DOI: 10.15625/vap.2019.000105

ASSESSING THE EXTENT OF SALTWATER INTRUSION OF THE MIDDLE–UPPER PLEISTOCENE AQUIFER IN CA MAU PROVINCE

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ABSTRACT

The extraction of groundwater has increased rapidly over the past decades and forms one of the main causes of saline water intrusion into the coastal aquifers. Such the intrusion has been accelerated by the on-going rise of the sea level. Saline intrusion in groundwater in the Vietnamese Mekong Delta is highly complex as it depends heavily on different factors, including changes in water supplies (e.g. the magnitude of the annual upstream hydrograph during both the flood and dry seasons and timing distribution of the annual rainy season) and rising water demands (e.g. the amount of fresh groundwater extracted for different purposes like domestic, agriculture and aquaculture use). This article is to extent of saltwater intrusion of the Middle–Upper Pleistocene (qp_{2-3}) in Ca Mau province. Based on samples analyzing data, 2 regression equations of each couple of the conductivity, total dissolved solids (TDS) were formulated and displayed on graphs, these can be applied to calculate TDS from available conductivity values in any areas. Calculating all input data, a variogram was created, which indicates the spatial correlation between points. Then, Krigging interpolation was applied in map-making proccess. Finally the spatial distribution of fresh and saltwater and the extent of saltwater intrusion of the qp_{2-3} aquifer was delineated. Freshwater districts are located in the southern part of the Ca Mau province and Ca Mau City.

Keywords: Saltwater intrusion, Middle–Upper Pleistocene aquifer, Hydrogeology, Ca Mau province, Total Dissolved Solids (TDS).

1. INTRODUCTION

Ca Mau is the southern province of Vietnam and one of the twelve provinces in the Mekong Delta region. Upper-aquifers in the area are mostly brackish water or saltwater not suitable for eating and living. Therefore, deep groundwater is a safe choice and has become a major source of water for activities in Ca Mau (Wagner et al., 2012). According to the results of monitoring national groundwater movement in recent years, the water level has shown signs of deep drop of 13.9 m (Q177020 station - Ca Mau city), 9.6 m (Q199020 station -Nam Can), at station Q177020 from 4/1995 -12/2008, the water level decreased by 6.5 m, average speed was 0.8 m per year (Nguyen Kim Quyen, 2009). Especially in the last 10 years, deep aquifers such as qp_{2-3} aquifer have become the target of exploitation (Wagner et al., 2012). Because deep water aquifers are the main target for exploitation and use in the area, there is pressure on deep water aquifers. In 2000, the volume of exploited water in the four deep aquifers (qp_{2-3}, qp_1, n_2^2) was 152,874 m^3/day, of which the discharge of qp_{2-3} aquifer accounted for more than 50% (82,919 m^3/day) of total groundwater exploitation in the area (Ngo Hong Tho et al., 2001). This study assesses the extent of previous saltwater intrusion and current status to provide the current level of saltwater intrusion and a reasonable management solution.

The qp_{2-3} aquifer is distributed across the entire study area, and is not exposed on the surface. Depth of the top of the aquifer ranges from 60 m to 117.5 m (borehole Q199 in the South of Ca Mau), with an average of 89.04 m. The depth of the aquifer bottom varies from 80 m to 146 m,

with an average of 104 m. Its thickness varies from 2.0 m (LK81) to 31 m (LK83, Q199), average 14 m (IPGVN, 2016).

2. MATERIALS AND METHODS

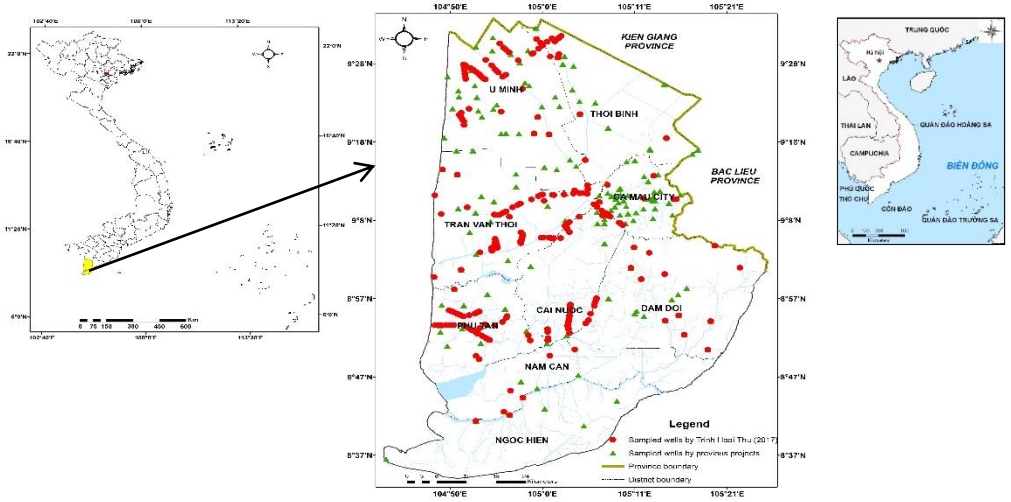

Figure 1. Location of study area and sample points.

- Water sampling: *The paper used water samples in qp_{2-3} aquifer in research and mapping, where: 172 samples in all districts (triangle symbol in Fig.1) were collected from previous projects (2004-2009): Tong Duc Liem, 2004; Nguyen Kim Quyen, 2009. Those samples were analyzed by chemical method; 233 samples (circle symbol) were taken in April, 2017 around the freshwater boundary of previous studies. The results of measurement and analysis was used to particularize and standardize the fresh-saltwater boundary of study area.*

- Chemical analysis: *Chemical analysis had been conducted in Environmental Chemistry Lab (INPC) for investigating TDS, conductivity and chloride concentration.*

- Geostatistic: *Geostatistics is a class of statistics used to analyze and predict the values associated with spatial. The estimation of geostatistic is based on the sample data and on a variogram which characterizes the spatial continuity or roughness of a data set.*

- Kriging interpolation: *The study used Kriging - a geostatistical analysis tool to interpolate TDS values from sample points.*

3. RESULTS AND DISCUSSION

The TDS distribution map of the previous period

This section presents the fresh - saltwater distribution of two previous period and the status, with the fresh-saltwater boundary (TDS=1g/l) which were interpolated from field water samples and water samples of previous studies. Two TDS distribution maps of previous period (2004-2009) and the current saltwater distribution map (2017) were processed, analyzed and mapped with the same database and the interpolation method which is used to determine the level of saltwater intrusion in the study area. The TDS distribution map of the previous period was contributed from 127 water samples that were collected from previous studies (2004-2009) by Odinary Kriging interpolation (310m x 310m). According to the data interpolation result, the groundwater in qp_{2-3} aquifer is mostly brackish water, the highest TDS value is 4.19 g/l in the North of U Minh district. The saline water area located in the South of Ca Mau province, including: Nam Can, Ngoc Hien districts; the Northern U Minh and Thoi Binh dictricts; a part of Tran Van Thoi and Phu Tan districts. Total area of saltwater is about 2.016 km^2, accounts for 37.8 % of the study area (Tab.1). The change of TDS value is lower at the locations with high density of sample points, which also means the accurary is higher.

The current TDS distribution map

The TDS distribution map of previous period (2004-2009) (Fig.2a) and the current TDS distribution map (Fig.2b) showed the moving of salt-freshwater boundary between two period in the northern U Minh district and the Southern Dam Doi district. The groundwater in qp_{2-3} aquifer is mainly brackish water. The highest TDS value is 3.25 g/l in the Northen Thoi Binh district. The saltwater area located in the South of Ca Mau province. Total area of saltwater is about 2315 km^2, accounts for 44% of the study area (Tab. 1). However, two maps are different from salt-freshwater boundary in Phu Tan, Tran Van Thoi districts where the author collected samples for the TDS map with standard boundary of the previous studies. Fig.3 zoom to this area and clarifies this different.

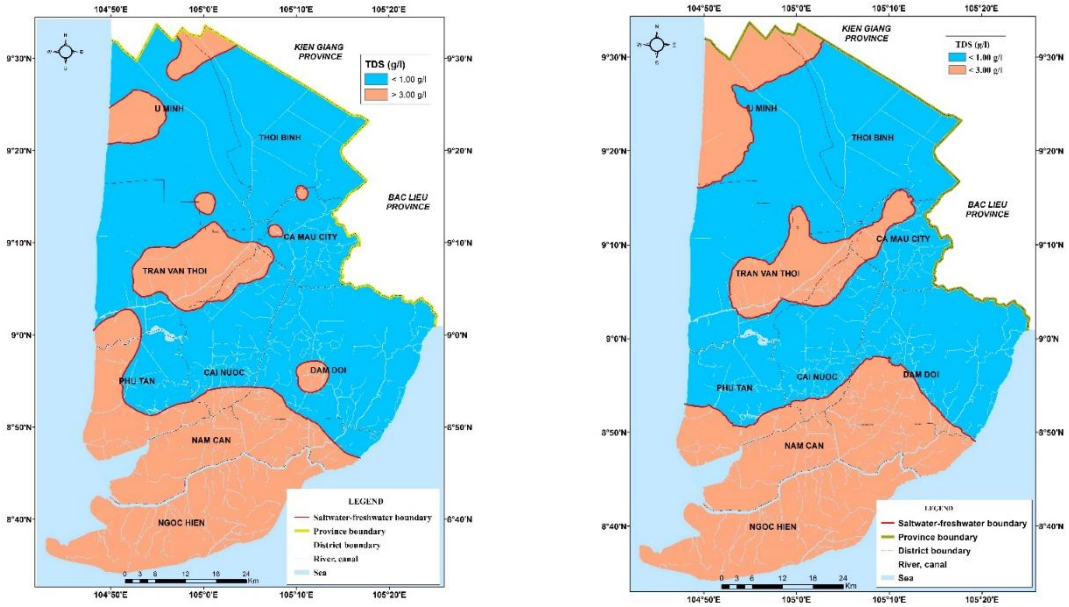

Figure 2. (a) The TDS distribution map of previous period (2004-2009) and (b) The current TDS distribution map (2017) in aquifer qp_{2-3}.

Table 1. The saltwater area of previous period (2004-2009) and current status (2017)

No.	District	Area (km^2)	Previous saline (km^2)	Previous saline water intrusion (%)	Current saline (2017) (km^2)	Current saline water intrusion (%)
1	Ca Mau city	250	12	4.8	66	26.4
2	Thoi Binh	640	29	4.5	30	4.7
3	U Minh	775	150	19.4	319	41.2
4	Tran Van Thoi	716	278	38.8	234	32.7
5	Cai Nuoc	417	87	20.9	90	21.6
6	Phu Tan	464	241	51.9	158	34.1
7	Dam Doi	862	89	10.3	212	24.6
8	Nam Can	509	397	78.0	509	100.0
9	Ngoc Hien	733	733	100.0	733	100.0
10	Total	5,332	2,016	37.8	2,351	44.1

Map of salinity intrusion.

The saltwater intrusion levels in the previous period (before 2009 to 2017) has increased considerably, the moving of salt-freshwater boundary was clearly visible (Fig. 4). The salinity boundary changed and levels of saltwater intrusion was higher, as much as Nam Can district, the area of salinity before 2009 was 397 km^2 increased to 509 km^2 (up 22.0 %) and similar to U Minh district (up 21.8 %), Ca Mau city (up 21.6 %) and Dam Doi district (up 14.3 %) (Tab. 1). Total area of saline area of Ca Mau province in 2017 is 2,351 km^2, increasing by 6.3 % compared to the area of saline area in the previous period (2004 - 2009) is 2016 km^2.

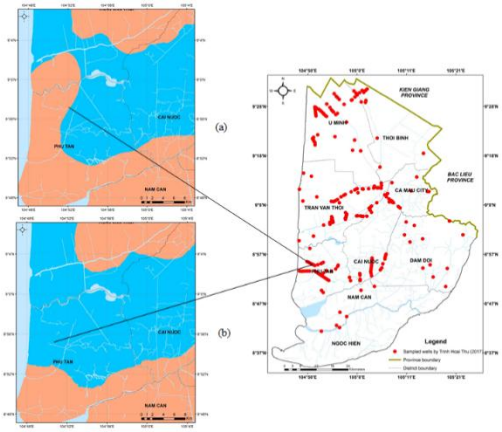

Figure 3. The TDS distribution map before standardized (a), after standardized (b).

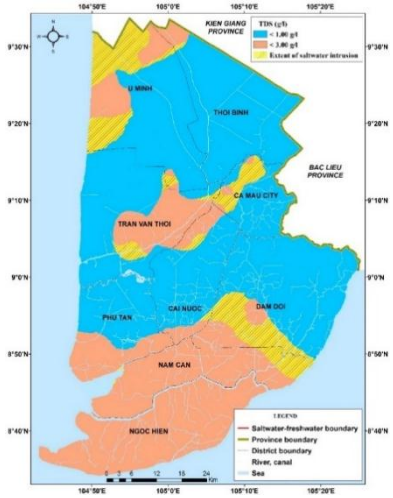

Figure 4. Level of salinity intrusion map in groundwater in the aquifer qp_{2-3}.

4. CONCLUSIONS

The level of saltwater intrusion map in the qp_{2-3} aquifer was simulated based on two TDS distribution maps from the previous data (2004 - 2009) that were constructed from 172 water samples collected from previous reports and the current TDS distribution map (2017) was created from 233 water samples taken in the field by Trinh Hoai Thu et al., 2017.

The level of saltwater intrusion in the two period has increased considerably, the salt-fresh water boundary was clearly moved in U Minh district with saltwater up to 21.8 %, Dam Doi up to 14.3 % and Ca Mau city increased 21.6 %. However, the Southern part of Phu Tan and Tran Van Thoi districts have been particularized and standardized by using detailed sampling around the previous salt-fresh water boundary. This shows that data from previous studies, especially in the last decade may not be accurate, is one of the most important restriction in groundwater quality studies in this area. Therefore, detailed sampling of salinity boundaries is essential for the study and calculation of high-confidence mapping.

Acknowledgments

This paper was completed thank to the support of Vietnam Academy of Science and Technology (VAST) project: *"Investigation and assessment salt-freshwater aquifers of Ca Mau province for serving groundwater resources management"* code VAST.DTCB.03/17-18 and project: *"The study of assessment quality and storage aquifers of coastal zone in Ninh Thuan province for serving groundwater resources management under the climate change and drought" code KHCBTD.01/19-21.*

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