Application of Entropy weight in groundwater quality index (EWQI) and GIS for groundwater quality zoning in the Southeastern Coastal region, Vietnam

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Abstract. Groundwater in the Southeast coastal region of Vietnam is exploited for many purposes, including irrigation, livestock, domestic and production activities. In this study, Groundwater Quality Index calculated by Entropy weight method (EWQI) and Geographic Information System (GIS) are applied for zoning water quality through determining the weight of each parameter in accordance with the variation of each value in terms of. Spatial distribution the suitability of groundwater use in the study area. Groundwater samples were collected from 46 wells in the dry and wet seasons in 2018 for analyzing seven selected water quality parameters, including: pH, total dissolved solids (TDS), total hardness (TH), ammonium (NH₄⁺-N), nitrate (NO₃⁻-N), sulphate (SO₄²⁻) and ferrous (Fe²⁺). The groundwater quality is divided into five (05) categories corresponding to Entropy Water Quality Index (EWQI), comprising: excellent, good, medium, poor and extremely poor. The analysis results of Entropy weight indicated that pH, NH₄⁺-N, NO₃⁻-N are the most affected on the quality of groundwater at the study area. According to EWQI results, more than 41.30% of wells’ water quality are "very good" in both the dry and wet seasons, mainly in the coastal of Ba Ria - Vung Tau province and 13.04% of the total surveyed wells in the study area are “extremely poor”, mainly in Ho Chi Minh city. Accordingly, the zoning map of Entropy weighted Water Quality Index (EWQI), showed that the area with good quality of groundwater accounts for 34.3% and 37.72% of the total study area in the dry and the rainy season, respectively.

1. Introduction
Water is indispensable to human life as well as the ecosystems and affects all socio-economic activities. Besides surface water sources (rivers, streams, lakes), groundwater is an important source of safe water in many regions of the world. Groundwater is a limited resource which is widely used for agricultural production and domestic in developing countries. On the other hand, rate of urbanization, industrialization can cause environmental problems such as groundwater pollution.

Groundwater in the Southeast coastal region of Vietnam is used mainly for domestic purposes with small to medium scale exploitation to meet population growth and rapid urbanization, exploited mainly
pore-hole aquifers of Pleistocene sediments with distribution depths from 15-50m. In addition, groundwater in the region is also affected by climate change along with agricultural activities on inland sources through the canal system.

Nowadays, to manage and evaluate the suitability of water sources for water supply and agriculture purposes, some methods of water quality assessment are used such as fuzzy mathematics method, membership degree method, factor analysis method, gray modeling method, and analytic hierarchy process method [1]. Among them, the Water Quality Index method is widely used for water quality assessment in many countries. This is a numerical tool that can be used for determining the suitability of water for water supply purposes, providing the aggregate effect of each quality parameter on the overall water quality.

“The WQI method has the high ability in describing water quality data in addition to using effective parameters in water quality assessment and management” [2]. Therefore, WQI is used to evaluate water quality data monitoring and allows scientists to explain the monitoring of results as well as to analyze the significance of the water quality results, especially when the concentration of parameters exceed water quality standards. WQI is also useful in presenting water quality information in an easy way to the public [3].

The weighted average WQI method is determined by the weighting in the formula, calculated by many different weighting methods, such as the optional weighting method, the AHP order analysis method and the Entropy method. In particular, the optional weight is widely used in the world, mainly in WQI application studies to assess water quality in India [4], Turkey [5], Bangladesh [6] with the importance of the weights depending on the author's experience in evaluation. Hierarchical weighting provides an objective algorithm that separates an individual or group's individual claims in decision making [7], the AHP weighted water quality index is applied at Indonesia [8], India [9] and Vietnam [10]. In recent years, the Entropy weight-based method in the water quality index was widely recognized to deploy for water quality assessment around the world, such as Iran [2, 11], China [1, 12], and India [13]. Entropy weight is a measure of data dispersion, which can be employed to evaluate the effectiveness of the information provided by the data. Therefore, entropy can be used to calculate weights [14]. Based on the bias level of the data source, the entropy index will be determined, thereby finding the weight of all parameters. When the subjects are assessed with a large difference, the entropy value will be small and vice versa. The smaller the amount of information provided, the smaller the weight will be. Therefore entropy weighting method is an objective method because the weight of all parameters is calculated based on the degree of variation of each value and is depended on the data source [15].

In Vietnam, WQI method has been extensively used to assess the surface and groundwater quality for agricultural purposes [16], domestic purposes [17, 18]. However, in the WQI methodology, the selection of parameter weights is usually given by the assessor's personal opinion based on the experience. As a result, it may increase the subjectivity in the calculating and assessing process, which can eventually lead to bias in results because the weight found depends on the expert's level of expertise; additionally, there is a lot of valuable data at risk of being discarded at the same time [11].

In this research, the Entropy weighted WQI method is used to assess water quality of Pleistocene aquifer in Phu My town, Ba Ria - Vung Tau province, Southeastern Vietnam, in order to provide more complete information about the quality of water supplies for irrigation and domestic purposes.

In order to analyze and visualize data spaces, support decision-making in many research fields, GIS provides an efficient, fast environment for organizing and quantitatively explaining large volumes of data. space [19]. Many studies on the application of GIS combined with GWQI method were conducted to assess groundwater quality in India [20, 21]. Likewise, Egypt have used integrating traditional geochemical analysis and GIS with analysis factors to understand the factors that control groundwater chemistry [19]. Iranian researchers have also used GIS method with Groundwater Quality Index to analyze water quality, determined by performing slab removal sensitivity analyzer, for the purpose of potable water quality zoning in semi-arid regions [22]. In Vietnam, there have been a number of studies
applied for the groundwater quality index method [17, 18]. However, there are currently no studies applying GIS-based GWQI method to zone and assess of water quality in the Southeast coastal region. The purpose of this study is to zone groundwater quality in Pleistocene aquifer in the Southeast coastal region according to EWQI combined with geographic information system, seasonal variation and regional visualization, to determine whether groundwater is suitable or unsuitable for domestic uses.

2. Materials and methods

2.1. Study area
The study area includes Ho Chi Minh City and the coastal area of Ba Ria - Vung Tau province, with an area of about 2806 km². The study area is in the tropical monsoon climate with a high temperature base. The study area is formed mainly from alluvial deposits of Holocene and Pleistocene age. Most of the area is made up of marine and weathered sediments - the Middle - Late Holocene age sea formed from clayey silt, pebble and gravel, along with Pleistocene age river sediments and Holocene age-sea sediments, including loam, sandy loam, pebble, gravel and boulder. Barrier islands formed from erupting rocks of Kreta age include Granit and Diorite of Deo Ca complex.

Groundwater in the study area includes 3 main pore aquifers, including the upper Pleistocene (qp₃) with wells with an average depth of 3.9 - 36m; Middle-upper Pleistocene (qp₂₃) with wells of average depth from 5 to 50m and lower Pleistocene (qp₁). The distribution of wells is mainly concentrated in the West and Northwest of the region. In which, two aquifers with pore-hole sediments of Upper Pleistocene (qp₁) and Middle-upper Pleistocene (qp₂₃) are distributed throughout the study area with great water richness. The main chemical composition of the Pleistocene layer is light water, which is the main supply source for medium- to large-scale industrial-grade wells in the coastal area of Ba Ria - Vung Tau province in particular and small in the Southeast coastal area in general. This is the outlet of the surface currents of the upper river system as well as of the groundwater. Main lithological composition of the Pleistocene aquifer includes silver to coarse sand contains gravel, silty sand, bright gray silty sand, mixed with silty loam or intercropped thin lenses of silty clay, silver silty sand, with main minerals: Fluorite - apatite, feldspar, gypsum, turmalin, montmorillonite, ilmenite and some other impurities [19].

2.2. Materials
In this study, regional geology, petrographic units, and aquifer units are described and used from previous studies. In the study area, a total of 46 water samples from groundwater quality monitoring wells with 7 water quality parameters (pH, TH, TDS, SO₄²⁻, NH₄⁺-N, NO₃⁻-N và Fe²⁺) in the suburbs South East Sea was implemented in the dry and rainy season in 2018. Those samples were processed and assessed. The locations of the monitoring wells are shown in the position diagram in Figure 1.
2.3. Methods

2.3.1. Entropy weight

The calculating process of Entropy weighted Water Quality Index (EWQI) was adapted from L. Peiyue, W. Jianhua and Q. Hui [1].

Assuming m water samples are taken to assess the water quality (i = 1,2,… m). Each sample has n estimated parameters (j = 1,2,… n). According to the observed data, a matrix X can be constructed as follows:

\[
X = \begin{bmatrix}
    x_{11} & x_{12} & \cdots & x_{1n} \\
    x_{21} & x_{22} & \cdots & x_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}
\]

Data preprocessing is applied to eliminate the effects of different units, characteristic indices and quality categories. According to the distribution of all metrics, metrics can be divided into four categories: performance type, value type, fixed type, and range type.

For the performance category, the standardized build formula is:

\[
Y_{ij} = \frac{x_{ij} - (x_{ij})_{\text{min}}}{(x_{ij})_{\text{max}} - (x_{ij})_{\text{min}}}
\]  (1)

For the value type, the standardized construction formula is:

\[
Y_{ij} = \frac{(x_{ij})_{\text{max}} - x_{ij}}{(x_{ij})_{\text{max}} - (x_{ij})_{\text{min}}}
\]  (2)

In this report, formula (2) was used to build standardized value types because the observed parameters are the measured values.

After transformation, the standard matrix Y is obtained as follows:
\[ Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \]

The formula for calculating the index value of index j and in sample i is:

\[ P_{ij} = \frac{y_{ij}}{\sum_{j=1}^{m} y_{ij}} \]  (3)

Entropy parameters information is shown by the formula (4):

\[ e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln(P_{ij}) \]  (4)

Finally, the Entropy weight can be calculated using equation (5):

\[ \omega_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} \]  (5)

In the above formula, \( \omega_j \) is defined as the Entropy weight of parameter j.

### 2.3.2. Entropy weighted water quality index

The first step in calculating the EWQI is to define a quality rating scale (\( q_j \)) for each parameter. \( q_j \) is calculated by the following formula:

\[ q_j = \frac{C_j}{S_j} \times 100 \]  (6)

Where:
- \( C_j \) is the concentration of each chemical parameter in each water sample in mg/L.
- \( S_j \) is the standard parameter in the National Technical Regulation on Groundwater Quality (QCVN 09-MT: 2015/BTNMT) calculated in mg/L.

The above equation ensures that if parameter \( j \) is completely absent in water then \( q_j = 0 \) and when this parameter is equal to its allowable value, then \( q_j = 100 \).

EWQI can be calculated by the formula below:

\[ EWQI = \sum_{j=1}^{n} \omega_j q_j \]  (7)

For the EWQI, groundwater is classified into five grades, from very good water quality to very poor water quality. The classification standards listed in Table 1 are referenced from international articles [2, 11, 12], because Vietnam currently has not had specific studies on the quality classification standards table.

| EWQI   | Rank | Water quality                  |
|--------|------|--------------------------------|
| <50    | I    | Excellent water quality        |
| 50-100 | II   | Good water quality            |
| 100-150| III  | Medium or average water quality|
| 150-200| IV   | Poor water quality            |
| >200   | V    | Extremely poor water quality  |
2.3.3. Geographic Information System (GIS)

The spatial distribution maps of groundwater quality parameters were prepared using ArcGIS 10.4.1 software. Distance-weighted inverse technique (IDW) is used to create spatial interpolation maps for various parameters in the spatial analysis tool.

The IDW interpolation method is a popular and easy-to-apply method, determining the unknown point values through performing the distance-weighted average of the known points of each pixel. The nearer the points are, the more affected done by the large weight value to the calculated value will be and vice versa, thereby zoning a defined radius can be used to determine the output value for each position.

After being calculated by the IDW method, the data will be superimposed through the calculator tool in GIS to give accurate seasonal zoning results in the study area.

The map of groundwater quality parameters is calculated based on parameters of pH, hardness, TDS, NH$_4^+$-N, NO$_3^-$-N, SO$_4^{2-}$, Fe$^{2+}$. The parameters are interpolated and map layers are built for each parameter, then layers are overlapped to clearly see the evolution of groundwater quality in each season.

The layers of groundwater quality parameters are superimposed by the following formula [23]:

$$ MEWQI = \Sigma MQi $$

Where, Mqi is total layers of ground water quality parameters.

The map in the study was made using ArcGIS 10.4.1 software, the Inverse Distance Weight method (IDW) was applied in the assessment study and the research area was mapped in the UTM 48N region.

3. Results and discussion

3.1. Concentration of parameter in groundwater

Descriptive statistics of the groundwater quality parameter information are shown in Table 2. The distribution of groundwater quality parameters is assessed by determining the maximum value, minimum value, median value and standard deviation of the monitoring data set including 7 parameters.

The results show the fluctuation trend of groundwater quality parameters are taken from 46 Pleistocene aquifer’s monitoring wells in the study area.

| Parameters | Unit | Dry season | Wet season |
|------------|------|------------|------------|
| pH         | -    | 2.76       | 3.44       |
|            |      | 7.76       | 7.9        |
|            |      | 5.45       | 6.23       |
|            |      | 0.98       | 1.15       |
| TH         | mg/L | 6.6        | 3.5        |
|            |      | 9125       | 9750       |
|            |      | 357.87     | 335.13     |
|            |      | 1386.93    | 1454.85    |
| TDS        | mg/L | 8.4        | 6.59       |
|            |      | 10220      | 10180      |
|            |      | 687.67     | 621.33     |
|            |      | 1758.92    | 1653.29    |
| SO$_4^{2-}$ | mg/L | 0.1        | 0.29       |
|            |      | 2853.3     | 1652.56    |
|            |      | 99.67      | 91.65      |
|            |      | 426.49     | 286.1      |
| NH$_4^+$-N | mg/L | 0.02       | 0.03       |
|            |      | 89.14      | 55.49      |
|            |      | 5.18       | 5.4        |
|            |      | 14.98      | 12.81      |
| NO$_3^-$-N | mg/L | 0.07       | 0.1        |
|            |      | 35.37      | 33.74      |
|            |      | 3.77       | 4.56       |
|            |      | 7.04       | 8.38       |
| Fe$^{2+}$  | mg/L | 0.13       | 0.04       |
|            |      | 91.3       | 134.24     |
|            |      | 9.18       | 8.38       |
|            |      | 16.33      | 21.06      |

The total dissolved solids (TDS) content of the water samples (n = 46) in the study area ranged from 8.4 to 10,220 mg/L with an average value of 687.67 mg/L and from 6.59 to 10,180 mg/L with average value 621.33 mg/L in the dry season and the wet season, respectively. The sulphate (SO$_4^{2-}$) content of water samples in the study area ranged from 0.1 to 2,853.3 mg/L with an average value of 99.67 mg/L in the dry season and from 0.29 to 1652.56 mg/L with the average value of 91.65 mg/L in the wet season.

Ammonium (NH$_4^+$-N) content of groundwater samples varied from 0.02 to 89.14 mg/L with an average value of 5.18 mg/L and 0.03 to 55.49 mg/L with an average value of 5.4 mg/L in the dry season and the wet season, respectively. Ferrous content dominates whole dry season and wet season, while NO$_3^-$-N has less concentration in both seasons (dry season and wet season).
3.2. Entropy weight
Entropy weighted method are used to analyzing 7 water quality parameters, the results shown in table 3.

In this study, the parameter weights are selected based on the Entropy information index. This means that the information data source of the parameter is effective, the weight of that parameter will be high and vice versa.

In the dry season, parameters such as pH, TDS, SO$_4^{2-}$, NH$_4^+$-N, NO$_3^-$-N and Ferrous are parameters affecting groundwater quality. Due to the Entropy weight of these parameters are higher than 0.1.

Similarly, for the wet season, the parameters of pH, SO$_4^{2-}$, NH$_4^+$-N, NO$_3^-$-N are important parameters that determine the quality of groundwater.

This weighted result is consistent with Vasanthavigar [17] that the basis of weight selection based on the importance and dominance of the parameters in the water quality dataset. In this study, the parameters of pH, TDS, SO$_4^{2-}$, NH$_4^+$-N, NO$_3^-$-N are dominant, so these parameters’s weight will be higher than the rest.

| Table 3. Entropy weights of chemical parameters |
|-----------------------------------------------|
| pH    | TH   | TDS | SO$_4^{2-}$ | NH$_4^+$-N | NO$_3^-$-N | Fe$^{2+}$ |
|--------|------|-----|-------------|------------|------------|-----------|
| Dry season | 0.17 | 0.08 | 0.12 | 0.11 | 0.14 | 0.19 | 0.18 |
| Wet season | 0.30 | 0.06 | 0.10 | 0.12 | 0.15 | 0.17 | 0.10 |

3.3. Entropy weighted water quality index
The spatial distribution from the result of preliminary interpolation of each water quality component parameters in the dry and wet seasons is visually shown in Figure 2.

![Spatial distribution of groundwater quality parameters of Pleistocene aquifer in the dry and wet seasons.](image)
Figure 2. Spatial distribution of groundwater quality parameters of Pleistocene aquifer in the dry and wet seasons (Continued).
According to the result of preliminary interpolation of each water quality component parameters. It shows that the majority of parameters tend to decrease in the wet season due to the amount of freshwater recharge to the aquifers, reducing the concentration of pollutants that affect groundwater quality.

However, the NH$_4^+$-N, NO$_3^-$-N concentration are extremely high mainly concentrated in the Northwest of the study area due to the strong agricultural activity in this area. Ammonium and Nitrate are completely dissolved in water and can move easily through the soil into your drinking water supply. Fertilizers and domestic wastes are major sources of nitrogenous compounds and they are converted to Ammonium and Nitrate in the soil.

**Table 4.** Type of waters in the dry and wet season in the study area

| Sample No. | Dry season Σ SI | Classification | Wet season Σ SI | Classification |
|------------|----------------|----------------|----------------|----------------|
| CTDT       | 1306.8         | V              | 941.03         | V              |
| LX         | 65.56          | II             | 44.85          | I              |
| DHT        | 341.79         | V              | 636.9          | V              |
| GV         | 109.59         | III            | 112.03         | III            |
| TSN        | 63.62          | II             | 72.8           | II             |
| CVBC       | 188.57         | IV             | 207.16         | V              |
| PT         | 74.62          | II             | 106.66         | III            |
| TaT        | 100.91         | III            | 84.52          | II             |
| BH         | 1007.23        | V              | 771.82         | V              |
| TPT        | 52.18          | II             | 75.82          | II             |
| TTT        | 25.11          | I              | 29.16          | I              |
| TCH        | 56.47          | II             | 189.16         | IV             |
Table 4. Type of waters in the dry and wet season in the study area (Continued)

| Sample No. | Dry season | Wet season |
|------------|------------|------------|
|            | Σ SI       | Classification | Σ SI       | Classification |
| TML        | 91.18      | II          | 51.28      | II            |
| LTM        | 50.35      | II          | 38.64      | I             |
| BM         | 110.79     | III         | 59.18      | II            |
| XTT        | 60.14      | II          | 62.13      | II            |
| VLA        | 64.07      | II          | 59.16      | II            |
| TMT        | 133.62     | III         | 159.47     | IV            |
| ANT        | 35.86      | I           | 57         | II            |
| LMX        | 579.96     | V           | 707.31     | V             |
| LH         | 305.22     | V           | 849.24     | V             |
| NB2A       | 20.3       | I           | 30.81      | I             |
| NB2B       | 16.55      | I           | 43.08      | I             |
| NB2C       | 23.53      | I           | 36.97      | I             |
| NB1A       | 17.48      | I           | 29.66      | I             |
| NB1B       | 24.94      | I           | 30.3       | I             |
| QT11       | 17.15      | I           | 26.29      | I             |
| QT5A       | 15.73      | I           | 44.2       | I             |
| QT5B       | 22.89      | I           | 38.98      | I             |
| NB3A       | 25.04      | I           | 28.98      | I             |
| NB3B       | 41.03      | I           | 30.22      | I             |
| QT7A       | 30.94      | I           | 91.34      | II            |
| QT7B       | 541.46     | V           | 96.85      | II            |
| VT4A       | 21.74      | I           | 72.79      | II            |
| VT4B       | 86.06      | II          | 40.96      | I             |
| VT6        | 76.77      | II          | 54.5       | II            |
| M7         | 98.89      | II          | 51.6       | II            |
| M8         | 41.42      | I           | 29.63      | I             |
| M11        | 58.93      | II          | 40.28      | I             |
| VT7A       | 20.38      | I           | 38.8       | I             |
| VT8A       | 67.92      | II          | 68.01      | II            |
| VT13A      | 30.02      | I           | 24.61      | I             |
| VT10A      | 99.84      | II          | 25.3       | I             |
| VT11A      | 18.08      | I           | 47.72      | I             |
| VT12A      | 57.34      | II          | 25.71      | I             |
| VT19       | 31.92      | I           | 34.77      | I             |

Entropy weighted water quality index (EWQI) is used as a technique to compute the total ratio of each groundwater quality parameter in the study area to determine the sustainability of groundwater quality. The calculation results were compared with National Technical Regulation on Groundwater Quality (QCVN 09-MT:2015/BTNMT).

The analysis and rating results of water quality are shown in Table 4 and the groundwater quality of Pleistocene partition charts in study area in both the dry and wet seasons (Figure 2) shows that EWQI fluctuates from 15.73 to 1306.8 in the dry season, its value downtrend in the wet season (24.61 to 941.03). During the dry season, 41.30% of groundwater samples represent “Excellent water quality”, 34.78% shows “Good water quality”, 10.87% of wells are “Medium water quality” to “Poor water quality” and 13.04% of wells are “Extremely poor water quality” of the total number of monitoring wells in the study area. During the wet season, 47.83% of monitoring wells are “Excellent water quality”, 30.43% shows “Good water quality”, 8.7% indicates the total of “Medium water quality” and “Poor water quality” and “Extremely poor water quality” accounts for 13.04% of the total number of monitoring wells. Groundwater quality of wells in the wet season is significantly improved, wells from
“Good” and “Excellent” quality of groundwater accounts for 76.09% and 78.26% in the dry and the wet season, respectively. Ammonium concentration is still relatively high because it influenced by agricultural activities taking place around the monitoring area, wells located near industrial crops are affected by organic matter from food residues during the cultivation process. But it has declined compared to the dry season. This may be due to the fact that in the wet season, dilution phenomenon causes the Ammonium concentration to decline, the wells with high this anion content in the dry season also return to “average water quality” level. However, soft water was recharged into the aquifers with high intensity in a certain period of time increases amount of Ferrous and Nitrate in water.

Figure 3. Entropy weighted water quality index (EWQI) map in the dry season

Figure 4. Entropy weighted water quality index (EWQI) map in the wet season

Figure 3 shows that in the dry season, quality of groundwater from “Good” to “Excellent” are 34.3% (962.46 km$^2$) of the total study area, which mostly exists in the coastal of Ba Ria - Vung Tau province.
“Medium” quality of groundwater appropriations 25.25% (708.52 km²), quality from “Poor” to “Extremely poor” of groundwater accounts for the majority in study area with 40.45%, mainly concentrated in the Ho Chi Minh City area with 1135.02 km².

Corresponding with the EWQI map in the wet season (Figure 4), the study area of Ba Ria – Vung Tau province shows that the area with “Excellent” and “Good” quality of groundwater accounts for 37.72% of the area with 1058.43 km². The groundwater quality categories “Medium water quality”, “Poor water quality” and “Extremely poor water quality” accounts for 15.58% (437.17 km²), 20.6% (578.04 km²) and 26.1% (732.37 km²) of the total study area, respectively. The area with “Extremely poor” quality of groundwater is narrowed and the area with "Excellent water quality" and "Good water quality" has been expanded due to the amount of fresh water recharged to the aquifers.

4. Conclusion
The GIS-based water quality index calculation technique is used in this study as a tool to evaluate and visually partition the rank of groundwater quality pollution, helping managers to understand in Pleistocene aquifer quality in this study area. Then, proposes solutions for sustainable management of water resources in the region.

The Entropy weight result shows that the parameters of pH, NH₄⁺-N, NO₃⁻-N were the main parameters affecting quality of groundwater in the study area. Groundwater quality in the area is divided into five main categories. In which, the water quality reached “Excellent water quality”, accounting for over 75% of wells in both dry and rainy seasons, concentrated in the coastal area of Ba Ria - Vung Tau province. Only 13% of wells have "Extremely poor water quality" quality out of 46 wells in the study area, mainly distributed in Ho Chi Minh City.

Correspondingly, the EWQI map shows that good quality of groundwater accounts for 34.3% with 962.46 km² and 37.72% with 1058.43 km² of the study area in the dry and the wet season, respectively.

Date Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of interest
The authors declare that they have no conflicts of interest.

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References
[1] Li P, Wu J, and Qian H 2010 Groundwater quality assessment based on entropy weighted osculating value method International Journal of Environmental Sciences 1 (4) 621-630
[2] Gorgij A D, Kisi O, Moghaddam A A, and Taghipour A 2017 Groundwater quality ranking for drinking purposes, using the entropy method and the spatial autocorrelation index Environmental earth sciences 76 (7) 269
[3] Berry J, Steffy L, and Shank M J M 2019 Development of a Water Quality Index (WQI) for the Susquehanna River Basin
[4] Desai B and Desai H 2012 Assessment of water quality index for the ground water with respect to saltwater intrusion at coastal region of Surat city, Gujarat, India Journal of Environmental Research and Development 7 (2) 607-621.
[5] Varol S and Davraz A 2015 Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey) Environmental Earth Sciences 73 (4) 1725-1744
[6] Bodrud-Doza M, Islam A T, Ahmed F, Das S, Saha N, and Rahman M S 2016 Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh Water Science 30 (1) 19-40

[7] Emrouznejad A and Marra M 2017 The state of the art development of AHP (1979–2017): a literature review with a social network analysis International Journal of Production Research 55 (22) 6653-6675

[8] Sutadian A D, Muttil N, Yilmaz A G, and Perera B 2017 Using the Analytic Hierarchy Process to identify parameter weights for developing a water quality index Ecological Indicators 75 220-233

[9] Chakraborty S and Kumar R N 2016 Assessment of groundwater quality at a MSW landfill site using standard and AHP based water quality index: a case study from Ranchi, Jharkhand, India Environmental Monitoring and Assessment 188 (6) 335-341.

[10] Minh H V T, Avtar R, Kumar P, Tran D Q, Ty T V, Behera H C, and Kurasaki M 2019 Groundwater Quality Assessment Using Fuzzy-AHP in An Giang Province of Vietnam Geosciences 9 (8) 330

[11] Amiri V, Rezaei M, and Sohrabi N 2014 Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran Environmental Earth Sciences 72 (9) 3479-3490.

[12] Jianhua W, Peiyue L, and Hui Q 2011 Groundwater quality in Jingyuan County, a semi-humid area in Northwest China E-Journal of Chemistry 8 (2) 787-793

[13] Kangabam R D, Bhoominathan S D, Kanagaraj S, and Govindaraju M 2017 Development of a water quality index (WQI) for the Loktak Lake in India Applied Water Science 7 (6) 2907-2918

[14] Shannon C E 1948 A mathematical theory of communication Bell system technical journal 27 (3) 379-423

[15] Yan H and Zou Z 2014 Water quality evaluation based on entropy coefficient and blind number theory measure model Journal of Networks 9 (7) 1868 -1874

[16] Dung B X, Quynh K T, Linh N T M, and Phuc D T T 2019 Water quality and residuals of nitrate-nitrite in some vegetable planted in cemetery at Thanh Tri district, Hanoi, Vietnam Journal of Forestry Science and Technology

[17] Nguyen A H, Hoang T N, Pham N T T, Tat V H M, Phan N N H, and Nguyen Q K 2018 Application of groundwater quality index (GWQI) and principle component analysis (PCA) to assess the groundwater quality of Pleistocene aquifer in Tan Thanh district, Ba Ria–Vung Tau province Science & Technology Development Journal-Science of The Earth & Environment 2 (2) 107-115

[18] Hai Đ H, Ky N V, Vuong B T, and Sang T T 2016 Assessment of groundwater quality of middle – Upper Pleistocene aquifer in Ca Mau peninsula Science and Technology Development 19 (1K) 35-44

[19] El-Rawy M, Ismail E, and Abdalla O 2019 Assessment of groundwater quality using GIS, hydrogeochemistry, and factor statistical analysis in Qena governorate, Egypt Desalination and Water Treatment 162 14-29

[20] Adimalla N and Taloor A K 2020 Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using Geographic Information System (GIS) and groundwater quality index (GWQI) techniques Groundwater for Sustainable Development 10 100288 - 100308

[21] Mehra M, Oinam B, and Singh C K 2016 Integrated Assessment of Groundwater for Agricultural Use in Mewat District of Haryana, India Using Geographical Information System (GIS) Journal of the Indian Society of Remote Sensing 44 (5) 747-758

[22] Honarbakhsh A, Tahmoures M, Tashayo B, Mousazadeh M, Ingram B, and Ostvari Y 2019 GIS-based assessment of groundwater quality for drinking purpose in northern part of Fars province, Marvdasht Journal of Water Supply: Research and Technology-Aqua 68 (3) 187-196
[23] B A E, Huag T, E H A, Zhao J, K M E, Abbass W, and M M B 2019 Geospatial Distributions of Groundwater Quality in Gedaref State Using Geographic Information System (GIS) and Drinking Water Quality Index (DWQI) Int J Environ Res Public Health 16 (5) 731-751

[24] Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, Ganthi R R, Chidambaram S, Anandhan P, Manivannan R, and Vasudevan S 2010 Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India Environmental Monitoring and Assessment 171 (1-4) 595-609