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Applying Harmony Degree Equation and TOPSIS Combined with Entropy Weights in Surface Water Classification

Kieu Diem Le [1], Giao Thanh Nguyen [2*]

[1] Department of Environmental Sciences, Faculty of Natural Resources and Environment, Dong Thap University, Dong Thap 81000, Vietnam.

[2] College of Environment and Natural Resources, Can Tho University, Can Tho 900000, Vietnam.

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Abstract

This study classified surface water quality in Can Tho city using the Eutrophication index, Harmony Degree Equation (HDE), and Technique of Order Preference by Similarity to Ideal Solution (TOPSIS). Water quality data were collected in two seasons at 38 locations with 18 parameters, including temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), orthophosphate ($P\text{-}PO_4^{3-}$), Fe, F^-, Pb, As, Hg, coliform, chlorine-, and phosphorus-based pesticides. Water quality parameters are compared with national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT). The HDE method based on entropy weight has been applied to evaluate the comprehensive harmony degree of water quality for various purposes. In addition, the TOPSIS was also used to rank water quality at each location and determine the priority level that required mitigation and treatment solutions. Surface water quality in the study area had low dissolved oxygen content and was contaminated with TSS and coliform in both seasons. Water quality in the rainy season tends to decrease compared to the dry season. Based on HDE results, water quality in the study area in the dry season was assessed as suitable for domestic activities (needs treatment), irrigation, and navigation (HD_{II} = 0.922), while the rainy season was suitable for irrigation and navigation (HD_{III} = 1.00). Moreover, surface water in the study area was in a state of potential eutrophication (EI > 0), in which eutrophication was higher during the dry season. The SW25 and SW28 were the most seriously eutrophic in the dry and rainy seasons, respectively. TOPSIS analysis indicated that SW22 and SW28 need treatment measures in both seasons; furthermore, SW2-SW4 (dry season) and SW23 (rainy season) also need appropriate management and impact mitigation solutions. SW4 was affected by the most significant seasonal impacts, which have high priority in the dry season and are lowest in the rainy season. Therefore, future studies are needed to identify specific sources of variation at these locations to reduce impacts. The study results provide helpful information for the decision-making process and water quality management.

Keywords: Can Tho City; Eutrophication; Harmony Degree Equation; TOPSIS; Water Quality Assessment.

1. Introduction

Rapid socio-economic development seriously affects domestic activities [1, 2] and the ecological environment in many countries worldwide [3]; this can be explained by the combination of impact factors such as land use/land cover changes and waste discharge [4]. According to the previous study by Wehrheim et al. [5], surface water quality in the Mekong Delta is mainly affected by agricultural and aquaculture activities. Therefore, natural ecosystems have been transformed in a more complex manner [4]. For instance, the excessive accumulation of organic matter has changed the nutritional structure, reduced oxygen content, and caused the death of aquatic animals in water bodies [6]. Furthermore, variations in natural processes also affect water quality, typically seasonal changes in rainfall and surface runoff [7].

* Corresponding author: ntgiao@ctu.edu.vn

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Therefore, pollution problems could seriously affect the purpose of various activities and sustainable socio-economic development [8, 9]. Hence, quality monitoring and assessment are critical to forecasting pollution problems accurately, thereby proposing appropriate mitigation and management solutions [4]. However, due to these complex variations in effects, using a single method may not be appropriate and may lead to many discrepancies in results and management [10]. Therefore, multidimensional analysis methods and computing techniques have been focused on development and research [11].

Water quality parameters (i.e., pH, DO, BOD, COD, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, and coliform) can be calculated as a Water Quality Index (WQI) [12] or nutrient parameters converted to Eutrophication Index (EI) to describe the level of nutrient pollution [13, 14]. Furthermore, many mathematical methods have been applied to evaluate water quality and propose management solutions, such as the water quality index (entropy-weighted water quality index (EWQI), integrated water quality index (IWQI), modified water quality index (MWQI) [15, 16], Set Pair Analysis (SPA) [17, 18], Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) [19, 20], and other multivariate statistical analysis methods (Principal Component Analysis (PCA), Cluster Analysis (CA), Factor Analysis (FA), Discriminant Analysis (DA) [4, 8, 15, 21-23]. Among them, TOPSIS is commonly used in assessing water quality and identifying alternative solutions [19, 24-27]. In addition, the harmonic degree equation (HDE) is also used in water quality assessment studies [4, 28-30]. The approach based on harmony theory and the TOPSIS model has been applied in many previous studies, such as allocating water resources [31], determining the level of harmony between water quality and people [4, 30, 32], and evaluating and ranking water quality [19, 25, 33, 34]. Therefore, applying diverse assessment methods/techniques can overcome the limitations of a single assessment.

Can Tho is one of the central municipal cities of southern Vietnam. The process of industrialization and urbanization in Can Tho city is developing rapidly and strongly; this has contributed to increasing pressure on the natural environment [35]. Currently, the city is facing serious problems such as climate change (flooding and saltwater intrusion) and water pollution from wastewater and waste from industrial and agricultural production activities [36, 37]. Several previous studies have discovered very high COD, BOD, coliform, TN, and $N\text{-}NH_4^+$ pollutants in water bodies in Can Tho City, which are likely to increase in the future. This has reduced surface water quality and harmed aquatic life in water bodies in Can Tho City [36-38]. In addition, several studies have also applied multivariate statistical techniques to evaluate and identify pollution sources in the study area [22, 37]. Nevertheless, none of these studies has simultaneously applied calculation methods based on Vietnamese standards and the weights of each parameter to propose the use purpose and treatment priority order for each monitoring location. Hence, the study aims to evaluate surface water quality, the status of eutrophication, and the suitability of water bodies for purposeful use by HDE and rank prioritized locations that need treatment solutions using TOPSIS. The results provide crucial scientific information on water quality management in Can Tho City.

2. Material and Methods

2.1. Description of the Study Area

Can Tho city has a total area of 140,894.9 hectares, accounting for 3.5% of the total area of the Mekong Delta region. The city has flat terrain, high in the north and gradually lower in the southwest. The north of Can Tho city borders An Giang province, the south borders Hau Giang province, the west borders Kien Giang province, and the east borders Vinh Long and Dong Thap provinces [39]. Can Tho is located in the tropical monsoon climate zone, with two distinct seasons: the rainy season (from May to November) and the dry season (from December to April of the following year). The hydrological regime is influenced by the Mekong River flowing through the Hau River, the East Sea tidal regime, and intra-regional rainfall. The density of rivers and canals in Can Tho city is quite large, about 1.8 km/km^2, in which the area along the Hau River in Ninh Kieu, O Mon, Cai Rang, and Thot Not districts is up to more than 2 km/km^2. A total of 158 large and small rivers and canals are tributaries of two large rivers (i.e., the Hau River and the Can Tho River). The dense system of rivers/canals provides an essential source of fresh water, serves as irrigation in the dry season, and is significant in transportation in Can Tho. Currently, Can Tho city has only one centralized wastewater treatment plant, which collects and treats wastewater for nine wards in Ninh Kieu district. In addition, there is still a situation where the treatment system is overloaded and the treatment efficiency has not reached 100%. Surface water sources are affected by pollutants from domestic, aquaculture, agricultural, and industrial activities and solid waste generated in the city [37, 39]. Hence, surface water environmental monitoring is carried out regularly, and the sampling locations are shown in Figure 1.

2.2. Data Collection

The water quality monitoring data was collected from the Department of Natural Resources and Environment of Can Tho City [40]. Surface water samples were collected at 38 locations on 25 main rivers and canals in districts of Can Tho city and were signed from SW1 to SW38 (Figure 1). The sampling frequency is two times per year in March and September for physicochemical parameters and one time per year in May for two pesticide residue parameters. There were a total of 18 parameters to assess water quality in the study area, namely temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), orthophosphate ($P\text{-}PO_4^{3-}$), Fe, F^-, Pb, As, Hg, coliform, chlorine-based, and phosphorus-based pesticides. Surface water samples were collected and preserved according to national standards (TCVN 6663-1:2011, TCVN 6663-3:2008, TCVN 5994:1995, TCVN 6663-6:2008). pH, temperature, and DO were measured on-site, while the remaining parameters were analyzed in the laboratory using standard methods [41]. The descriptors of analysis methods and allowable limits in the National Technical Regulation (QCVN 08-MT:2015/BTNMT) [42] are presented in Table 1.

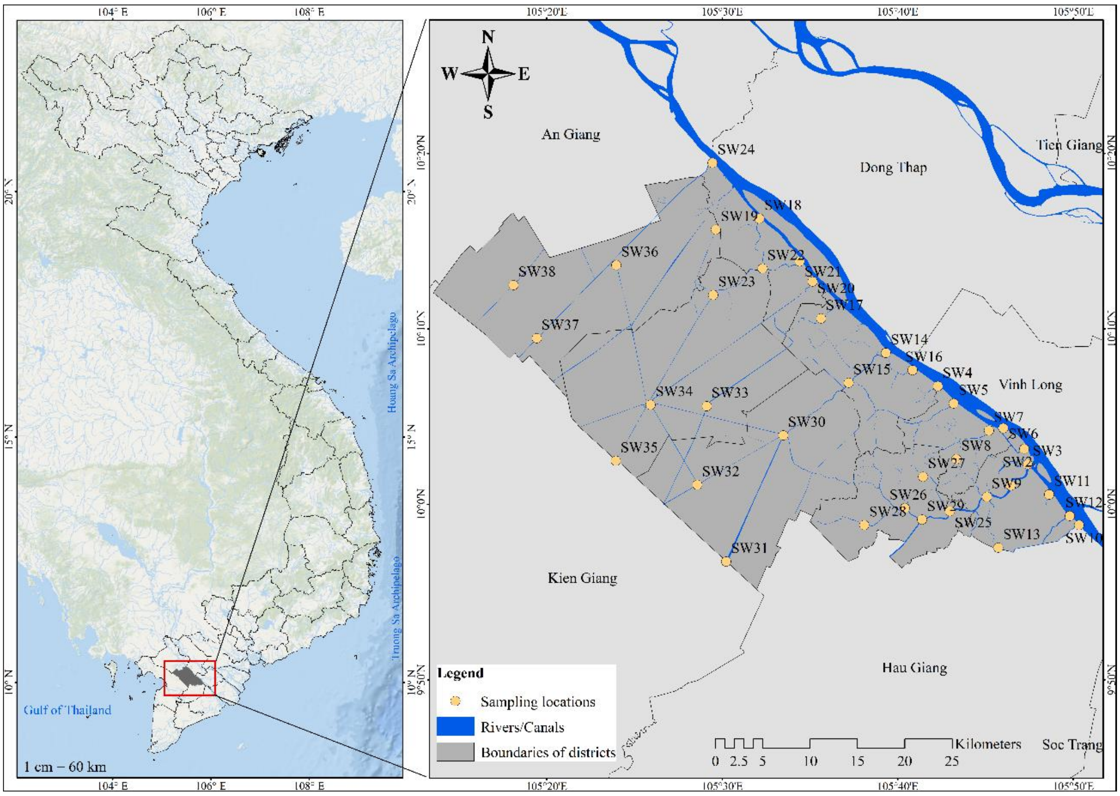

Figure 1. Sampling locations in the study area

Table 1. Surface water quality parameters and analytical methods

Parameters	Unit	Analytical methods	QCVN 08-MT:2015/BTNMT			
			Column A1 (I)	Column A2 (II)	Column B1 (III)	Column B2 (IV)
Temperature	℃	SMEWW 2550B:2012	-			
pH	-	TCVN 6492:2011	6-8.5	6-8.5	5.5-9	5.5-9
Dissolved oxygen (DO)	mg/L	TCVN 7325:2004	≥ 6	≥5	≥4	≥2
Biological Oxygen Demand (BOD)	mg/L	TCVN 6001-1:2008	4	6	15	25
Chemical Oxygen Demand (COD)	mg/L	TCVN 6491:1999	10	15	30	50
Total Suspended solids (TSS)	mg/L	TCVN 6625:2000	20	30	50	100
Ammonium ($N\text{-}NH_4^+$)	mg/L	TCVN 6179:1996	0.3	0.3	0.9	0.9
Nitrite ($N\text{-}NO_2^-$)	mg/L	SMEWW 4500-NO_2^-.B:2012	0.05	0.05	0.05	0.05
Nitrate ($N\text{-}NO_3^-$)	mg/L	TCVN 6180:1996	2	5	10	15
Phosphate ($P\text{-}PO_4^{3-}$)	mg/L	SMEWW 4500-P.E:2012	0.1	0.2	0.3	0.5
Total iron (Fe_t)	mg/L	TCVN 6177:1996	0.5	1	1.5	2
Fluoride (F^-)	mg/L	SMEWW 4500-F^-.B&D:2012	1	1.5	1.5	2
Lead (Pb)	mg/L	SMEWW 3113B:2017	0.02	0.02	0.05	0.05
Arsenic (As)	mg/L	TCVN 6626:2000	0.01	0.02	0.05	0.1
Mercury (Hg)	mg/L	TCVN 7877:2008	0.001	0.001	0.001	0.002
Organochlorine pesticides	µg/L	GC/MS (SCION QC/SCION 456)	-	-	-	-
Organic phosphate pesticides	µg/L	GC/MS (SCION QC/SCION 456)	-	-	-	-
Coliform	MPN/100 mL	TCVN 6187-2:1996	2500	5000	7500	10,000

Note: "-" is not available in the National Technical Regulation.

2.3. Data Processing

2.3.1. Evaluate Water Quality Characteristics

Surface water quality data were calculated on average and compared with National Technical Regulation QCVN 08-MT:2015/BTNMT on surface water quality [42]. Moreover, the Independent Sample T-Test method at the 5% significance level was used to compare the difference in surface water quality between the rainy and dry seasons. This analysis was processed using IBM SPSS 22 statistical software for Windows (IBM Corp., Armonk, NY, USA).

2.3.2. Calculate the Harmony Degree of Water Quality for Various Uses

In this study, the harmony degree equation (HDE) was applied to determine the harmony of water quality in the dry and rainy seasons for water use purposes specified in QCVN 08-MT:2015/BTNMT [42]. The harmony degree of each parameter with water quality levels is calculated based on Equation 1 [11].

$$HD = ai - bj \tag{1}$$

in which, HD is the harmony degree, a is the unity degree, b is the difference degree, and i and j are the harmony coefficient and disharmony coefficient, respectively.

(1) Establishment of limit values for each parameter according to different levels:

The limit values will be classified into levels s. Specifically, the limit values are graded according to QCVN 08-MT:2015/BTNMT (Table 1) [42], with four levels specified in descending order (s = I, II, III and IV).

(2) Establish a water quality level matrix for each parameter:

From the analytical data set, the study has input data with a set of parameters P ($k = p_1, p_2, p_3, p_4, \ldots p_n$), in which n is the number of parameters. The value of the parameter belongs to one of the evaluation levels in Table 1. Particularly, if the value p_n corresponds to a level s, it would be encoded as 1 at this level. Simultaneously, the smaller s levels were also coded 1. On the contrary, if the value of p_n did not correspond to one of the s levels, it would be coded 0. The level matrix table of each parameter is shown as the matrix X.

$$X = \begin{bmatrix} X_{(p_1,I)} & X_{(p_1,II)} & X_{(p_1,III)} & X_{(p_1,IV)} \\ X_{(p_2,I)} & X_{(p_2,II)} & X_{(p_2,III)} & X_{(p_2,IV)} \\ X_{(p_3,I)} & X_{(p_3,II)} & X_{(p_3,III)} & X_{(p_3,IV)} \\ \ldots & \ldots & \ldots & \ldots \\ X_{(p_n,I)} & X_{(p_n,II)} & X_{(p_n,III)} & X_{(p_n,IV)} \end{bmatrix} \tag{2}$$

(3) Calculate the parameter weight using the Entropy method:

- Set up the normalized matrix of each parameter:

$$A_{pq} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & \ldots & A_{1n} \\ A_{21} & A_{22} & A_{23} & \ldots & A_{2n} \\ A_{31} & A_{32} & A_{33} & \cdots & A_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ A_{t1} & A_{t2} & A_{t3} & \ldots & A_{tn} \end{bmatrix} \tag{3}$$

After that, normalize the matrix A_{pq} by using Equation 4:

$$B_{pq} = \frac{C_{pq} - C_{pq\,min}}{C_{pq\,max} - C_{pq\,min}} \tag{4}$$

where p is the water quality parameter, q is monitoring locations (q = 1, 2, 3,...t). C_{pq} is the concentration of parameter p at the monitoring location q.

- Calculate the information coefficient (H_p) by Equation 5:

$$H_p = -\frac{1}{\ln t}\sum_{q=1}^{t}\left(\frac{B_{pq}}{\sum_{q=1}^{t} B_{pq}} \ln\left(\frac{B_{pq}}{\sum_{q=1}^{t} B_{pq}}\right)\right) \tag{5}$$

In this case, if the A_{pq} = 0 or 1, the information coefficient is calculated according to Equation 6:

$$H_p = -\frac{1}{\ln t}\sum_{q=1}^{t}\left(\frac{1+B_{pq}}{\sum_{q=1}^{t}(1+B_{pq})} \ln\left(\frac{1+B_{pq}}{\sum_{q=1}^{t}(1+B_{pq})}\right)\right) \tag{6}$$

- Calculate the Entropy weight for each parameter:

$$\omega_p = \frac{1 - H_p}{n - \sum_{p=1}^{n} H_p} \tag{7}$$

(4) Calculate the harmony degree of different water quality levels

The harmony degree of each parameter is calculated using Equation (1). In which, the values i and j are selected depending on the specific characteristics of the region and other matrix iterations of $HD_{(pn, s)}$. According to Zou et al. [28], it could be set i = 1 and j = 0, so the unit degrees of $HD_{(pn, s)}$ is equal to the value in matrix X. The comprehensive degree of harmony is calculated using Equation 8.

$$HD_s = \sum_{p=1}^{n} \omega_{p_n} \times HD(p_n, s) \tag{8}$$

In which, HDs is the comprehensive harmony degree of sampling location with level s and $HD_s \in [0, 1]$ and $HD_{(pn, s)}$ is the harmony degree of parameter p_n with level s.

(5) Determine the appropriate water quality level and purpose based on the harmony degree

Based on comprehensive harmonization degrees, water quality levels were determined according to Equation 9.

$$0 \le HD(I) \le HD(II) \le HD(III) \le HD(IV) \le 1 \tag{9}$$

According to Zou et al. [28], the expected minimum harmony target (HD_0) value could be set as a criterion to evaluate water quality level. The larger the HD_0 value, the higher the water quality criterion. Normally, $HD_0 = 0.8$ will have a higher recognition ability for different levels, high reliability, and be more consistent with reality status [28]. In this study, HD_0 was set up at two levels ($HD_0 = 1$ and $HD_0 = 0.8$). This means that when $HD_0 = 1$, water quality is ranked at the lowest level. Similarly, when $HD_0 = 0.8$, it allows 20% of the parameters to be worse than the level s.

2.3.3. Calculate the Eutrophication Index

The eutrophication index (EI) was used to determine the eutrophication of water bodies based on three parameters (COD, DIN and DIP). The eutrophication index was calculated according to Equation 10 [43].

$$EI = \frac{COD \times DIP \times DIN}{4500} \times 10^6 \tag{10}$$

In which, COD is the concentration of COD; DIN is the total concentration of $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$; DIP is the concentration of $P\text{-}PO_4^{3-}$. EI is classified into two types, including EI < 0 (not eutrophic) and EI > 0 (water is in a eutrophic state) [13, 43]. The eutrophication index (EI) results were presented visually in map form using QGIS 3.16 software (Open-Source Geospatial Foundation - OSGeo, Chicago, IL, USA).

2.3.4. Evaluate Treatment Priority using the Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

The technique of Order Preference by Similarity to Ideal Solution (TOPSIS) was used to rank water quality and water treatment priorities of monitoring locations [20, 44]. The steps in the method are performed and calculated from Equations 11 to 15.

(1) Setting up the initial matrix was done similarly to calculating the weights. Matrix normalization is then performed by Equation 11.

$$r_{pq} = \begin{cases} \dfrac{c_{pq}}{\left[\sum_{q=1}^{t} c_{qp}^2\right]^{\frac{1}{2}}} \\ \dfrac{-c_{pq}}{\left[\sum_{q=1}^{t} c_{pq}^2\right]^{\frac{1}{2}}} \end{cases} \tag{11}$$

(2) Determine the weighted normalized value using formula 12

$$f_{pq} = r_{pq} \times \omega_p \tag{12}$$

where f_{pq} is the weighted normalized value of parameter p at monitoring site q and ω_p is the weight of each parameter.

(3) Determine positive and negative ideal reference points, with positive and negative ideal reference points that can be determined using formula 13.

$$\begin{cases} f^+ = \max\,(f_{1p}, f_{2p}, f_{3p}, \dots) \\ f^- = \min\,(f_{1p}, f_{2p}, f_{3p}, \dots) \end{cases} \tag{13}$$

From the calculation results of Equation 13, the set of positive and negative ideal reference values of each parameter are recorded and shown at C and D, respectively.

$$C = \{f_1^+, f_2^+, \dots, f_n^+\} \tag{14}$$

$$D = \{f_1^-, f_2^-, \dots, f_n^-\} \tag{15}$$

(4) Calculate the distance to the positive and negative ideal reference points; they are calculated using Equation 16.

$$\begin{cases} d_q^+ = \sqrt{\sum_{p=1}^{n} \left[f_{pq} - (f_p)_C\right]^2} \\ d_q^- = \sqrt{\sum_{p=1}^{n} \left[f_{pq} - (f_p)_D\right]^2} \end{cases} \tag{16}$$

In which, $(f_{pq})_C$ and $(f_{pq})_D$ are the weighted standardized values in the positive and negative ideal reference points, respectively; d_q^+ and d_q^- are the distances to the positive and negative ideal reference points at the monitoring sites q, respectively.

(5) Calculation of the closeness coefficient (CC) of each site according to Equation 17.

$$CC = \frac{d^-}{d^+ + d^-}, \text{with } CC \in [0, 1] \tag{17}$$

In this method, the closeness coefficient close to the positive ideal reference point is sorted in descending order to determine priority [24]. A more considerable CC value indicates better water quality. In contrast, the lower the CC value, the higher the treatment priority rank of the location [26].

A summary of the research methods is presented in Figure 2.

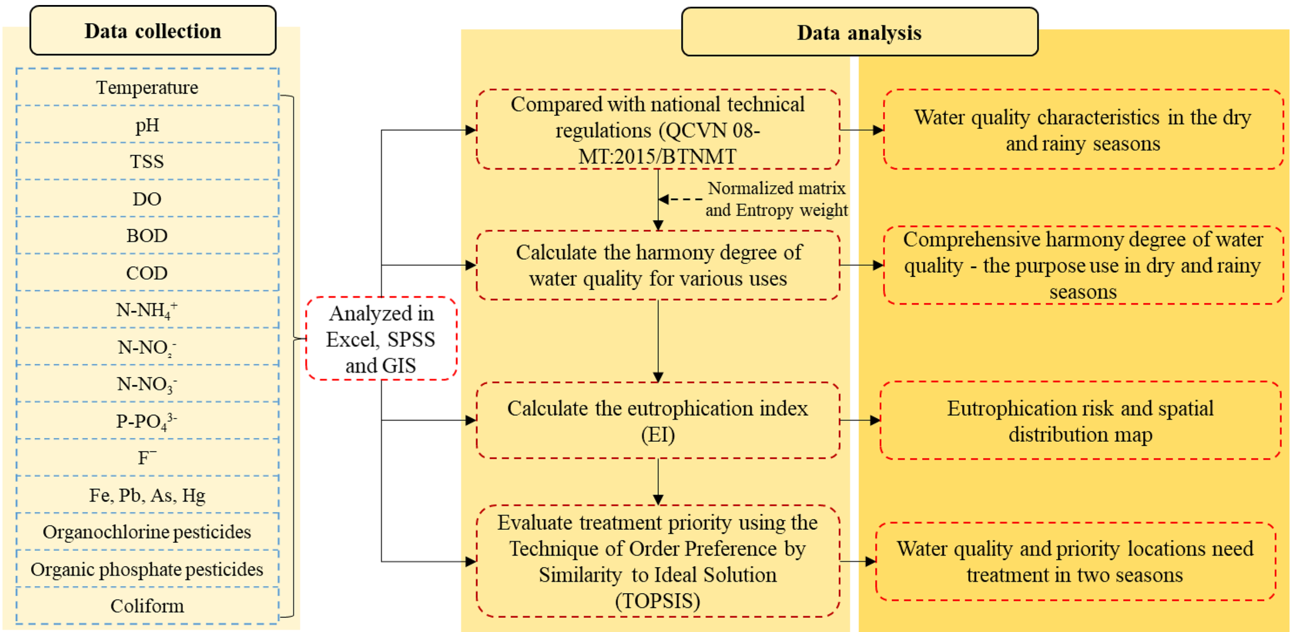

Figure 2. The summary flowchart of research methods

3. Results and Discussion

3.1. Overall Surface Water Quality in the Study Area

The results of the water quality analysis are presented in Table 2. The concentrations of As, Hg, chlorine-, and phosphorus-based pesticides in the dry and rainy seasons were all below the detection limits (Detection limits of As = 0.001 mg/L, Hg = 0.0003 mg/L, organochlorine pesticides = 0.0001 µg/L, and organophosphorus = 0.01 µg/L). Table 2 shows that the average water temperature and pH had no statistically significant differences at the 5% level between the dry and rainy seasons ($p>0.05$). In particular, the average temperature and pH in the dry and rainy seasons varied from 29.47±1.80-29.62±1.84℃ and 7.19±0.10-7.21±0.08, respectively. Generally, the pH range was insignificant and is within the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (6.0–8.5) [42].

The TSS values showed a statistically significant difference between the two seasons ($p<0.05$). TSS concentrations in the dry season were 20.11±2.76 mg/L and increased to 30.16±5.52 mg/L in the rainy season. TSS exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (20 mg/L) by 1.50 times [42]. Some previous studies indicated that TSS values in rivers in the Mekong Delta were relatively high and partly influenced by wastewater and waste from agricultural, industrial, and domestic activities [45, 46].

Table 2. Seasonal variations of surface water quality in the study area

Parameters	Unit	Dry season	Rainy season	Sig.
Temperature	°C	29.47±1.8	29.62±1.84	0.612
pH	-	7.19±0.1	7.21±0.08	0.241
DO	mg/L	4.24±0.39	4.24±0.22	0.986
BOD	mg/L	3.67±0.94	3.8±0.65	0.319
COD	mg/L	9.77±1.72	9.48±1.76	0.321
TSS	mg/L	20.11±2.76	30.16±5.52	0.000
$N\text{-}NH_4^+$	mg/L	0.11±0.06	0.06±0.05	0.000
$N\text{-}NO_2^-$	mg/L	0.02±0	0.02±0.01	0.284
$N\text{-}NO_3^-$	mg/L	0.15±0.09	0.23±0.13	0.000
$P\text{-}PO_4^{3-}$	mg/L	0.08±0.03	0.03±0.03	0.000
Fe_t	mg/L	0.01±0.03	BDL	0.000
F^-	mg/L	0.01±0.0	BDL	0.033
Pb	mg/L	BDL	0.0006±0.0	0.000
As	mg/L	BDL	BDL	-
Hg	mg/L	BDL	BDL	-
Organochloride pesticides	µg/L	BDL	-	-
Organophosphate pesticides	µg/L	BDL	-	-
Coliform	MPN/100 mL	2674±0	3094±0	0.514

Note: BDL: Below Detection Limit.

The average DO concentration was relatively low, while the BOD and COD concentrations were relatively high in the study area. All the content of the parameter, which indicated organic matter pollution, was below the allowable threshold compared to QCVN 08-MT:2015/BTNMT column A1 (DO ≥ 6 mg/L, BOD ≤ 4 mg/L, and COD ≤ 10 mg/L) [42]. There was no statistically significant difference in DO, BOD, and COD content between the dry and rainy seasons ($p > 0.05$). This shows that water quality in the study area has improved compared to the previous report by Giao et al. [22], which documented organic pollution in water bodies. DO concentrations in the dry season (4.24±0.39 mg/L) were nearly similar to the rainy season (4.24±0.22 mg/L). The BOD in the dry season (3.67±0.94 mg/L) was lower than in the rainy season (3.8±0.65 mg/L), whereas the reverse was true for the COD (9.77±1.72 mg/L - in the dry season and 9.48±1.76 mg/L - in the rainy season). BOD and COD contents are affected and change significantly by seasons [47]. The variation of BOD and COD depends on human activities [48], the change in temperature, biological activity, and respiration of organisms, leading to an increased or decreased decomposition rate of organic matter in water bodies [49]. The concentrations of nutrients were significantly different between the dry and rainy seasons ($p < 0.05$), except for $N\text{-}NO_2^-$. In addition, the content of $N\text{-}NH_4^+$ and PO_4^{3-} in the dry season tended to be higher than in the rainy season; in contrast, $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ have tended to be higher in the rainy season. The concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ ranged from 0.06±0.05-0.11±0.06 mg/L, 0.02±0-0.02±0.05 mg/L, 0.15±0.09-0.23±0.13 mg/L, and 0.03±0.03-0.08±0.03 mg/L, respectively (Table 2). The concentration of nutrients was generally low compared to QCVN 08-MT:2015/BTNMT column A1 [42]. There were also low levels of nutrients found in the Mekong Delta water bodies in several previous studies [46, 50, 51].

Heavy metals (Fe, Pb) and F^- in water dramatically fluctuated between the dry and rainy seasons. Fe and F^- concentrations were only recorded in the dry season, with the values 0.01±0.03 mg/L and 0.001±0.0 mg/L, respectively. This was compatible with the previous study by Tam et al. [48], which reported that the Fe concentration in surface water in Can Tho city is usually low and focuses the highest content on agricultural production rather than industrial and residential areas. High Fe concentrations could strongly impact the growth and development of aquatic ecosystems [52]. On the other hand, F^- is also a vital substance that can be beneficial or harmful to organisms, depending on its concentration in water. F^- often originates in nature or is artificially produced by human and industrial activities [53]. Meanwhile, the concentration of Pb has a value of 0.0006±0.0 mg/L in the rainy season. Fe, Pb, and F^- were below the allowable thresholds of QCVN 08-MT:2015/BTNMT column A1 (Fe ≤ 0.5 mg/L, F^- ≤ 1 mg/L, and Pb ≤ 0.02 mg/L). There were statistically significant differences between the dry and rainy seasons ($p < 0.05$). According to the former study of Pham et al. (2022) [54], they indicated that human activities can be the primary source of heavy metals in surface water.

The average coliform density was not significantly different between the dry and rainy seasons ($p > 0.05$). The coliform value was found in the dry season at 2674±0 MPN/100mL and 3094±0 MPN/100mL in the rainy season. Coliform density exceeded the allowable limit of QCVN 08-MT:2015/BTNMT column A1 (2500 MPN/100mL) by 1.06-1.23 times [42]. The coliform often originates from human or animal waste, and coliform concentrations in Mekong Delta water bodies are always relatively high [55, 56]. Generally, TSS and coliform exceeded the allowable thresholds of QCVN 08-MT:2015/BTNMT, column A1. Surface water quality in the study area was seasonally fluctuated. In particular, DO, COD, $N\text{-}NH_4^+$, N- $P\text{-}PO_4^{3-}$, Fe_t and F^- in the dry season were higher than in the rainy season. In contrast, TSS, BOD, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$ and coliform in the rainy season were higher than in the dry season.

3.2. Harmony Degree of Water Quality with Various Purpose

The matrix of the harmony degree of each parameter and entropy weights is shown in Table 3. The input data of the method includes only 11 parameters, which have been removed from parameters below the detection limits and are not specific to national regulations. The weight of coliform, $N\text{-}NO_2^-$, Fe, and $N\text{-}NH_4^+$ was determined to be higher than the remaining parameters, with values of 0.190, 0.155, 0.140, and 0.130 (accounting for more than 60% of the importance level of the data set), respectively. The results showed that the matrix of harmony degree of each parameter in the study area reached level I, except for DO, TSS, and coliform.

Table 3. Matrix of harmony degree of each parameter in dry and rainy seasons

Parameters	Dry season				Rainy season				ω
	I	II	III	IV	I	II	III	IV	
pH	1	1	1	1	1	1	1	1	0.041
DO	0	0	1	1	0	0	1	1	0.078
BOD	1	1	1	1	1	1	1	1	0.073
COD	1	1	1	1	1	1	1	1	0.058
TSS	0	1	1	1	0	0	1	1	0.056
$N\text{-}NH_4^+$	1	1	1	1	1	1	1	1	0.130
$N\text{-}NO_2^-$	1	1	1	1	1	1	1	1	0.155
$N\text{-}NO_3^-$	1	1	1	1	1	1	1	1	0.003
$P\text{-}PO_4^{3-}$	1	1	1	1	1	1	1	1	0.077
Fe_t	1	1	1	1	1	1	1	1	0.140
Coliform	0	1	1	1	0	0	1	1	0.190

From the results of Table 3 combined with the entropy weights of each parameter, the comprehensive harmony degree of water quality for various uses in the dry and rainy seasons is shown in Table 4. The comprehensive harmony degree varied from 0.677-1.00, which was considered relatively uniform. Specifically, the degree of comprehensive harmony in the dry season with levels and uses at levels I, II, III, and IV was 0.677, 0.922, 1.00, and 1.00, respectively. Meanwhile, the harmony degree in the rainy season was recorded similarly at levels I and II ($HD_{I, II} = 0.677$) and III and IV ($HD_{III, IV} = 1.00$). Compared with the harmonized target value ($HD_0 = 1$), water quality in the dry and rainy seasons was consistent with level III, which was used for irrigation or other purposes with lower water quality requirements (level IV) [42]. However, when using $HD_0 = 0.8$, the comprehensive harmonization of water quality in the dry season was at a higher level (level II), suitable for domestic water supply purposes, but treatment technology must be applied suitable or for level III and IV uses [42]. Meanwhile, the degree of harmony in water quality and intended use was still determined at level III in the rainy season. This can be explained by the influence of TSS and coliform levels in water that have reduced the level of water quality in harmony with level II (Table 3), which is often reported to have higher concentrations in the rainy season [5, 57]. Therefore, TSS and coliform are the most influential parameters, requiring a solution to limit and handle their effects.

Table 4. The value of comprehensive harmony degree HD_s and water quality classification

Seasons	Comprehensive harmony degree (HD_s)				Judgement values (HD_0)	
	I	II	III	IV	$HD_0 = 1$	$HD_0 = 0.8$
Dry	0.677	0.922	1.000	1.000	III	II
Rainy	0.677	0.677	1.000	1.000	III	III

3.3. Eutrophic Risk in the Study Area

The results of the eutrophication index (EI) in the dry and rainy seasons in Can Tho city are shown in Figure 3. The results showed that the EI index in the study area ranged from 6.02–103.07 (dry season) and 0–82.30 (rainy season). It can be seen that all monitoring stations in the dry season had greater than 0, which showed that the rivers and canals in the study area were eutrophic. The value of EI in the rainy season was about 71.05% greater than 0, which means the sites were likely to be eutrophic. Meanwhile, 10 locations were recorded as not being eutrophic, namely SW4, SW7, SW8, SW9, SW10, SW13, SW14, SW15, SW31, and SW38. In addition, surface water eutrophication at SW25 (dry season) and SW28 (rainy season) was relatively serious, with the highest EI value. These monitoring locations belong to the areas of tourism, agricultural activities, and people's activities (markets). In particular, the excess use of fertilizers in agricultural activities has increased the amount of nutrients in water, affecting aquatic species [36, 58]. The lowest EI values were found at location SW20 in dry seasons, where fishing gear is mainly produced, with little impact on the area's water environment. The EI value in the dry season was higher than that of the rainy season, about 1.25–6 times. Some previous studies by Son et al. [13] and Youping et al. [59] also reported that the EI value in the dry season was always higher than that of the rainy season. The studies of Phung et al. [60] and Tuan et al. [51] pointed out that the study area is mainly polluted by organic substances and nutrients at relatively high levels by industrial, agricultural, and daily activities of people. This is consistent with the results of this study, and the study area is in a state of eutrophication.

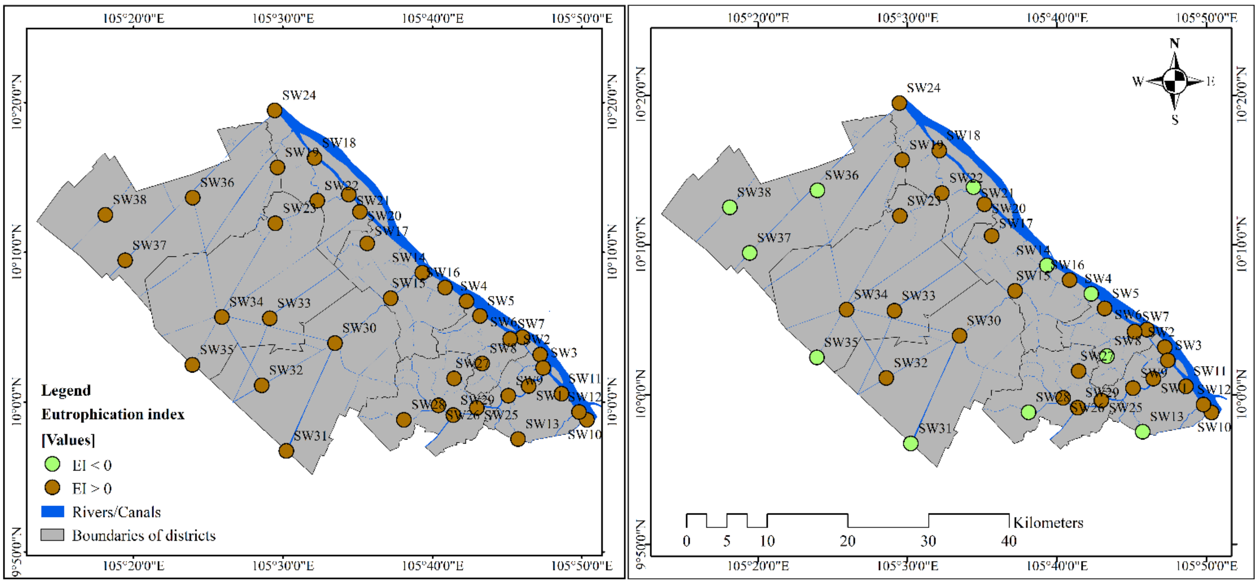

Figure 3. Spatial variation of eutrophication index in the study area

3.4. Rank the Treatment Priority Order of Locations Based on the TOPSIS Method

The overall ranking of the sampling locations given by the TOPSIS method is shown in Figure 4. In the study, several locations had relatively stable water quality, such as SW13, SW17, SW31, and SW32. In the dry season, the closeness coefficients of SW6, SW8, SW30, SW36, and SW19 were 0.9365, 0.7485, 0.7477, 0.6615, and 0.6520, respectively; these are the five locations with the best water quality. However, these locations have low closeness coefficients in the rainy season, which has bad water quality, typically SW36. In fact, SW36 is located in a market area with many people and agricultural cultivation activities. In the rainy season, the closeness coefficient of locations with positive ideal values was recorded to tend to decrease. The locations with the best water quality were arranged in descending order, including SW4 (0.8403) < SW8 (0.6820) < SW5 (0.6641) < SW7 (0.5954) < SW17 (0.5307). Similarly, SW4 has poor water quality in the dry season, which receives domestic wastewater as part of the industrial park. This indicates that if the parameters are considered as a whole, water quality at each location is significantly affected by seasonal changes in activity. According to the classification of Sonavane et al. [27], the closeness coefficient is divided into four groups to evaluate water quality, including very good ($CC \geq 0.8$), good ($0.6 \leq CC < 0.8$), bad ($0.3 \leq CC < 0.6$), and unsuitable ($CC < 0.3$). According to this classification, water quality in the dry season in the region has 8 locations unsuitable for use (accounting for 21.05%), 21 locations at a bad level (accounting for 55.26%), 8 locations at a good level (accounting for 21.05%), and 1 location with excellent quality (2.63%). In the rainy season, there were 15 unsuitable locations (39.47%), 20 locations at a bad level (52.63%), 2 locations at a good level (5.26%), and 1 location at an excellent level (2.63%).

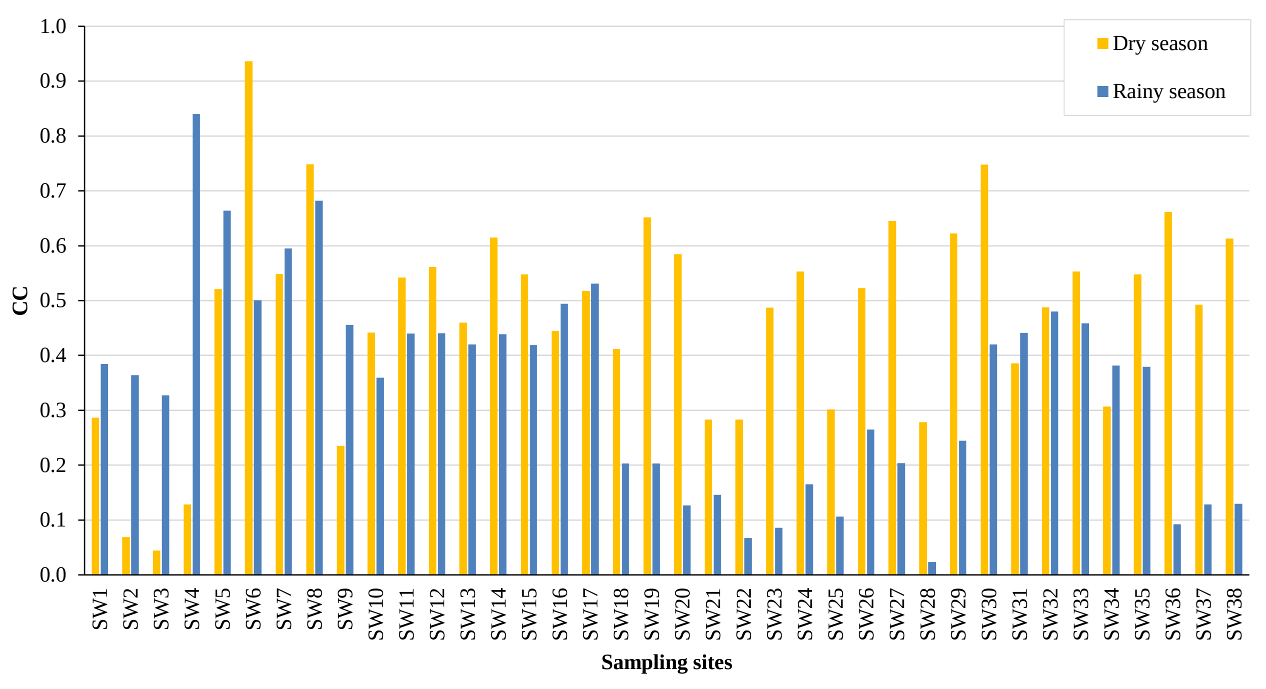

Figure 4. Closeness coefficient at the sampling sites in the dry and rainy season

Table 5 shows the ranking of monitoring locations (SW1 to SW38) in order of priority requiring treatment solutions. Based on the closeness coefficient (CC) at the locations, the treatment priority of the locations has significant fluctuations between the rainy and dry seasons; for instance, some locations have a reduced priority and vice versa. In the dry season, SW1-SW4, SW9, SW21, SW22, and SW28 were identified as having high treatment priority, indicating that the water quality at these locations has limited uses. The priority ranking results in the rainy season have changed. Specifically, the eight locations with high priority in descending order were SW28, SW22, SW23, SW36, SW25, SW20, SW37, and SW38, respectively. Combined with the results of eutrophication risk, water quality in the study area should be prioritized for treatment at SW2-SW4 in the dry season, SW23 in the rainy season, and SW22 and SW28 in both seasons.

Table 5. The positive and negative ideal points, closeness coefficient and ranking and priority ranking

Sites	Dry season				Rainy season			
	d^+	d^-	CC	Rank	d^+	d^-	CC	Rank
SW1	0.1865	0.0750	0.2868	8	0.4142	0.2591	0.3848	21
SW2	0.2444	0.0180	0.0687	2	0.4293	0.2458	0.3641	18
SW3	0.2611	0.0121	0.0445	1	0.4522	0.2203	0.3275	16
SW4	0.2308	0.0340	0.1285	3	0.1227	0.6458	0.8403	38
SW5	0.1252	0.1362	0.5212	20	0.2314	0.4576	0.6641	36
SW6	0.0174	0.2564	0.9365	38	0.3354	0.3365	0.5008	33
SW7	0.1172	0.1423	0.5483	25	0.2743	0.4036	0.5954	35
SW8	0.0659	0.1961	0.7485	37	0.2196	0.4709	0.6820	37
SW9	0.2014	0.0619	0.2351	4	0.3694	0.3094	0.4558	29
SW10	0.1456	0.1152	0.4418	13	0.4316	0.2422	0.3594	17
SW11	0.1198	0.1417	0.5418	22	0.3767	0.2960	0.4400	26
SW12	0.1160	0.1485	0.5615	28	0.3756	0.2960	0.4407	27
SW13	0.1425	0.1212	0.4596	15	0.3897	0.2825	0.4203	24
SW14	0.1030	0.1646	0.6151	31	0.3786	0.2960	0.4388	25
SW15	0.1202	0.1456	0.5478	23	0.3921	0.2826	0.4188	22
SW16	0.1467	0.1175	0.4446	14	0.3440	0.3363	0.4944	32
SW17	0.1275	0.1366	0.5173	19	0.3212	0.3633	0.5307	34
SW18	0.1544	0.1081	0.4120	12	0.5313	0.1352	0.2029	11

Sites	Dry season				Rainy season			
	d^+	d^-	CC	Rank	d^+	d^-	CC	Rank
SW19	0.0934	0.1751	0.6520	34	0.5306	0.1352	0.2031	12
SW20	0.1101	0.1548	0.5843	29	0.5822	0.0843	0.1264	6
SW21	0.1883	0.0744	0.2833	7	0.5693	0.0972	0.1459	9
SW22	0.1882	0.0742	0.2828	6	0.6217	0.0449	0.0674	2
SW23	0.1351	0.1283	0.4872	16	0.6084	0.0573	0.0861	3
SW24	0.1197	0.1481	0.5529	26	0.5561	0.1100	0.1652	10
SW25	0.1843	0.0797	0.3018	9	0.5932	0.0703	0.1060	5
SW26	0.1257	0.1377	0.5228	21	0.4886	0.1762	0.2651	15
SW27	0.0936	0.1705	0.6455	33	0.5296	0.1357	0.2039	13
SW28	0.1908	0.0736	0.2785	5	0.6471	0.0157	0.0236	1
SW29	0.0990	0.1635	0.6228	32	0.5007	0.1622	0.2447	14
SW30	0.0683	0.2024	0.7477	36	0.3918	0.2839	0.4201	23
SW31	0.1623	0.1018	0.3855	11	0.3765	0.2969	0.4409	28
SW32	0.1350	0.1286	0.4879	17	0.3513	0.3248	0.4804	31
SW33	0.1197	0.1481	0.5530	27	0.3663	0.3104	0.4586	30
SW34	0.1827	0.0810	0.3072	10	0.4156	0.2563	0.3814	20
SW35	0.1221	0.1481	0.5480	24	0.4192	0.2563	0.3794	19
SW36	0.0901	0.1760	0.6615	35	0.6080	0.0617	0.0921	4
SW37	0.1331	0.1292	0.4926	18	0.5837	0.0862	0.1286	7
SW38	0.1025	0.1624	0.6130	30	0.5837	0.0867	0.1293	8

4. Conclusion

The results showed that the surface water quality in Can Tho City was polluted with total suspended solids (TSS) and coliform. The parameters of DO, COD, N-NH_4^+, and P-PO_4^{3-} were high in the dry season, whereas the reverse was true for pH, temperature, TSS, BOD, N-NO_2^-, N-NO_3^-, and Pb. The comprehensive harmony degree of water quality-purpose use has determined that water quality in the dry season was suitable for domestic purposes (Level II) but requires appropriate treatment measures; the rainy season was suitable for irrigation (Level III) and lower purposes. TSS and coliform are the most influential parameters for the purpose of use. The results showed that the EI index in the study area ranged from 6.02–103.07 (dry season) and 0–82.30 (rainy season), indicating that surface water was eutrophic, especially at SW25 and SW28. Based on the result of TOPSIS, the locations with decreasing priority are as follows: SW3 > SW2 > SW4 > SW9 > SW28 > SW22 > SW21 (dry season) and SW28 > SW22 > SW22 > SW36 > SW25 > SW20 > SW37 > SW38. Water quality at SW4 has significant potential source impacts by season. The research results can be a scientific basis for prioritizing decisions to implement mitigation or treatment measures based on priority order and recommended water use for the two seasons.

5. Declarations

5.1. Author Contributions

Conceptualization, N.T.G. and L.D.K.; methodology, N.T.G. and L.D.K.; software, N.T.G.; validation, L.D.K.; formal analysis, N.T.G. and L.D.K.; resources, N.T.G. and L.D.K.; data curation, N.T.G.; writing—original draft preparation, N.T.G. and L.D.K.; writing—review and editing, N.T.G. and L.D.K.; visualization, N.T.G. and L.D.K.; supervision, N.T.G. and L.D.K.; project administration, N.T.G. and L.D.K. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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