2016 (c), and October 2016 (d).

3.3. Approaches for water quality improvement

Among the many solutions to control water quality for Ben Tre Province, three main approaches were suggested in below:

- Control the nine industrial enterprises which caused the serious environmental pollution;
- Improve the three landfills in three districts: Phu Hung, Binh Dai, and Thanh Phu;
- Develop the automatic water quality monitoring system for Ben Tre Province;
- Build the new drainage and sewage systems for Ben Tre City and main towns;
- Build the more hygienic toilets for the rural areas.

4. Conclusion

The results indicated that the water quality of many sites from the main rivers and canals of Ben Tre in April and October from 2015 to 2016 many were polluted with TSS values at 75 – 304 mg/L, BOD₅ from 7.0 – 25.0 mg/L; and coliform from 1.1x10³ to 2.3x10⁵ MPN/100 mL. Additionally, the WQI based on the parameters pH, TSS, DO, BOD₅, COD, NH₄⁺, PO₄³⁻, and coliform in combination with GIS system were calculated. The results classified water quality of Ben Tre at 5 classes, as described by the Vietnam Environmental Protection Agency, good quality for water supply (1); use for water supply required appropriate treatment (2); usage for water use for irrigation (3); water use for navigation (4); and, heavy pollution (5). The main cause of water pollution in the main rivers and canals of Ben Tre was the discharge of untreated wastewater directly into surrounding canals by various residential areas and industrial enterprises. This research could be a scientific reference to suggest effective approaches for water quality improvement in Ben Tre Province. There were some the prior projects for environmental pollution control these have been implemented to improve the water quality for main river and canals in Ben Tre Province.
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