# WATER QUALITY ASSESSMENT AND INTEGRATED SOLUTIONS FOR SUSTAINABLE WATER RESOURCES MANAGEMENT IN SOC TRANG PROVINCE

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**Abstract:** *This work aims to assess water resources for domestic and irrigation purposes in coastal areas of Soc Trang province- one of the most vulnerable regions in the Mekong Delta to climate change and sea level rise, especially along the coastal areas where is severely affecting by seawater intrusion. The water quality index (WQI) and variable irrigation water quality indexes (IWQIs) such as sodium adsorption ratio (SAR), Kelly's ratio (KR), residual sodium carbonate (RSC), solute sodium percentage (SSP) and permeability index (PI) were deployed to evaluate water quality regarding domestic and agricultural water demands. Totally, 142 water samples were taken by seasonal characteristics and tidal regime in 2013 and 2014, and analyzed for the calculation of WQI and IWQIs. The results show that, most of the groundwater samples at shallow aquifers, some of the deeper aquifers and river water samples in dry season were seriously affected by seawater intrusion and nitrate contamination. Meanwhile, most of the groundwater samples at middle and lower Pleistocene aquifers and surface water in rainy season seem to be good for both drinking and irrigation. However, the groundwater source in Soc Trang province has been excessively extracted without suitable regulation and appropriate management. This situation may threat the groundwater source because it can be easily contaminated by seawater intrusion and wastewater. In order to effectively extract, use and manage the fresh water source in coastal areas in the Mekong delta, emergent management practices should be considered.*

**Keywords:** Water quality assessment, Soc Trang province, Mekong Delta

## 1. INTRODUCTION

Water plays an extremely important role for human's life and ecosystems on the planet. And ensuring water quality for drinking and irrigation is a big challenge in the context of water resources deterioration due to negative effects of anthropogenic activities and climate change (UN-Water, 2010). Monitoring and evaluating water quality are needed to understand water resources status and consider relevant solution for sustainable use and effective management. Practically, however, monitoring system provides us a large and complex water quality data while the reviewers who would access these data are variable, including managers, policy makers and publics (Saffran et al., 2001). Therefore, the overall water quality index that comprises main water parameters to assess water quality for drinking and irrigation purposes have been developed and globally applied as well-known water quality index (WQI), (GEMS, 2007; Tyagi et al., 2013) and irrigation water quality indexes (IWQIs) such as sodium adsorption ratio (SAR), Kelly's ratio (KR), residual sodium carbonate (RSC), solute sodium percentage (SSP) and permeability index (PI). Although, these water quality indexes have been widely applied in

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many countries in the world, the application of these water quality indexes in assessing water resources quality in Vietnam is still limitation. Therefore, this paper intends to make clear understanding on water quality in coastal areas of the Mekong Delta.

Mekong Delta is the most important delta in Vietnam where contributing more than 60% of agricultural production of the country and accounting for more than 53% of national rice production (Mart A. Stewart, Peter A. Coclanis, 2011). In the Mekong Delta, surface water and groundwater contribute significant benefits to socio-economic development (Ghassemi.F and Brennan.D, 2000). However, water quality, especially surface water has been increasingly deteriorated due to human activities (Toan et al., 2013), seawater intrusion (Nguyen et al., 2012). Consequently, groundwater source has been excessively extracted and seriously threaten by seawater intrusion directly from East Sea, saline diffusion (IUCN, 2011; Wagner et al., 2010) and arsenic contamination (Laura E. Erbana et al., 2013). These affect not only on groundwater uses at present but also for future sustainability of water use in the Mekong Delta, especially in coastal regions.

In Soc Trang province, the coastal region of Mekong Delta, surface water is strongly affected by seawater. Thus, groundwater has become a preliminary fresh water source for domestic, industrial and agricultural activities. However, because of locating in coastal areas, groundwater source in Soc Trang province is highly vulnerable than other parts of the Mekong Delta due to the effects of over groundwater extraction, human wastes and waste water, seawater intrusion, acid sulfate soils dissolution. Therefore, the assessment of both surface water and groundwater quality is a vital concern for sustainable use and effective management of water resources.

## 2. STYDY AREA

This study was carried out in Soc Trang province, a coastal region of the Mekong Delta, Vietnam. The province is located in the lower reach of the Mekong River. It covers an area of 2311.76 $km^2$, approximately 0.7% and 5.9 % areas of Vietnam and Mekong Delta, respectively with average population of 1,308,300 people (VGSO, 2013).

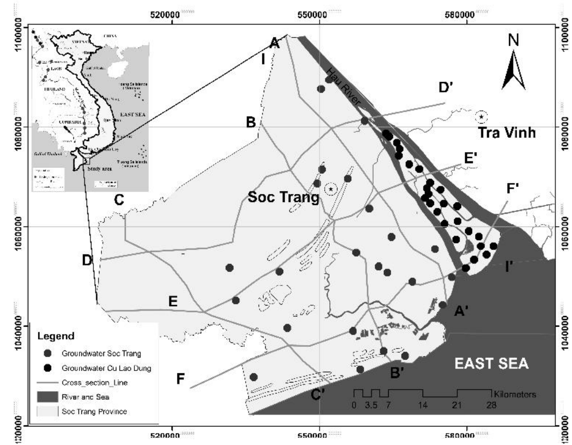


*Fig 1. Location of Soc Trang province, Vietnam*

Soc Trang province falls in strong tropical monsoon activity region with two different seasons; the dry and the rainy seasons. In the wet season, the province is strongly affected by the Southwest Monsoon, which brings more than 85% amount of rainfall annually, high temperatures and high humidity. Meanwhile, the Northeast Monsoon dominates in the dry season from November until April, receiving dry air with hardly rainfall (15% of the annual rainfall), lower temperature and lower humidity. The average annual air temperature in Soc Trang province is 26.8°C with over 28°C in the warmest months (April and May) and the lowest mean monthly temperature in January is 24.6°C; average annual relative humidity of 84%; and annual precipitation of 1,772 mm with lack of rain from January to April annually (MIST, 2013). Because topography is relatively low, around 0.5 to 2.5 m above mean sea levels, coupled with facing directly with East Sea and the Hau river (Bassac River). Soc Trang province is frequently influenced by inflow from upstream, flooding and river-marine dynamic interactions such as tidal regime, sea wave, sediment transportation and deposition as well as riverbank erosion. These factors can affect significantly on water quality in the province.

## 3. MATERIALS AND METHODS

The field investigation and sampling of river, canal and groundwater (Fig.1), were performed in dry and rainy seasons between 2013 and 2014. Totally, 142 water samples were stored in 100ml bottles, including 101 groundwater and 41 surface water samples. Groundwater samples were collected from private tube-wells at seven aquifers, including Holocene (qh),upper Pleistocene (qh3), middle Pleistocene (qp23), lower Pleistocene (qp1), middle Pliocene (n22), lower Pliocene (n21) and Miocene (n13) in Soc Trang province (as shown in Figure 2) with the depth of wells ranges from 4.5 m to 480m under land surface. Surface water samples were taken along the Hau river and its tributaries at Soc Trang province. The pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total dissolved solids (TDS) were on-site measured using portable meters. Meanwhile, main ion compositions including major cations ($Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$) and major anions ($Cl^-$, $SO_4^{2-}$, $NO_3^-$, $HCO_3^-$) were analyzed at University of Tsukuba, Japan.

The results of hydrochemistry as shown in Table 1, were used to calculated WQI and irrigation water quality indexes (SAR, KR, RSC, SSP, PI) in order to understand acceptable water quality for drinking and irrigation purposes.

## 4. RESULTS AND DISCUSSION

### 4.1 Water quality for drinking

Water quality index (WQI) was widely used as a very useful tool to evaluate water quality servicing for drinking purpose (Jagadeeswari and Ramesh, 2012; Tyagi et al., 2013). WQI is defined as a rating reflecting the composite influence of different water parameters (Sahu and Sikdar, 2008). Calculating WQI based upon perspective of suitability of water sources for human consumption via three steps. In the first step, each of the chemical parameter was assigned a weight ($w_i$), based on its perceived effects on human health. The highest weight of five was assigned to parameters, which have the major effects on water quality. In this area, nitrate concentration ($NO_3^-$) was assigned the highest weight because of its importance to water quality assessment. The second step involves in computing the relative weight of each parameter via using the equation Eq. [1] as below:

$$W_i = \frac{w_i}{\sum w_i} \quad (1)$$

where, $\sum w_i$ is the sum of the weights of all parameters. In this research, $\sum w_i$ were 31. Table 3 shows the $w_i$, $W_i$ and WHO standard for each chemical composition in this study. In the third step, a quality rating scale ($q_i$) was computed for each parameter using the equation Eq. [2], given below:

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

where, $C_i$ and $S_i$, respectively present the concentration and the WHO standard for each parameter, in mg/L. The water quality sub index, $SI_i$ of each parameter was calculated by using equation Eq. [3], given below:

$$SI_i = W_i \times q_i \quad (3)$$

Eventually, WQI is calculated by summing ten sub-indexes ($SI_i$) of each water sample, as described in Eq. [4] below:

$$WQI = \sum SI_i \quad (4)$$

The desirable value is less than 100 that demonstrates water can be used for domestic and industrial purposes.

In general, the groundwater quality in all aquifers is stable between rainy and dry season which demonstrates that groundwater quality may not be influenced by seasonal characteristics. The WQI values of surface water and groundwater in this study were presented in Table 2, showing different tendencies. The WQI values of groundwater samples vary largely, ranging from 22.27 to 2319.25 with coefficient of variation of 217.04%, indicating the different water quality between aquifers. The WQI values of surface water demonstrate distinctly changes between rainy and dry seasons. In the dry season, despite of seawater intrusion effects, the WQI values of surface water were higher than that of values in the rainy season with average of 534.93 and 88.77, respectively. Groundwater samples at Holocene (qh) and upper Pleistocene (qh3) aquifers show very poor water quality and cannot use for drinking purpose and approximately 30% - 40% groundwater samples at deeper aquifers (Pliocene, Miocene) can use for that purpose. Most of groundwater samples at middle and lower Pleistocene aquifers present good quality and are favorite aquifers for extracting to meet the demand of fresh water in coastal areas of Soc Trang province. Surface water shows very different quality between dry and rainy seasons. In the dry season, 95.24% of surface water samples cannot use for human consumption due to seawater intrusion, however in the rainy season 75% of surface water samples can be used for drinking purpose, excepting some areas along the coast despite of effect of salinity. Notably, although surface water can be used in the rainy season, it should be carefully considered for human use because of being contaminated by wastes and wastewater from human activities via runoffs.

**4.2 Water quality for irrigation**

Despite of salt intrusion, surface water quality in Soc Trang province changes significantly between the dry and rainy seasons, especially in coastal areas. Meanwhile, groundwater has been intensively exploited for both domestic and irrigation purposes. Therefore, assessing water quality of both surface and groundwater provides useful information for balancing between usage and extraction water resources in coastal areas. Similar to other coastal areas of the Mekong Delta, the province's groundwater plays an important role to agricultural activities such as onion, legume, and sugarcane cultivation household consumption. It is estimated that more than 85% of water for agricultural water in coastal areas such as Tran De, Vinh Chau some parts of Cu Lao Dung and

Long Phu districts, depends on groundwater resource. River and canal water can use for irrigation in other parts of Soc Trang province where are not affected by seawater intrusion . In order to evaluate water quality for irrigation purposes, variable indicators including sodium adsorption ratio (SAR), Kelly's ratio (KR), residual sodium carbonate (RSC), solute sodium percentage (SSP) and permeability index (PI) were calculated. The sodium absorption ratio (SAR) for surface and groundwater was estimated as the given equation Eq [5] below:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (5)$$

Where,

$Na^+$, $Ca^{2+}$ and $Mg^{2+}$ are solute concentrations of sodium, calcite and magnesium in meq/L.

The water samples having SAR values less than 10 are categorized excellent water quality, from 10 to 18 as good, from 18 to 26 as fair and above 26 are unsuitable for irrigation use (USDA, 1954). The Kelley's ratio was calculated by using the following expression.

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (6)$$

where,

$Na^+$, $Ca^{2+}$ and $Mg^{2+}$ are solute concentrations of sodium, calcite and magnesium in meq/L.

The Kelley's ratio of unity or less than one indicates good water quality for irrigation, while above one is unsuitable for agricultural purpose because of alkaline hazards (Karanth, 1987). The residual sodium carbonate (RCS) is determined by using the equation (Eq.[7]) below.

$$RCS = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (7)$$

where, the concentration of ions are expressed in meq/L.

According to USDA (1954), RCS less than 1.25 meq/L, the water source is safe for irrigation, RCS ranges from 1.25 to 2.5 meq/L, indicating quite suitability, while RCS exceeds 2.5 meq/L, the water is generally unsuitable for irrigation. Since 1955, Wilcox proposed classification scheme for rating water irrigation on the basis of soluble sodium percentage (SSP). The SSP was calculated by using the following formulate:

$$SSP = \frac{Na^+ \times 100}{Ca^{2+} + Mg^{2+} + Na^+} \quad (8)$$

Where,

$Na^+$, $Ca^{2+}$ and $Mg^{2+}$ are solute concentrations of sodium, calcite and magnesium in meq/L.

The values of SSP less than 50 reveal good quality of water for irrigation whilst higher values (above 50) are unsuitable for agriculture (USDA, 1954). The permeability index is computed by using equation Eq. [9] below:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \qquad (9)$$

Where, solute concentrations are expressed in meq/L.

The PI values more than 75 illustrate excellent quality of water for irrigation, while the PI values are between 25 and 75, indicating good quality of water. However, the PI values are less than 25, reflecting unsuitable water source for irrigation purpose.

The results of water quality assessment of both surface and groundwater for irrigation purpose are presented in Table 2. It is clearly demonstrated that water quality for irrigation practices in this area varies widely depending on seasons and types of aquifers. About 60% of surface water samples in the wet weather from June to December can be used for irrigation, excepting some areas close to the coast, while in the dry season just only 4.76% of surface water in northwestern parts of Ke Sach, Cu Lao Dung Island and Long Phu districts can be met irrigation. This shows strong effects of seasonal seawater intrusion in the coastal river system. Unlikely, groundwater quality depends significantly on features of aquifers. Most groundwater samples of Holocene (qh), upper Pleistocene (qh3), some of middle and lower Pliocene (n22. n21) and Miocene (n13) aquifers cannot use for irrigation, while almost groundwater samples of middle and lower Pleistocene (qp23, qp1) aquifers are good quality for both drinking and irrigation purposes, spelling the reason for these aquifers have been intensively pumped for those purposes, resulting in rapid groundwater drawdown of the large scale of the province.

Furthermore, Wilcox diagram as shown Fig 2 was deployed to classify water quality for irrigation. It can seen clearly that almost groundwater at middle and lower Pleistocene (qp23, qp1) aquifers and surface water in the rainy season fall in the categories C1-S1 (Low salinity and low SAR), C2-S1 (medium salinity and low SAR) that can be used for irrigation purposes while almost groundwater of Holocene (qh), upper Pleistocene (qh3) and surface water in the dry season were characterized by C3-S1 (high salinity and low SAR), C4-S3 (very high salinity and high SAR) and C4-S4 (very high both salinity and SAR) that cannot use for irrigation. Remained groundwater samples of Pliocene (n22, n21) and Miocene (n13) aquifers were ranged between C3-S3 (high salinity and high SAR) and C3-S4 (high salinity and very high SAR) groups that also are unsuitable for irrigation.

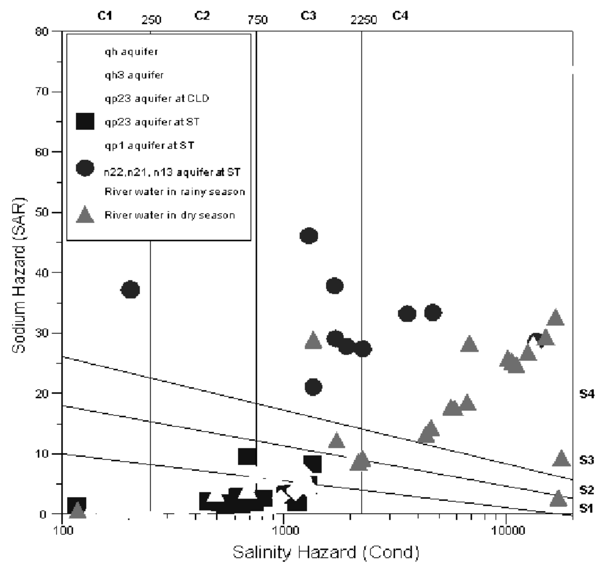


*Fig 2. Wilcox diagram of water classification for irrigation*

## 5. CONCLUSIONS AND RECOMMENT DATIONS

### 5.1. Conclusion

Water resources along coastal areas of the Mekong Delta are facing with serious environment pressures, mainly because of seawater intrusion and anthropogenic activities. Major findings of this study are as follows.

(i) The quality of surface water shows seasonal variation and strongly influenced by seawater intrusion, anthropogenic effects, while that of groundwater represents stable trend and groundwater quality depends significantly on hydro-geological processes. (ii) Groundwater at Pleistocene aquifer is good for both drinking and irrigation purposes, however some parts close to estuaries seem to be increasingly affected by seawater intrusion due to intensive groundwater extraction. (iii) The results of WQI and IWQIs indicate that surface water and groundwater at shallow (Holocene) and some parts of deeper (Pliocene and Miocene) aquifers are unsuitable for drinking and irrigation of both dry and rainy seasons. Thus, in order to extract, use and manage sustainably fresh water source in coastal areas in the Mekong delta, integrated water resources management practices should be urgently considered.

**Table 2. Results of water quality assessment for drinking and irrigation purposes**

| Indexes | Range values | Aquifers: Shallow -> Deep aquifers | | | | | | River water | |
|---|---|---|---|---|---|---|---|---|---|
| | | qh | qh3 | qp23 CLD | qp23 ST | qp1 | n13 | Dry season | Rainy season |
| WQI | Max | 1665.52 | 2319.25 | 1665.52 | 135.97 | 441.18 | 895.00 | 1415.58 | 743.99 |
| | Mean | 888.29 | 1413.40 | 888.29 | 72.00 | 129.25 | 254.93 | 534.93 | 88.77 |
| | Min | 111.06 | 227.65 | 111.06 | 22.27 | 60.37 | 80.35 | 31.53 | 24.02 |
| | Desirable value | | | | | | | | **< 100.0** |
| **Drinking** | **Percent. A.V** | **0.00** | **0.00** | **98.15** | **90.48** | **40.00** | **30.00** | **4.76** | **75.00** |
| SAR | Max | 73.72 | 39.29 | 73.72 | 9.59 | 30.77 | 46.17 | 38.71 | 28.19 |
| | Mean | 40.07 | 26.65 | 40.07 | 2.98 | 7.70 | 32.18 | 20.12 | 4.30 |
| | Min | 1.77 | 1.57 | 1.77 | 0.48 | 0.77 | 3.42 | 0.62 | 0.37 |
| | Acceptable value | | | | | | | | **< 26.0** |
| KR | Max | 7.32 | 3.84 | 7.32 | 3.90 | 5.79 | 58.55 | 4.07 | 3.47 |
| | Mean | 4.55 | 2.42 | 4.55 | 1.11 | 2.37 | 24.31 | 3.25 | 1.29 |
| | Min | 1.77 | 1.57 | 1.77 | 0.48 | 0.77 | 3.42 | 0.33 | 0.26 |
| | Acceptable value | | | | | | | | **< 1.0** |
| RSC | Max | 47.47 | 146.30 | 47.47 | 4.34 | 10.82 | 41.11 | 58.42 | 30.90 |
| | Mean | 24.58 | 86.69 | 24.58 | 1.44 | 3.52 | 15.74 | 19.24 | 2.58 |
| | Min | 1.69 | 5.12 | 1.69 | 0.14 | 0.31 | 8.62 | 0.27 | 0.02 |
| | Acceptable value | | | | | | | | **<2.5** |
| SSP | Max | 87.98 | 79.36 | 87.98 | 79.57 | 85.27 | 98.32 | 80.28 | 77.63 |
| | Mean | 75.97 | 69.08 | 75.97 | 48.45 | 64.21 | 92.48 | 74.46 | 46.38 |
| | Min | 63.95 | 61.07 | 63.95 | 32.61 | 43.54 | 77.37 | 24.89 | 20.60 |
| | Acceptable value | | | | | | | | **<50** |
| PI | Max | 30.52 | 22.72 | 30.52 | 95.14 | 53.51 | 44.63 | 57.81 | 91.60 |
| | Mean | 25.59 | 17.56 | 25.59 | 43.44 | 36.30 | 35.12 | 23.69 | 54.68 |
| | Min | 20.66 | 15.02 | 20.66 | 23.44 | 21.51 | 18.35 | 18.39 | 18.83 |
| | Acceptable value | | | | | | | | **>25** |
| **Irrigation** | **Percent. A.V** | **0.00** | **0.00** | **92.59** | **57.14** | **0.00** | **0.00** | **4.76** | **60.00** |

Note: Percent.A.V: The percentage of acceptable values in comparison with standard values for drinking and irrigation.

**5.2. Recommendation for sustainable water management**

As mention above, increasing excessive extraction and salinization of groundwater in Soc Trang province requires an adequate response in frame of new water management strategies from responsible authorities. In addition to this, despite of locating in coastal areas of the Mekong Delta, water resources in this province are facing with many serious problems mainly because of reducing water flow into the Mekong Delta due to Hydropower plants operation and unsustainable water uses in the upstream of the Mekong River Basin while unpredictable effects of climate change and sea levels rise are likely affected on this region. Thus, in order to implement the sustainable water management in the coastal region of the Mekong Delta we should consider integrated solutions:

**i. Controlling water extraction:**

Continuously updated information about the water extraction status is crucial for managing water resources. This comprises not only governmental (communal) water extraction, but also extraction wells for industrial, agro- and aquaculture purpose as well as an assessment about the decentralized extraction from private households.

**ii. Water registration and extraction licensing:**

The national decrees, guidelines about water registration and extraction licensing measures must be realized consequently and transparently. Stronger criteria are recommended for future extraction well licenses in the area of central and East of Soc Trang where groundwater levels are rapidly depleted and widely saline depression, such as water use only for human consumption and irrigation purpose.

**iii. Reducing extraction:**

In this coastal region of the Mekong Delta, surface water cannot use for any purpose due to seawater intrusion and water pollution, whereas groundwater has been excessively exploitation for domestic, industrial and irrigation purposes. However, availability of high quality groundwater is a limited national reserve and, therefore, it should be kept for drinking water purposes. Besides that, it is crucial to retreated all unusable private well in this province to prevent groundwater contaminations.

**iv. Conjunctive usage**:

Mixing of high quality water with poorer quality water may extend the available amount of water with still acceptable quality for water supply. This should be understood as an intermediate action while realizing the recommendations above.

**v. Water resources monitoring:**

Water monitoring plan need to be established including funding for continuous monitoring of groundwater quality and quantity. Data collection and analysis must be carried out by technical experts with sufficient hydrogeological background. The current national & provincial monitoring efforts must be synchronized and data exchange to the provincial level improved.

**5.3. Future study**

Assessment of water resources for sustainable socio-economic development in Soc Trang in particular and in the Mekong Delta in general is a crucial issue. In order to archive this target, the further research is needed to evaluate both quality and quantity in comparison with water demand in this region based on multi-scenarios socio-economic development and climate change.

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**Tóm tắt:**

**ĐÁNH GIÁ CHẤT LƯỢNG NƯỚC VÀ GIẢI PHÁP TỔNG HỢP QUẢN LÝ BỀN VỮNG TÀI NGUYÊN NƯỚC TỈNH SÓC TRĂNG**

*Chỉ số đánh giá chất lượng nguồn nước cấp cho sinh hoạt (WQI) và các chỉ số liên quan đến chất lượng nguồn nước tưới (IWQs) như chỉ số hấp phụ Natri (SAR), tỷ số Kelly (KR), chỉ số dư hàm lượng Natri carbonate (RSC), hàm lượng hòa tan Natri (SSP) và chỉ số khả năng thấm (PI) là các chỉ tiêu quan trọng nhằm đánh giá chất lượng nguồn nước cấp cho sinh hoạt và phục vụ tưới cho các loại cây trồng. Kết quả nghiên cứu cho thất rằng, 92.5% nguồn nước ngầm tại hầu hết các khu vực tỉnh Sóc Trăng nằm ở các tầng trung và hạ Pleistocene, và một số khu vực thuộc tầng Pliocene và Miocene có thể đáp ứng chất lượng nước phục vụ ăn uống, sinh hoạt và tưới cho cây trồng. Trong khi đó, các tầng chứa nước có nồng độ muối cao, các chỉ số chất lượng nước phục vụ cho tưới tiêu không đạt yêu cầu. Ngoài ra, vào mùa khô chỉ có khoảng 4.67% nguồn nước mặt có thể sử dụng cho cấp nước, trong khi đó vào mùa mưa có thể tận dụng 60% nguồn nước mặt phục vụ các mục đích cấp nước sinh hoạt và tưới. Dựa trên các kết quả nghiên cứu này, các giải pháp tổng hợp về quản lý, khai thác và sử dụng bền vững tài nguyên nước khu vực tỉnh Sóc Trăng nói riêng và vùng ven biển ĐBSCL nói chung đã được đề xuất bao gồm các giải pháp quản lý khai thác nước ngầm, nước mặt, kết hợp sử dụng đa dạng các nguồn nước khác nhau tại vùng ven biển gồm nước ngầm, nước mặt nước mưa... phục vụ cho phát triển kinh tế xã hội và bảo vệ môi trường.*

**Từ khóa:** Đánh giá chất lượng nước, tỉnh Sóc Trăng, Đồng bằng sông Cửu Long.

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