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The zoning of surface water quality by WQI index in the Tien Giang province, Vietnam

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Abstract:

According to Decision No. 711/QD-TCMT of the Ministry of Natural Resources and Environment, the water quality index (WQI) formula has been adjusted toward localisation, particularly, for the Nhue Day and Cau river basins. In this work, the WQI formula was amended by adjusting the weights of the components of surface water quality. This is an advance forward toward enhancing the effectiveness of local environmental management so that local economic development conditions are shaped according to its own potential and in accordance with the natural characteristics and culture of the regions. Based on surface water quality data from 2012 to 2019 in Tien Giang and the theory of fuzzy entropy weighting to identify component weights, this study adjusted the WQI formula in accordance with natural conditions as well as special characteristics of the socio-economic development of Tien Giang. Finally, a zoning map of surface water quality in the province was set up.

Keywords: **Tien Giang province, water quality index, water quality management, zoning water quality, 711/QD-TCMT.**

Classification number: **5.1**

Introduction

Assessment of the surface water quality by an index is widely applied in research in the water sector as well as in environmental management. The water quality index (WQI) formula has many forms based on the researcher(s) and location of the research. For example, it could be the arithmetic mean, average multiplication, or a combination with a weighted or non-weighted set [1]. In Vietnam, the WQI is commonly used and it is considered a good tool for determining water quality [2, 3]. In addition, formula and water quality assessments have been standardised and unified over the whole country through Decision No. 879/QD-TCMT of the General Department of Environment under the Ministry of Natural Resources and Environment.

Table 1. The weight sets of water quality groups and each parameter used in the WQI formula under Decision No. 711/QD-TCMT.

Name of water quality group	Name of water quality parameter	Weight set for group		Weight set for parameter	
		Cau river	*Nhue river*	*Cau river*	*Nhue river*
Group 1 (WQI_a)	TSS	0.30	0.20	0.17	0.12
	Turbidity			0.13	0.08
Group 2 (WQI_b)	DO	0.60	0.65	0.17	0.20
	COD			0.12	0.13
	BOD			0.12	0.12
	$N\text{-}NH_4^+$			0.10	0.10
	$P\text{-}PO_4^{3-}$			0.09	0.10
Group 3 (WQI_c)	Coliform	0.10	0.15	0.10	0.15

Nowadays, Vietnam has developing economic sections like agriculture, industry, trade service, and tourism that has conformed to the local natural characteristics of all provinces. The common use of the WQI formula is simple but its level of accuracy in a special location is limited. The General Department of Environment recognised and

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implemented an initial step with Decision No. 711/QD-TCMT in 2015, which adjusted the weight set of the WQI formula under Decision No. 879/QD-TCMT applied to the specific river basins of the Nhue Day and Cau rivers. Table 1 summarises the weights of the water quality groups and the parameters that were determined to have different importance levels in accordance with natural conditions and key economic sectors in the two river basins.

In this study, the authors used the entropy weighting method combined with fuzzy theory. Particularly, the authors used the combination of entropy weighting with a part of the fuzzy comprehensive evaluation method [2, 4]).

Methods

This research determined the weighted sets of local water quality parameters and groups in the following way:

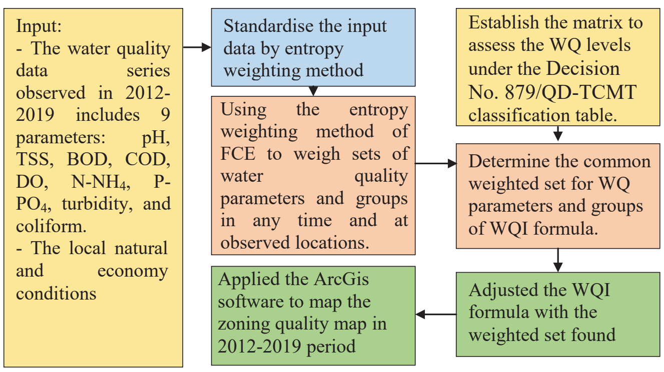

Fig. 1. Flow chart of the research approach.

The current WQI formula for assessing local surface water quality was included in the dataset of the following surface water quality parameters: pH, TSS, turbidity, COD, BOD_5, DO, $N\text{-}NH_4$, $P\text{-}PO_4$, and coliform. Fuzzy theory combined with entropy weighting calculations [3] were used to determine the weighted set of the water quality parameters and groups according to the implementation guidelines of Decision No. 711/QD-TCMT. The determination of the weight set for the formula to assess surface water quality was carried out in the same manner as Fig. 1. In detail:

The first step: standardising the water quality measurement data by entropy.

Prepare the standardised matrix R as follows:

$r_{i,j} = (x_{i,j} - \text{Min}(\Sigma x_{i,j}))/(\text{Max}(\Sigma x_{i,j}) - \text{Min}(\Sigma x_{i,j}))$ for parameters pH and DO (1)

$r_{i,j} = (\text{Max}(\Sigma x_{i,j}) - x_{i,j})/(\text{Max}(\Sigma x_{i,j}) - \text{Min}(\Sigma x_{i,j}))$ for remaining parameters (2)

Determine the value of entropy (H_i):

$$H_i = \frac{1}{lnn}\sum_{j=1}^{n} f_{ij}\ln(ij) \text{ with } f_{i,j} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}, \quad 0 \le H_i \le 1 \quad (3)$$

$f_{ij} = (1+r_{ij})/\sum_{j=1}^{n}(1+r_{ij})$ with $f_{ij} = 0$

Determine the weights of entropy as follows:

$$w_i = (1 - H_i)/(m - \sum_{i=1}^{m} H_i),\ 0 \le w_i \le 1,\ \sum_{i=1}^{m} w_i = 1 \quad (4)$$

The original matrix, X, after standardisation: $x^E_{i,j} = x_{i,j} * (1-w_i)$ (5)

The second step: applying the surface water quality classification table. Using in the fuzzy comprehensive evaluation [2, 4] for determining the weighted set of the water quality parameters and groups in the WQI formula, the pollution level of water sources were categorised according to five levels. A hierarchy for evaluation factors based on the pollution/water quality classification was developed and is provided in Table 2.

Table 2. Classification of surface water quality [2].

Parameters	Pollution/water quality classification				
	I (No pollution)	*II (Light pollution)*	*III (Medium pollution)*	*IV (Hard pollution)*	*V (Extreme pollution)*
pH	6.5-7.5	6-6.5/7.5-8	5-6/8-9	4.5-5/9-9.5	<4.5/>9.5
% $DO_{Saturated}$	88-112	75-88/112-125	50-75/125-150	20-50/150-200	≤20/≥200
BOD_5	≤4	6	15	25	≥50
$N\text{-}NH_4$	≤0.1	0.2	0.5	1	≥5
$P\text{-}PO_4$	≤0.1	0.2	0.3	0.5	≥6
TSS	≤20	30	50	100	>100
COD	≤10	15	30	50	>80
Coliform	≤2500	5000	7500	10000	>10000
Turbidity	≤5	20	30	70	≥100

The standardised matrix, X, was used to determine the contribution level of the parameters and groups to the CLN from the water quality according to the classification Table 2. Each level of water quality (pollution level) had a series of different contribution levels (weighted sets).

The sequence of the parameters' weighted sets for each year as a weighted set for the new WQI formula according to the conditions was determined. Namely, (1) the standard deviation of the sequence of contributions on a pollution step is minimal; (2) the standard deviation of the series of contributions on a pollution step is average; (3) the standard deviation of the series of contributions on a pollution step is the largest [5, 6]. In general, it is common to choose condition (1) because the size of the actual measured dataset is large and the weighted set of the water quality parameters and groups quickly converge.

Based on the WQI formula of Decision No. 879/QD-TCMT, the new WQI formula is to be adjusted to the form [6, 7]:

$$WQI = \frac{WQI_{pH}}{100}\left(WQI_a^{ra} \times WQI_b^{rb} \times WQI_c^{rc}\right) \quad (6)$$

where:

$WQI_a = h_1\, WQI_{DO} + h_2\, WQI_{BOD_5} + h_3\, WQI_{COD} + h_4\, WQI_{N\text{-}NH_4} + h_5\, WQI_{P\text{-}PO_4}$

$WQI_b = ly_1\, WQI_{TSS} + ly_2\, WQI_{turbidity}$

$WQI_c = s\, WQI_{coliform}$

r_a, r_b, r_c are the weights of groups with $r_a + r_b + r_c = 1$

h_1-h_5; ly_1, ly_2, and s are the parameters' weights with $h_1+h_2+h_3+h_4+h_5=1$; $ly_1+ly_2=1$; s=1.

The third step: applying ArcGis software to map water quality zoning of the Tien Giang province of Vietnam over the period 2012-2019.

Therefore, we proposed to adjust the weighted sets of quality parameters and groups in the WQI formula under the guidance of Decision No. 711/QD-TCMT, which was only applied to the assessment of surface water quality in Tien Giang province. Based on the new WQI formula, the map of surface water quality zoning in the Tien Giang province over the 2012-2019 period was created to serve the Tien Giang Provincial Department of Natural Resources and Environment in the management of surface water quality. The results are given below.

Results and discussion

The Tien Giang province is at the end of the Tien river in the Mekong delta. This is a province with similar natural characteristics governed by both the hydrological regime of the Mekong river system and the seashore current. The Tien Giang province is also an agricultural province in the Mekong delta that is predominant in rice cultivation. Therefore, the WQI formula must be suitable to the natural and economic development conditions in the Tien Giang province.

The water quality measurement data set was used for the determination of weighted sets from 2012 to 2019 at the observation locations presented in Fig. 2. The quality datasets were collected including 9 water quality parameters including pH, BOD_5, COD, DO, $N\text{-}NH_4$, $P\text{-}PO_4$, TSS, turbidity, and coliform (Table 3).

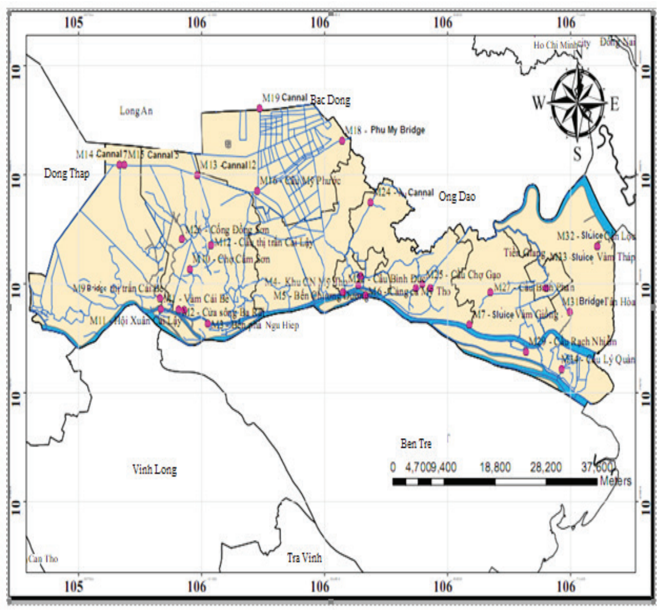

Fig. 2. Administration and observation locations map of Tien Giang.

Source: Department of Natural Resource and Environment of Tien Giang province, 2019.

Table 3. The observation database of water quality (Example on March 2018).

Location - name	°C	pH	DO	TSS	COD	BOD_5	$N\text{-}NH_4^+$	$P\text{-}PO_4^{3-}$	Coliform	Turb
			mg/l	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*MPN/100 ml*	*NTU*
M1 - Vam Cai Be	28.90	7.30	4.90	3.00	0.00	25.0	0.00	0.00	250	7.10
M2 - Ba Rai river mouth	28.40	6.86	4.22	13.0	5.00	22.0	0.00	0.00	350	6.30
M3 - Ngu Hiep ferry	28.00	6.80	4.25	17.0	7.00	26.0	0.00	0.00	400	7.40
M4 - My Tho industrial zone	29.20	7.07	3.90	9.00	3.00	36.00	0.02	1.24	110	10.3
M5 -Chuong Duong ferry	29.50	7.17	4.26	8.00	3.00	46.00	0.02	0.05	130	13.1
M6 - My Tho fish port	29.50	7.10	4.15	3.00	0.03	44.00	0.02	0.07	170	12.6

Source: Department of Natural Resource and Environment of Tien Giang province, 2019.

Using Eq. 1 through Eq. 5 with input from observed data of water quality in the Tien Giang province from 2012-2019, the final results of the first step is listed in Table 4.

Table 4. The weighted contribution of quality parameters in the determination of water quality level at M1 (observation location) in March 2018.

Parameters		The weighted contribution in each quality level (%)				
Name	*Values*	*1*	*2*	*3*	*4*	*5*
pH	7.23	0.268	0.731	0	0	0
% $DO_{satur.}$	63.92	0	0	0.443	0.556	0
COD	0.03	1	0	0	0	0
BOD_5	24.77	0	0	0.976	0.023	0
TSS	2.97	1	0	0	0	0
$N-NH_4$	0.02	1	0	0	0	0
$P-PO_4$	0.03	1	0	0	0	0
Coliform	247.66	1	0	0	0	0
Turbidity	7.08	0.138	0.861	0	0	0

The general weighted sets of the quality groups and parameters used in the new WQI formula were applied to the Tien Giang province and the results are given in Table 4. The final values of the weighted sets, as well as their convergence level, are listed in Tables 5-7 and shown in Figs. 3 and 4.

Table 5. The weighted set of organic quality parameters.

Name	General contribution at each quality level (%)					Weighted set of parameters at each quality level					General values
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	
% $DO_{Satur.}$	0.00	0.03	0.20	0.34	0.38	0.00	0.07	0.29	0.50	0.52	0.07
COD	0.12	0.12	0.14	0.07	0.04	0.25	0.27	0.20	0.10	0.06	0.27
BOD_5	0.06	0.13	0.20	0.14	0.15	0.12	0.29	0.29	0.20	0.20	0.29
$N-NH_4$	0.12	0.08	0.11	0.11	0.13	0.25	0.18	0.15	0.15	0.17	0.18
$P-PO_4$	0.18	0.09	0.04	0.03	0.03	0.37	0.20	0.06	0.05	0.05	0.20

Table 6. The weighted set of physical quality parameters.

Name	General contribution at each quality level (%)					Weighted set of parameters at each quality level					General values
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	
TSS	0.14	0.12	0.09	0.07	0.05	0.61	0.45	0.49	0.29	0.29	0.49
Turbidity	0.09	0.14	0.10	0.17	0.12	0.39	0.55	0.51	0.71	0.71	0.51

Table 7. The weighted set of quality groups.

Name	Weighted set of groups at each quality level					General values
	1	*2*	*3*	*4*	*5*	
Organic	0.53	0.60	0.77	0.73	0.75	0.53
Physics	0.25	0.35	0.21	0.25	0.17	0.25
Biology	0.22	0.05	0.03	0.02	0.07	0.22

The set of weights in Tables 5-7 did not change much when the number of calculation years was over 5 y. The magnitude of the fluctuation in weight value of the quality parameters and groups are summarised as shown in Figs. 3 and 4.

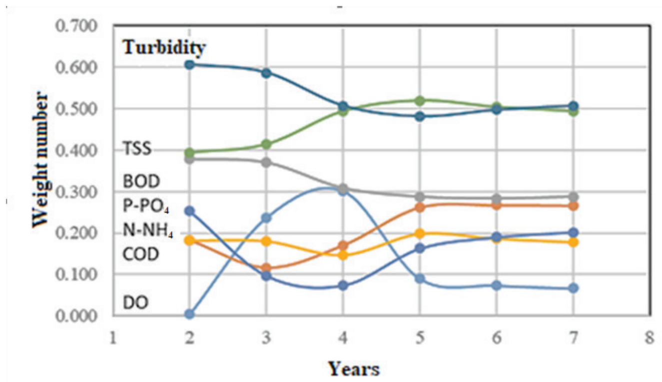

Fig. 3. The magnitude of fluctuation in weight value of quality parameters.

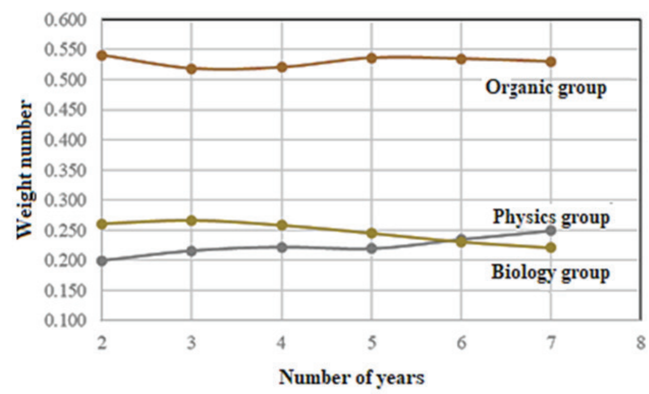

Fig. 4. The magnitude of fluctuation in weight value of quality groups.

Finally, the new WQI formula under Decision No. 711/QD-TCMT guidelines was applied to assess the water quality in Tien Giang province, which is given i Eq. 7.

$$WQI = \frac{WQI_{pH}}{100}\left[(0.07WQI_{DO} + 0.27WQI_{COD} + 0.29WQI_{BOD} + 0.18WQI_{N-NH_4} + 0.20WQI_{P-PO_4})^{0.53}(0.49WQI_{TSS} + 0.51WQI_{DD})^{0.25}WQI_{colif}^{0.22}\right] \quad (7)$$

Eq. 7 showed that the organic group leads and decides the water quality level in Tien Giang due to its highest weight (0.53). This is reasonable because the production structure is inclined toward the discharge of organic substances as agriculture, aquaculture, and urban areas are expended.

Eq. 7 is considered to reflect the development of the local economy as well as express local economic characteristics because the weighted set of water quality parameters determined from the water quality data was observed for a long time [6].

Nowadays, the Mekong river's flow has been reduced due to increasing upstream water use. The evidence for this is expressed by the decreasing flood peak level over time (Fig. 5). This leads to the decline of river and canal waters.

This is one of many reasons pollution is occurring in the inland canal system of Tien Giang.

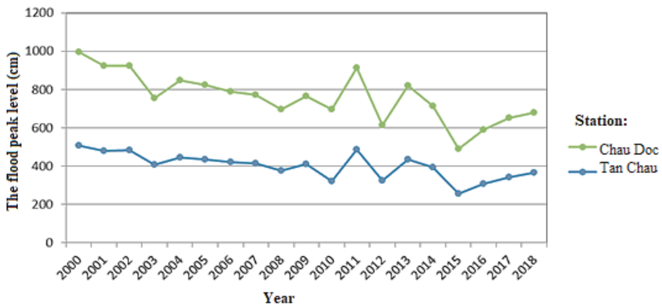

Fig. 5. The flood peak level lines at Tan Chau and Chau Doc upstream stations.

With the new WQI formula, the distribution of water quality in the river and canal system of Tien Giang was mapped from 2012-2019 by ArcGis and is shown in Figs. 6-8.

The water quality level of the river system in Tien Giang depends a lot on upstream flood conditions. A year with medium-to-large upstream floods flowing into Tien Giang comes along with improved water quality in the river system. The areas with low water quality are normally urban locations, agricultural locations, and adjacencies to Ho Chi Minh city (HCMC). The general assessment of water quality over the 2012-2019 period is good water quality in the river system of Tien Giang, except for some areas adjacent to HCMC with a medium pollution level. These areas are industrial parks that support HCMC.

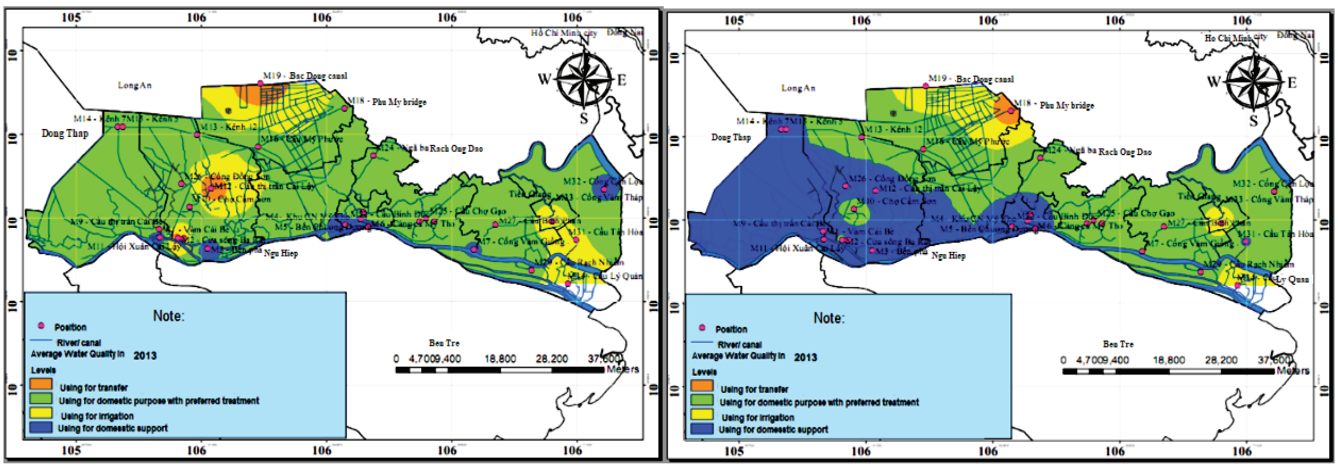

Fig. 6. The water quality distribution for years 2013-2014 with medium flood situation.

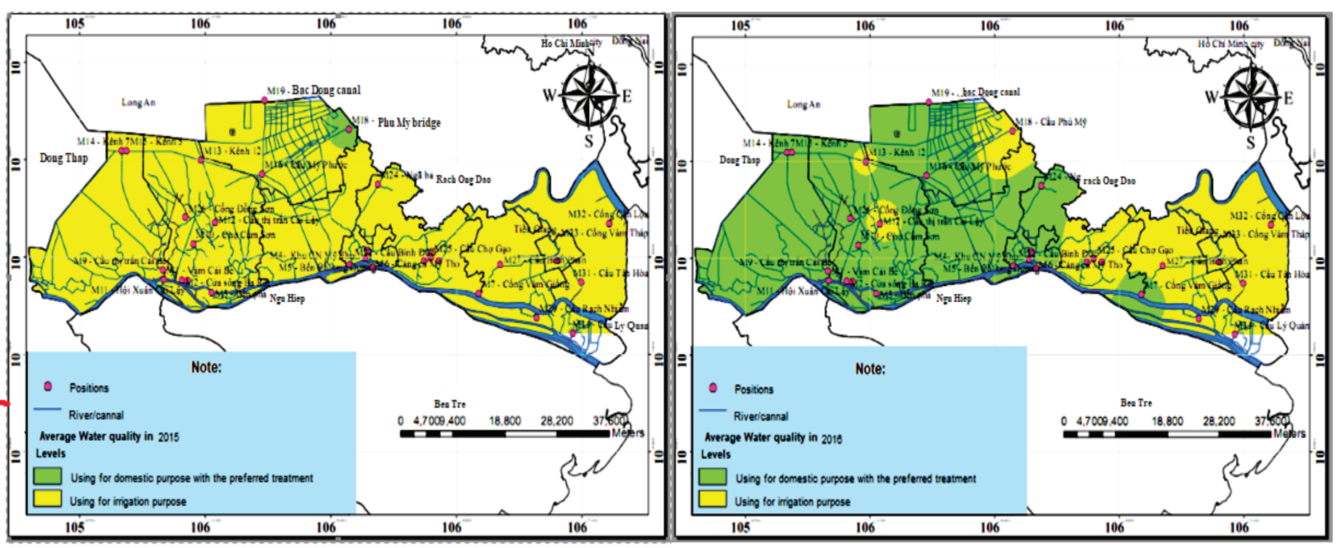

Fig. 7. The water quality distribution for years 2015-2016 with small flood situation.

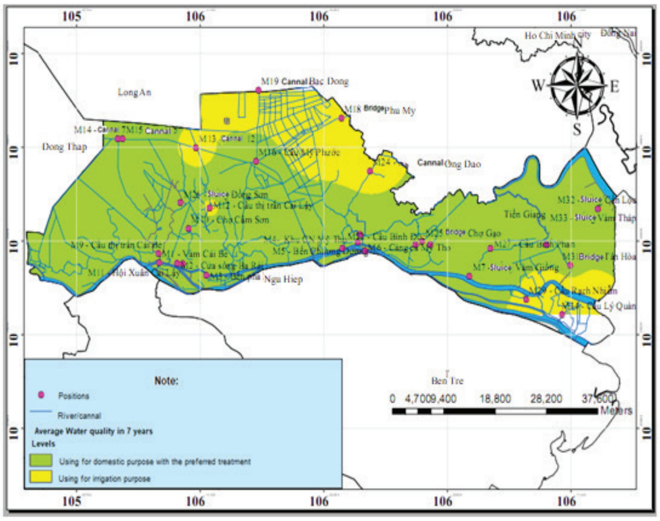

Fig. 8. The water quality distribution from 2012-2019 in Tien Giang.

Conclusions

The results of the surface water quality assessment according to the adjusted formula initially show conformity of the natural conditions and local economic development. However, it is also necessary to emphasise that the weight set of the water quality parameters and groups should be continuously recalculated to give the final formula by extending the number of years of the actual data series.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] P.T.M. Hanh (2010), "Development of water quality indices for surface water quality evaluation in Vietnam", *Journal of Environmental Engineering*, **137(4)**, DOI: 10.1061/(ASCE)EE.1943-7870.0000314.

[2] L.D. Che (2013), "Applying the 'fuzzy' comprehensive evaluation method in the model of water quality assessment of Saigon river flowing through Binh Duong province", *Jounal of Environment*, **6**, pp.30-42.

[3] Y. Geng, et al. (2011), "Fuzzy synthetic evaluation of weight water quality", *Environmental Engineering and Management Journal*, **10(10)**, pp.1477-1484.

[4] A. Lermontov, et al. (2009), "River quality analysis using fuzzy water quality index: Ribeira do Iguape river watershed, Brazil", *Ecological Indicators*, **9(6)**, pp.1188-1197.

[5] T.M.U. Nhi (2018), *Assessment the Surface Water Quality on the Main Canals in Vinh Long City*, University of Science - VNU of Ho Chi Minh city.

[6] B.V. Hung (2017), "Application of fuzzy comprehensive evaluation for surface water quality assessment", *The Science and Technology Results Collection 2016*, Southern Institute of Water Resource Research, **12**, pp.92-101.

[7] B.V. Hung, T.M.U. Nhi (2018), "Adjustment of the formula to assess the local surface water quality", *Journal of Agriculture and Development*, **5**, pp.102-113.