Developing a Water Quality Index (WQI) for River Resources Management in Kien Giang Province, Vietnam

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Abstract. The objective of this study was to develop a water quality index (WQI) for the surface water management of about 6,299 Km² in Kien Giang Province. The water quality index (WQI) methodology, which recommended by the Delphi method and Liou et al. (2004) was used. Seven parameters were selected to derive the WQI for the estimation of water quality in Kien Giang including pH, dissolved oxygen (DO), Biochemical Oxygen Demand (BOD₅), total solid suspended (TSS), chloride (Cl⁻), ammonia (NH₄⁺), and coliform. Total 48 samples were taken in March and September of 2014, 2015, 2016, 2017, and 2018. Through the result of WQI calculation for each monitoring time and seasonal differences in WQI were noted. The WQI was categorized from 51 to 85 in March 2018; and from 48 to 77 in September 2018. The water quality at the 48 sites in the study area was divided into three levels: (1) use for domestic purposes but need appropriate handling measures; (2) use for irrigation purposes; and, (3) use for other appropriate purposes. The WQI was established to assess the rivers and streams’ quality in Kien Giang as a tool to evaluate the river and canal water’s total quality. This WQI contributes to control of water quality effectively in order to provide informations to protect water resources as well as to serve people's lives.

1. Introduction
Kien Giang is a province at the end of the freshwater source of the Hau river branch, and affected by the salt water from the Thailand Gulf, so it faces the difficulties in freshwater resources. The main surface water source of Kien Giang is provided by rain water and Hau river [1, 2]. The canal systems have the different ecological characteristics and socioeconomic impacts following the regions such as seasonal changes, flood, flood drainage channel, agricultural activities and human impacts.

At present, there were some authors who have established the WQI for water quality assessment in Vietnam, including the WQI suggested by the Vietnam Environment Protection Agency for the whole Vietnam [3]; the WQI developed by Ton That Lang for Dong Nai river system [4]; or, as the WQI proposed by Le Trinh for Ho Chi Minh City [5], and Nguyen Le Tu Quynh for Thai Nguyen Province [6]. However, these WQI are not suitable for water quality assessment of rivers and canals with typical ecological characteristics in Kien Giang.

In order to contribute the water resources management and improve the water quality monitoring for the canal systems in Kien Giang, besides the specific assessment of each physicochemical parameter, the WQI has been developed to assess the general water quality and provide the useful information to managers and local peoples as well. The objectives of this study were to develop the WQI for river resources management in Kien Giang as follows: (1) Developing the WQI for Kien Giang; (2) Applying
the WQI in order to assess the water quality of river systems in Kien Giang; and (3) Disseminating the information on water quality to managers and local people.

2. Methods

2.1. Study sites and sample collection
Data were used the area of 6.299 km² Kien Giang Province, a province the Mekong Delta region of Southern Vietnam. Water samples for analysis in the field were collected according to the UN Water Programme (1992) [7, 8]. Total 48 samples were taken in March and August of 2014, 2015, 2016, 2017, and 2018 [9, 10, 11, 12]. Sample locations at each site were taken in the middle part of the river (Figure 1) [13, 14, 15].

Figure 1. Map of sampling sites.

2.2. Laboratory analysis
The aquatic environmental parameters and their analysis methods were briefly presented in Table 1.

Table 1. Parameters and methods of water quality analysis

| No. | Parameters | Unit | Methods          |
|-----|------------|------|------------------|
| 1   | Temperature| °C   | SMEWW 2550B:2012 |
| 2   | pH         |      | TCVN 6492:2011   |
| 3   | Salinity   | ‰   | SMEWW 2520B:2012 |
| 4   | EC         | mS/cm| SMEWW 2510B:2012 |
| 5   | Turbidity  | NTU  | SMEWW 2130B:2005 |
| 6   | DO         | mg/l | TCVN 7325:2016   |
| 7   | TSS        | mg/l | SMEWW 6625:2000  |
| 8   | BOD₅       | mg/l | TCVN 6001-2:2008 |
| 9   | COD        | mg/l | SMEWW 5220C:2012 |
| 10  | NH₄⁺       | mg/l | SMEWW 4500-NH₄ B&F:2012 |
| 11  | PO₄³⁻      | mg/l | SMEWW 4500 -P.E:2012 |
| 12  | Fe         | mg/l | SMEWW 3120B:2012 |
| 13  | Cl⁻        | mg/l | TCVN 6194:1996   |
| 14  | Coliform   | MPN/100mL| TCVN 6187-2:1996 |
2.3. Developing the water quality index (WQI)

The development of WQI for water bodies in Kien Giang was based on research by Liou et al. (2004) [16] and Delphi method [17]. The selection of typical parameters for aquatic ecosystems and water environment was consulted by experts on water quality and environmental management in Kien Giang. The steps to build water quality indicators were detailed below:

- Step 1: Identifying the impact groups based on parameters for developing the WQI
- Step 2: Selecting the parameters for developing the WQI
- Step 3: Identifying the weight for each parameter and changing the scale of variables to 0 – 100
- Step 4: Calculating the WQI values for each site
- Step 5: Mapping the WQI values by colours.

3. Results

3.1. Identifying the impact groups for WQI

Based on the results of water quality monitoring from 2014 to 2018 in Kien Giang Province, 14 indicators for impact groups were classified according to the characteristics as follows: physical factors (temperature, pH, EC); suspended solids (turbidity, TSS); dissolved oxygen (DO); saline intrusion (salinity, Cl\(^-\)); organic pollution (NH\(_4^+\), PO\(_4^{3-}\), BOD\(_5\), COD); health aspects (Fe, coliform).

3.2. Selecting the parameters, changing the scale, and identifying the weight for WQI calculation

Based on the results of water quality monitoring from 2014 to 2018, 20 knowledgeable and indigenous experts working in environmental monitoring and related fields have selected seven parameters following the score of each indicator, the representatives of impact groups, and the assessment weight for the WQI development at Kien Giang. Seven parameters were selected to derive the WQI for the estimation of water quality in Kien Giang (Table 2).

| No. | Parameters | Weight |
|-----|------------|--------|
| 1   | pH         | 0.19   |
| 2   | DO         | 0.17   |
| 3   | TSS        | 0.16   |
| 4   | BOD\(_5\)  | 0.14   |
| 5   | NH\(_4^+\) | 0.14   |
| 6   | Cl\(^-\)   | 0.11   |
| 7   | Coliform   | 0.09   |

3.3. Calculating the WQI values for each site

Typical parameters for aquatic ecosystems and water environment in Kien Giang were selected to build the WQI as follows:

\[
I = \sum_{i=1}^{n} q_i w_i
\]

Notes: I is the last value; \(q_i\) is the secondary index for parameters; \(w_i\) is the weight; \(n\) is the number of indicators included in the calculation.

3.4. Mapping the WQI values by colors

After calculating WQI values, these results were shown on the map by colours (Table 3).
Table 3. Showing the WQI values on the map by color.

| WQI Values | Water Quality Assessment                        | Color   |
|------------|------------------------------------------------|---------|
| 91 – 100   | Good use for drinking water purposes            | Blue    |
| 71 – 90    | Use for domestic purposes but need appropriate handling measures | Green   |
| 51 – 70    | Use for irrigation purposes                     | Yellow  |
| 26 – 50    | Use for other appropriate purposes              | Orange  |
| 1 – 25     | Heavy pollution water                           | Brown   |

The results of WQI calculation for assessment of river water quality at Kien Giang during the March and September in 2018 were shown in Table 4. The water quality at the 48 sites in the study area was divided into three levels: (1) use for domestic purposes but need appropriate handling measures; (2) use for irrigation purposes; and (3) use for other appropriate purposes (Table 4).

Table 4. The WQI values in March and September 2018.

| Sites | WQI Values 03/2018 | Water Quality Assessment | Sites | WQI Values 09/2018 | Water Quality Assessment |
|-------|--------------------|--------------------------|-------|--------------------|--------------------------|
| 001Q  | 55                 | Yellow                   | 025Q  | 61                 | Yellow                   |
| 002Q  | 53                 | Yellow                   | 026Q  | 64                 | Yellow                   |
| 003Q  | 59                 | Green                    | 027Q  | 64                 | Yellow                   |
| 004Q  | 61                 | Green                    | 028Q  | 63                 | Yellow                   |
| 005Q  | 72                 | Yellow                   | 029Q  | 61                 | Yellow                   |
| 006Q  | 67                 | Yellow                   | 030Q  | 66                 | Yellow                   |
| 007Q  | 62                 | Yellow                   | 031Q  | 69                 | Yellow                   |
| 008Q  | 72                 | Yellow                   | 032Q  | 69                 | Yellow                   |
| 009Q  | 69                 | Yellow                   | 033Q  | 71                 | Yellow                   |
| 010Q  | 61                 | Yellow                   | 034Q  | 64                 | Yellow                   |
| 011Q  | 63                 | Yellow                   | 035Q  | 64                 | Yellow                   |
| 012Q  | 71                 | Yellow                   | 036Q  | 58                 | Yellow                   |
| 013Q  | 79                 | Yellow                   | 037Q  | 63                 | Yellow                   |
| 014Q  | 52                 | Yellow                   | 038Q  | 56                 | Yellow                   |
| 015Q  | 64                 | Yellow                   | 039Q  | 55                 | Yellow                   |
| 016Q  | 63                 | Yellow                   | 040Q  | 70                 | Yellow                   |
| 017Q  | 51                 | Yellow                   | 041Q  | 51                 | Yellow                   |
| 018Q  | 65                 | Yellow                   | 042Q  | 60                 | Yellow                   |
| 019Q  | 67                 | Yellow                   | 043Q  | 63                 | Yellow                   |
| 020Q  | 67                 | Yellow                   | 044Q  | 54                 | Yellow                   |
| 021Q  | 50                 | Yellow                   | 045Q  | 69                 | Yellow                   |
| 022Q  | 50                 | Yellow                   | 046Q  | 69                 | Yellow                   |
| 023Q  | 51                 | Yellow                   | 047Q  | 85                 | Yellow                   |
| 024Q  | 58                 | Yellow                   | 048Q  | 53                 | Yellow                   |

Based on the values of WQI, the water quality assessment was classified in Figure 2. This information dissemination is very effective and intuitive after each monitoring phase. Posting through the Water Resource Newsletter on the Department's website is a new form because water quality reports were too long and the environmental experts understand it only. So this is a very effective form of information dissemination to alert for local communities and managers.
Figure 2. Maps of water quality classification for main rivers and canals in Kien Giang in 2018.

4. Conclusion
Based on the monitoring data of water quality in March and September 2014, 2015, 2016, 2017 and 2018, seven parameters were selected to derive the WQI for the estimation of water quality at typical water bodies in Kien Giang Province including pH, DO, TSS, NH$_4^+$, BOD$_5$, Cl$^-$, and Coliform. The water quality at the 48 sites in the studied area was divided into three levels: (1) use for domestic purposes but need appropriate handling measures; (2) use for irrigation purposes; and (3) use for other appropriate purposes.

The WQI was established as a technical tool to evaluate the water quality for river system in Kien Giang. The results of the periodic assessment were officially disseminated on the Department's website also. This research contributed the new WQI for the water resources protection as well as people's live serving purposes effectively.

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