Identification of freshwater - saltwater interface in coastal areas using combination of geophysical and geochemical methods: A case study in Mekong Delta, Vietnam

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Abstract. Saltwater intrusion is widely observed in coastal aquifers because fresh groundwater is over exploited and abstraction wells were installed too close to saltwater intrusion zone. Identification of salt/fresh groundwater interface is important for fresh groundwater protection. This study presents an application of combination groundwater investigation methods including vertical electric sounding (VES), geochemistry and geographic information system (GIS) tools for delineation of salt/fresh groundwater interface in Mekong Delta. Twenty-seven groundwater samples are collected in existing wells for chemical analysis. Vertical electric sounding (VES) method was conducted for 37 sites to delineate freshwater zone (TDS <1g/L) and saline groundwater zone (TDS>1 g/L). Two new wells are also installed after VES measurement for groundwater sampling. Result of geochemical analysis show that TDS values of groundwater samples range from 0.25 g/L to 1.3 g/L and Cl from 8.8 to 758.6 mg/L. Electrical resistivity values range from 2 to 18.4 $\Omega$m. The electrical resistivity values less than 10.4 $\Omega$m is well correlated to saline groundwater. The study shows that even though VES can be an effective tool for identification of fresh/saline groundwater distribution, the method could not identify the saltwater intrusion zone. Combination of geochemical and GIS methods can clearly delineate saltwater intrusion zone. The study results show that fresh groundwater is limited in a small area of upper-middle Pleistocene aquifers. The fresh groundwater is highly affected by salinization. Therefore, the area urgently needs to take proper measures for sustainable groundwater development.

Keywords: Groundwater, Saltwater intrusion, Vertical Electric resistivity, HFE-diagram, Mekong Delta
1. Introduction
Saline groundwaters are widely observed in coastal aquifers. The saline groundwater can be trapped in those aquifer materials for many thousand years during aquifer formation or recently intruded due to infiltration of seawater. Because hydrogeology condition varies according depth and location, the distribution of saline groundwater is complicated and coexist with fresh groundwaters in coastal aquifer system. Abstraction of fresh groundwater in those aquifers will cause of saltwater intrusion problems. Therefore, identification of saltwater intrusion zone is important for sustainable groundwater management.

Groundwater geochemical investigation, geophysics are traditional methods to apply for groundwater exploration [1]. Each method will have both advantages and disadvantages. For examples, analysis of groundwater chemistry will provide information of groundwater quality of the target aquifers; however, the method needs to have sufficient wells available or installation of new wells for collect sufficient samples. Installation of new well is expensive and time-consuming process. Electrical resistivities measurement is alternative method for groundwater sampling, the advantage of electrical resistivities measurement is cheap and quickly get information of groundwater potential area and salt/fresh groundwater zone [2,3]. However, electrical resistivities values are controlled by many factors such as water conductivity, aquifer material properties, pore, and measurement depth. Therefore, result of the method contains some uncertainties. Moreover, the geophysical method could not identify saline groundwater intrusion or freshening groundwater zone [2]. Therefore, combination of those method will provide an effective tool for groundwater exploration and groundwater protection.

Groundwater is important for water supply Vietnamese Mekong Delta (MVD) due to saline water intrusion and contamination of surface water [4]. However, distribution of saline groundwaters are widely observed in the MVD aquifers [5]. Over exploitation of fresh groundwater is causing groundwater level decline and saltwater intrusion in some part of the area. To protect saltwater intrusion problem, Vietnamese government have been investing a lot for identification of salt groundwater zone. The government also create some regulation for restriction of groundwater abstraction, for instance, groundwater exploration and exploitation are not allowed in the saltwater intrusion zone and in the area located within 1000 m from TDS > 1.5 g/L zone for avoiding saltwater intrusion [6]. However, whether the zone 1000 m from the groundwater TDS>1.5 g/L zone is appropriated for avoiding saltwater intrusion is not clear. The study aims to provide saltwater intrusion zone in coastal area for sustainable groundwater development by combination of multiple groundwater investigation methods.

2. Study area
The study area is located in Soc Trang province, a coastal area of Vietnamese Mekong Delta (MVD). This province is an active tropical monsoon region with annual precipitation of 1,772 mm and two distinguish seasons, the dry and rainy seasons. In the rainy season, climate condition is strongly affected by the Southwest Monsoon, which brings more than 85% amount of annual rainfall. The Northeast Monsoon is dominant in the dry season from November until April, contributing to 15% of the annual rainfall with a relatively low temperature and humidity. As a relatively lowland region (0.5 - 2.5 m above the mean sea level) and bordering with the Vietnamese East Sea, the hydrological regime in the VMD is regulated by upstream discharge, local rainfall and river-marine dynamic interactions. These factors remarkably affect the water quality of both surface water and groundwater sources in this region. Surface water quality are highly contaminated by seawater intrusion and pollutants from anthropogenic activities; therefore, groundwater is preferred by local people for domestic and industrial demand [7].
The geology and geomorphology in Soc Trang province were a part of southern Vietnam geological system and formed by the glacial-eustatic sea-level change and the ongoing tectonic activities [5]. According to a research of Division for Water Resources Planning and Investigation for the south of Vietnam (DWRPIS) [8], the sediment layer in southern Vietnam is classified into seven distinct confined aquifers namely Holocene (qh), Upper Pleistocene (qp3), Upper-Middle Pleistocene (qp23), Lower Pleistocene (qp1), Middle Pliocene (n23), Lower Pliocene (n21), Upper Miocene (n13). Groundwater in Holocene, upper Pleistocene aquifers are mostly saline, therefore, local people are abstracting groundwater in the qp23 aquifers. The aquifer depth ranges from 110 to 140 m below surface [7]. Saline groundwater observed in some abstraction wells in recent years suggesting that saltwater is being intruded to fresh groundwater zone due to over exploitation.

3. Method

3.1. Groundwater sampling

Twenty-seven groundwater samples were collected by electrical pump during May, 2016 in available wells of the area for analysing pH, major cations (Ca, Mg, Na, K), major anions (HCO3-, Cl, SO4, NO3) and NH4, Fe, Al, SiO2 and total dissolve solid (TDS) (Fig. 1). The information of well depths were also recorded by interviewing well owner during sampling. All chemical parameters were analysed in the water analysis laboratory of Division of Water Resources Planning and Investigation for the south of Vietnam (DWRPIS) following certified standards for each parameter. Flame emission spectrometry method is used for analysis of Na and K in groundwater, using EDTA titrimetric method for analysis of Ca, Mg, using spectrometric method for Fe, NO3, NO2, Al, SiO2, using titration method for HCO3, Cl, and using gravimetric method for SO4.

3.2. Vertical Electric Sounding (VES)
The VES is conducted at 37 points using the Schlumberger array with a maximum AB/2 spacing of 650 m (Fig. 1). The VES is useful in determining the depth of overburden, thickness, structure, and resistivity of flat-lying sedimentary beds and possibly the basement, if it is not too deep [9].

3.3. Well installation
2 wells were installed in 2017 for sediment and groundwater sampling and for well logging (Fig. 1). The well depth of 130 m and 150m and screened in qp23 aquifers. The wells were installed using PVC casing. Well development was also conducted till the wells completely clean by air lifting method and continue pumping by submersible pump four days 4. Two groundwater samples were collected in the wells at the end of pumping process by submersible pump. The chemical analysis is followed the same procedures of groundwater sampling mentioned above.

4. Result and discussions

4.1. Groundwater quality
Groundwater samples show TDS values ranging from 250 to 1380 mg/L, and Cl concentration ranging from 30 to 788 mg/L, SO$_4$ from 0.5 to 220 mg/L. Four out of 27 samples show TDS and Cl greater than those values of 1000 mg/L and 250 mg/L, respectively recommended in WHO guideline for drinking water. TDS greater than 1000 mg/L was observed mostly in the northern part of study area. (Fig. 2).

![Fig. 2. TDS value of groundwater samples collected in qp23 aquifers](image)

The relation of TDS and various parameters including Cl, SO$_4$, and HCO$_3$ suggest that TDS is increase by Cl or SO$_4$ concentration increase in groundwater. Linear relationship between Cl and TDS reflects that the groundwaters are influenced by seawater. It is well known phenomena in the area and described in some previous studies [5,10].
4.2. Distribution of salt/fresh groundwater

Due to limited number of sampling points, the extension of saltwater zone is unclear. The result show that resistivity values range from 8 Ωm to 18.4 Ωm. The resistivity values vary from 10.4 to 18.4 Ωm at depth range -100-150m and lower than 5 Ωm and 8.7Ωm for the shallow depth (<100m) and deeper depth (>150 m), respectively (Fig. 3). It is well known that the resistivity values from 1-10 may indicate saltwater, 10 – 100 mineral water and greater than 100 portable water [3,11]. Binh [12] suggest that the TDS value of groundwater samples are liner correlated to and electric resistivities values measured in aquifer system of Mekong Delta. The electric resistivity values < 10.9 Ωm is most likely indicated salt groundwater. Comparison with location of groundwater sampling data, it may suggest that the electric resistivity value <11 Ωm indicate saltwater zone. Anyway, the fresh groundwater can only observe in aquifer qp$^{23}$ from 100 to 150 m.

4.3. Saltwater intrusion
Even though saltwater and freshwater zone were well identified till this point, however, extension of saltwater intrusion area is unknown. Giménez-Forcada, [13] and [14] propose a method call HFE-diagram for understanding the temporal and spatial evolution of saltwater intrusion in coastal area. According to the HFE-diagram, saltwater samples collected in this study show that groundwater are influenced by saltwater intrusion and freshening. Most of groundwater sample with TDS >1 g/L show saltwater intrusion stage.

HFE-Diagram also suggested that groundwater samples collected in the well 1 and well 2 show that the groundwater in well 1 in the saltwater intrusion stage, but in the well 2 groundwater in freshening stage (Fig. 5). It provides information that saltwater intrusion is being intruded to fresh aquifer zone.

5. Conclusion
This study clearly identifies salt/fresh groundwater zone in a costal aquifer by application of VES and geochemical and GIS techniques. Groundwater samples show that TDS values are generally less than 1.5 g/L, four out of 29 sample show TDS > 1g/L. Saline groundwater observed in northern part of qp23 and the upper (qh, qp3) and lower (qp1) aquifers. This suggest that fresh groundwater in the area is very limited and susceptible to saltwater intrusion. The HFE - diagram show that saltwater intrusion actively occurs even in the fresh groundwater area located close to saline groundwater zone. Therefore, proper management of groundwater abstraction is recommended for sustainable groundwater management.

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