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Assessment of soil and soil-water salinity in Ben Tre province by electromagnetic technology

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ABSTRACT
Assessment of soil and soil-water salinity is essential in agricultural production, therefore it is necessary to find out the non-costly, effective, rapid and reliable integrated methodology for this purpose. The paper presents the results of using the electromagnetic induction instrument EM31-MK2™ in combination with collecting and analyzing soil and soil-water samples, and applying GIS and geostatistical techniques to assess the current status of soil and soil-water salinity in Ben Tre province. Apparent soil electrical conductivity EC_a measured from ground surface to 6 m in depth increases from inland to the sea in northwest - southeast direction; EC_a is closely related to topsoil salinity to 30 cm deep and to soil-water salinity at depth of 10–100 cm. Current status of soil and soil-water salinity in 2018 was assessed with a 4-fold increase in information, from 16 km^2/data point to 4 km^2/data point. Consequently four maps were established, consisting of electrical conductivity EC_e and total solube salt TSS distributions of soil; electrical conductivity σ_w and total dissolved solid TDS distributions of soil-water.

Keywords: Soil salinity, soil-water salinity, electromagnetic induction, EM31-MK2™ instrument, correlation, regression, distribution map.

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INTRODUCTION

Soil and soil-water salinity is usually determined by electrical conductivity (EC) [1, 2] according to traditional methods that involve drilling in a network, collecting and analyzing the physical and chemical properties of soil and water samples in a study area. Recently remote sensing method has also been applied in these studies [3, 4]. However, generally the above methods are still costly and laborious.

Over the past three decades, the geophysical methods proved to have many advantages in studying the soil and soil-water salinity with the support of applying the information technology to equipments and developing the modern algorithms in data processing. In particular, electromagnetic (EM) instruments that measure the apparent soil conductivity EC_a have been used very widely in assessing the soil [5–15] and soil-water [16–21] salinity.

Ben Tre is one of the provinces in the Mekong delta which was heavily affected by climate change - sea level rise. In 2003, saline intrusion began to become serious, especially in dry season 2015–2016: Salinity of 4‰ in the main rivers intruded into the inland up to 45–70 km; salinity of 1‰ covered throughout the province (162/164 communes, wards and towns). As a result, soil and soil-water became salinization that caused severe damage to agricultural production [22].

The article presents the results of using EM31-MK2 electromagnetic instrument along with collecting and analyzing the soil and water samples; applying GIS and geostatistics to assess the soil and soil-water salinity in Ben Tre province.

DATA AND METHODOLOGY

Study area

Ben Tre has a natural area of 2,360.2 km^2 with topographic elevation of 1–2 m above sea level. Riverside and coastal low-lying regions below 1.0 m are inundated regularly during high tide. Ben Tre land is in the form of a big river island in the Mekong river mouth, which has been formed by alluvial deposition process with an interlaced river/canal system, including four big rivers Co Chien, Ham Luong, Ba Lai and Tien, and a long coastline over 65 km (fig. 1).

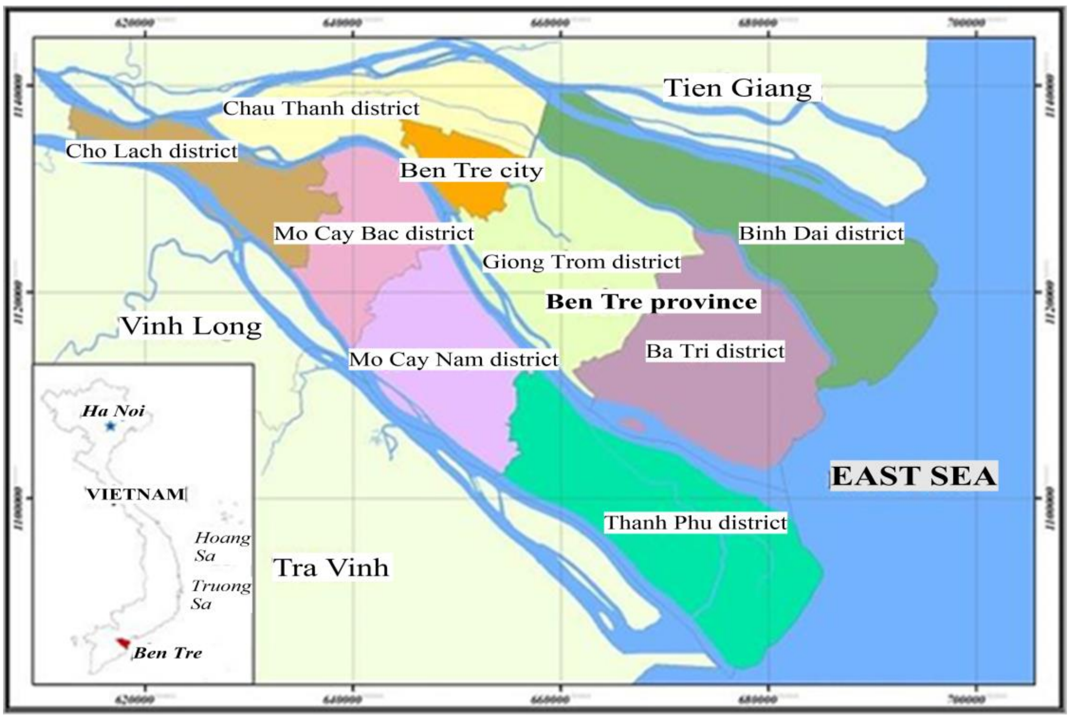

Fig. 1. Map of study area (Ben Tre province)

Establishment of monitoring network

To collect field data, a network of 150 monitoring points was established in the study area; distance between points about 5 km; average density 16 km^2/point. A monitoring point location was selected so that it is typical of the survey place, i.e. rice/garden land, river/canal banks... Coordinates of monitoring points were determined by Garmin handheld GPSmap 60CSx with an accuracy of ± 5 m in national reference system (VN2000, longitude 105^{o}45; zone 30) (fig. 2).

Data collection time is from the end of 2017 to June 2018.

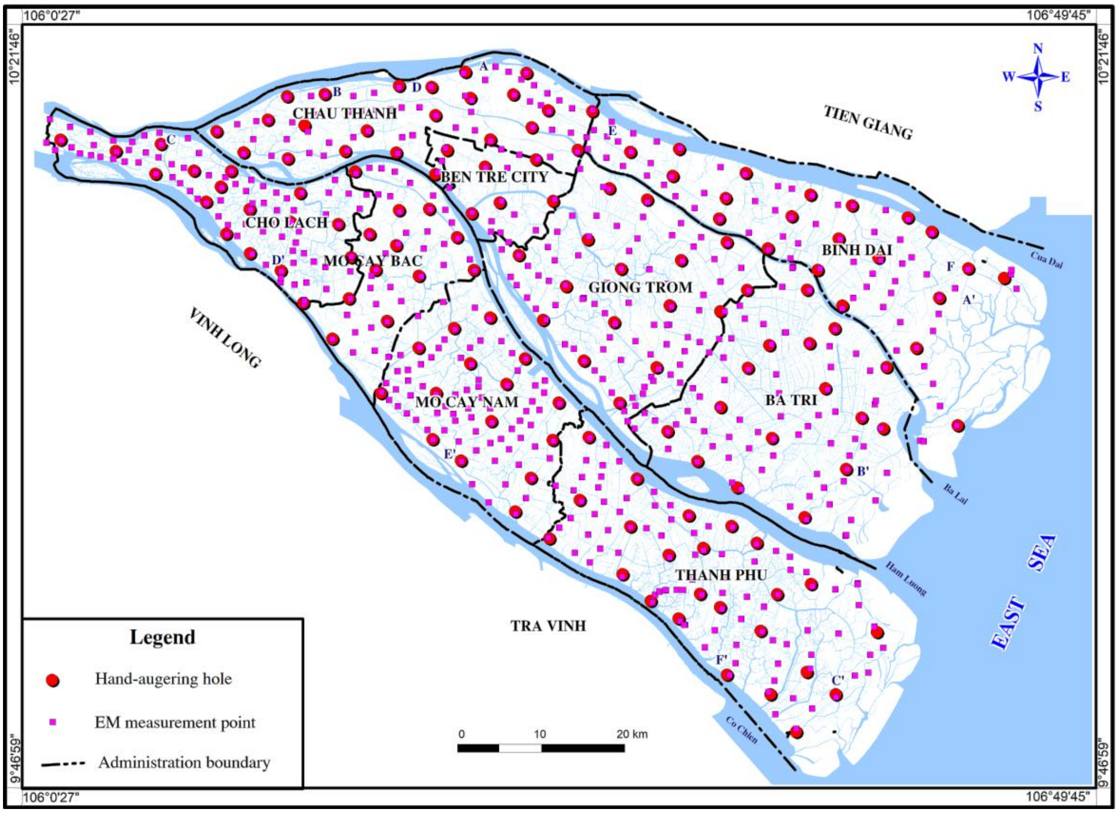

Fig. 2. Network of monitoring points and EM measurement points

Measuring electromagnetic induction and collecting soil and water samples

EM survey was conducted at 600 points, in which 150 measurement points coincide with 150 monitoring points; measurement points about 1.5 km apart, average density 4 km^2/point. Apparent soil electrical conductivity EC_a (mS/m) was measured by a EM31-MK2™ instrument with the array in the "vertical dipole" mode (fig. 3). This instrumental configuration was chosen because it is very sensitive to lateral variations of apparent conductivity and has a depth penetration of about 4–6 m. Apparent soil electrical conductivity data were collected with the DAT31W program installed in the EM31-MK2™ instrument, which allows the transfer of data files to a personal computer, and the data can then be displayed, edited, printed and plotted. The data files can serve as input for Geosoft, Surfer and other contour softwares with the suitable format [11, 12].

All 150 hand-augering holes reach a depth of 100 cm (fig. 4); 150 soil samples were taken with a weight of 2 kg in a depth of 0–30 cm; 150 soil-water samples were collected with a volume of 2 liters in a depth of 10–100 cm. All soil and soil-water samples were stored in a closed foam container at temperature 4^{o}C and brought to the laboratory.

Fig. 3. Instrument EM31-MK2™, manufactured by Geonics of Toronto, Canada

Fig. 4. Hand-augering at monitoring point BT82N at Huong My commune, Mo Cay Nam district

Laboratory analysis

Analysis of soil samples

Including 2 properties:

Soil electrical conductivity EC_e (mS/cm) was calculated by the empirical formula $EC_e = EC(1{:}5) \times 6.4$. *In which*: $EC(1{:}5)$ is the electrical conductivity calibrated to a temperature of 25^{o}C of the solution extracted from a soil sample that is dried with water at a temperature of 20^{o}C ± 1 in a ratio 1:5 (1 soil, 5 water) [23].

Total solube salts (TSS): Ratio between the water soluble salt weight and the dried weight of a soil sample, expressed as %.

Analysis of soil water samples

Including 2 properties:

Soil-water electrical conductivity σ_w (mS/cm): Measured with the multi-indicator device Sper Scientific 850081 (USA).

Total dissolved solids (TDS): Total amount of minerals, salts and metals dissolved in water was determined by gravity method, expressed in mg/l.

Ordinary Kriging interpolation method

Kriging is a spatial interpolation method based on the geostatistical principle of regionalized variables, which allows predicting an unknown value at a certain location by using a combination of nearby data. Ordinary Kriging interpolation method is most widely used compared to other Kriging interpolation methods [8].

Statistical analysis was performed with SPSS 20 software in Windows (SPSS Inc., Mat Lab, USA). MapInfo 15 software was used in geostatistical analysis and mapping.

RESULTS AND DISCUSSION

Apparent soil electrical conductivity distribution

Apparent soil electrical conductivity EC_a from ground surface to a depth of 6 m is divided into four distinct regions: (i) Northwest region has low EC_a, ranging from 20–100 mS/m including Ben Tre city, Cho Lach, Chau Thanh, Mo Cay Bac, Mo Cay Nam districts and a part of Giong Trom district, accounting for nearly half of province’s area; (ii) Central region has EC_a varying between 100–200 mS/m including Chau Thanh and Giong Trom districts and a part of Binh Dai, Ba Tri and Thanh Phu coastal districts; (iii) Coastal region with EC_a of 200–300 mS/m is distributed along Co Chien river banks to Mo Cay Nam district boundary and (iv) Sea contiguous region with EC_a over 300 mS/m (fig. 5).

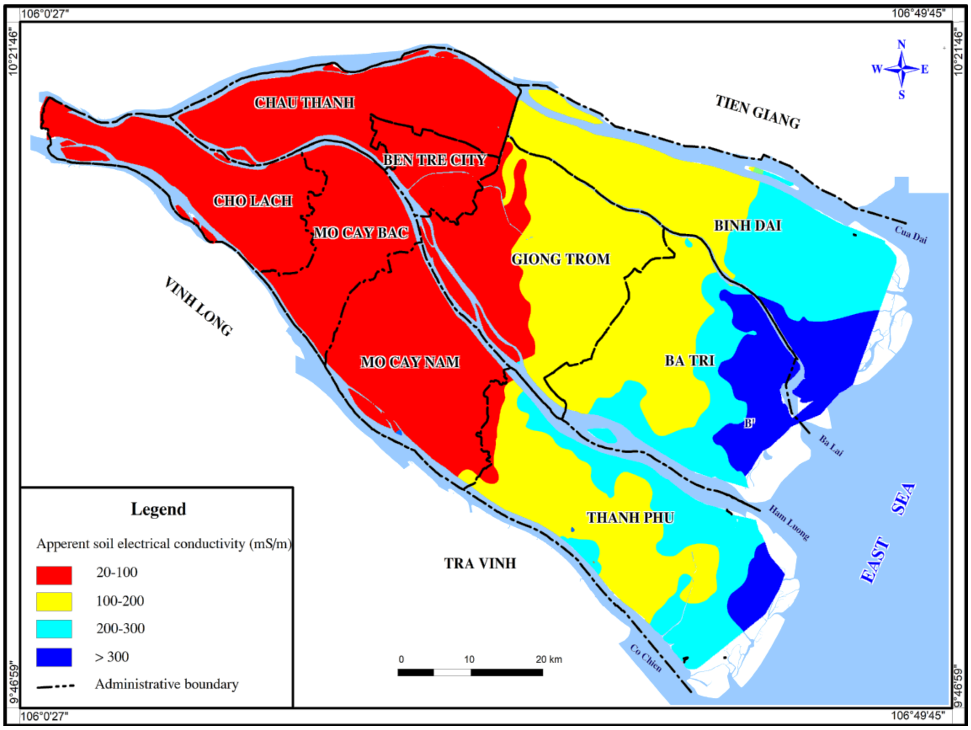

Fig. 5. Map of EC_a distribution from ground surface to depth of 6 m

Soil salinity status

Correlation between EC_a and EC_e

Because EC_e is a standard data for assessing soil salinity, it is necessary to determine the correlation between EC_a and EC_e. To replace EC_a with EC_e, the nonlinear transformations or linear calibration methods can be used [1, 2]. Here we choose the correlation between EC_a and EC_e which is determined by the regression equation:

$$ln(EC_e) = a_0 + a_1 ln(EC_a) \qquad (1)$$

Where: a_0 and a_1 are regression coefficients.

Using EC_e and EC_a values at 150 monitoring points of the network, we obtain:

$$a_0 = 0.852 \quad a_1 = 0.237 \qquad (2)$$

These coefficients are statistically significant ($P < 0.05$) for EC_e and EC_a data sets, i.e. from equation (1) we can calculate EC_e at 450 EC_a measurement points that do not belong to the monitoring network.

Analysis results of 150 soil samples allow determining the correlation between *TSS* and EC_e as follows:

$$TSS = 0.0002 + 0.0605EC_e \qquad (3)$$

With correlation coefficient $R^2 = 0.958$.

From (1) and (3) it is possible to calculate *TSS* with EC_a, therefore 450 *TSS* values out of the monitoring points can be determined from 450 measured EC_a values.

Soil salinity distribution

From the above results it is possible to produce the soil electrical conductivity and total dissolved salt distribution maps in 2018 according to soil salinity classification of FAO (1976).

Non-salinity soil region with EC_e < 4 mS/cm covers most inland area, including Ben Tre city and Chau Thanh, Cho Lach, Mo Cay Bac, Mo Cay Nam districts and a part of Binh Dai, Ba Tri and Thanh Phu coastal districts. Little salinity soil region (EC_e = 4–8 mS/cm) accounts for most three coastal districts, except for a small area with moderate salinity (EC_e = 8–10 mS/cm) along Tien river within Binh Dai district (fig. 6).

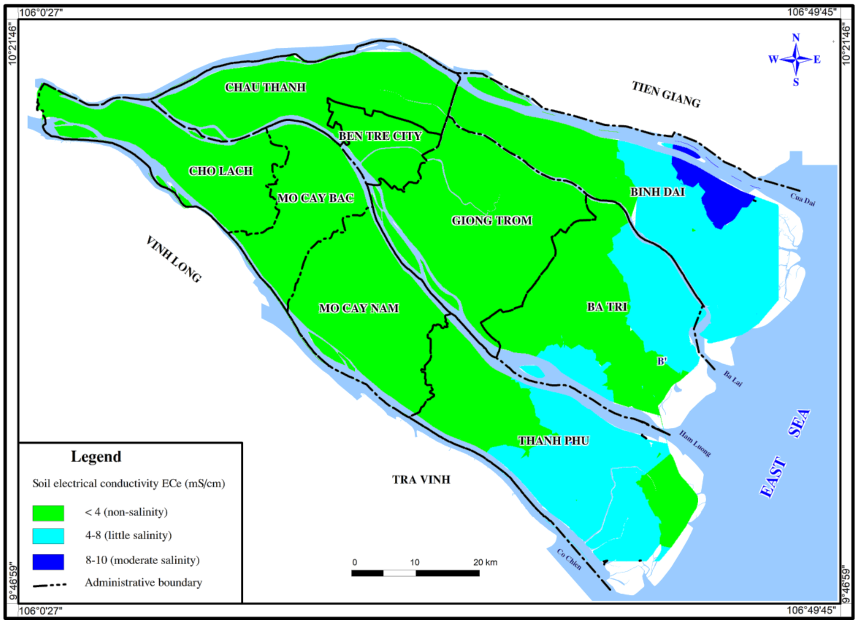

Fig. 6. Map of EC_e distribution from ground surface to depth of 30 cm in Ben Tre province in 2018

Non-salinity soil region with *TSS* < 0.15% accounts for more than half of the province's inland area, including Ben Tre city and Chau Thanh, Cho Lach, Mo Cay Bac and Mo Cay Nam districts. Little salinity soil region (*TSS* = 0.15–0.35%) covers most three coastal districts, except for some small areas with moderate salinity (*TSS* = 0.35–0.65%) (fig. 7).

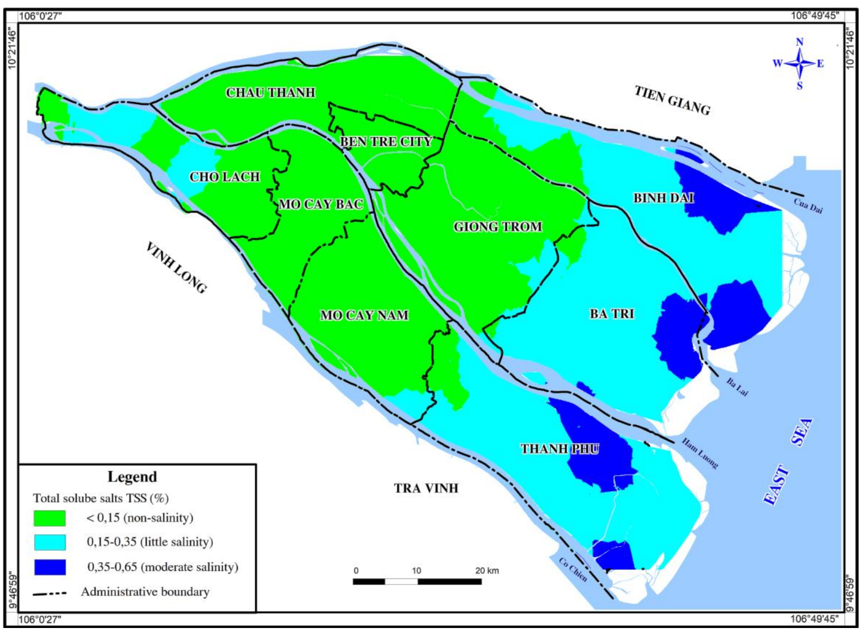

Fig. 7. Map of *TSS* distribution from ground surface to depth of 30 cm in Ben Tre province in 2018

Soil-water salinity status

Correlation between EC_a and σ_w

Correlation between the apperent soil electrical conductivity EC_a and the soil-water electrical conductivity σ_w is determined by Archie's empirical formula [2]:

$$EC_a = a\Phi^m \sigma_w = F\sigma_w \quad (4)$$

Where: a and m are the experimental coefficients; σ_w- soil-water electrical conductivity; Φ- porosity of soil-water bearing layer; F- formation factor.

Using EC_a and σ_w values measured at 150 monitoring points of the network, we obtain $F = 0.062$ with $P < 0.01$. Then from equation (4), 450 values of σ_w at measurement points out of the monitoring network can be calculated by 450 values of EC_a.

Analysis results of 150 water samples allow determining the correlation between *TDS* and σ_w as follows:

$$TDS = -446.16 + 846.71\sigma_w \quad (5)$$

With the correlation coefficient $R^2 = 0.990$.

From (4) and (5) it is possible to calculate *TDS* with EC_a, i.e. 450 values of *TDS* at measurement points out of the monitoring network can be determined by 450 values of EC_a.

Soil-water salinity distribution

Soil-water total dissolved solid distribution is classified according to classification of FAO (1976), from this the classification of soil-water electrical conductivity is obtained according to formula (5).

Soil-water electrical conductivity $\sigma_w < 10$ mS/cm covers the inland area, including Ben Tre city and Chau Thanh, Cho Lach, Mo Cay Bac and Mo Cay Nam districts. Most of Giong Trom and Ba Tri districts has $\sigma_w = 10–20$ mS/cm; Binh Dai and Thanh Phu districts have $\sigma_w = 20–40$ mS/cm. Coastal zone of Binh Dai, Ba Tri and Thanh Phu districts has $\sigma_w > 40$ mS/cm (fig. 8).

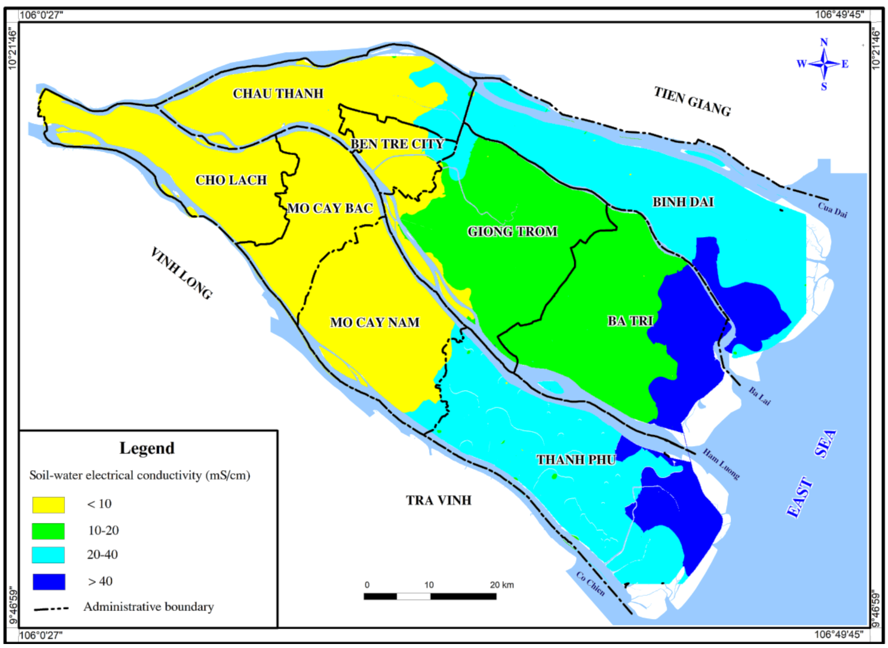

Fig. 8. Map of σ_w distribution at depth of 10–100 cm in Ben Tre province in 2018

Moderate saline region (*TDS* = 1,500–7,000 mg/l) covers one third of the northwestern area of the province, including half of Ben Tre city and Chau Thanh, Cho Lach, Mo Cay Bac and Mo Cay Nam districts. High saline region (*TDS* = 7,000–15,000 mg/l) accounts for most of Giong Trom district, while most of Binh Dai, Ba Tri and Thanh Phu coastal districts has very high saline (*TDS* = 15,000–35.000 mg/l), especially there exist two areas of salty water with *TDS* > 35,000 mg/l in coastal zone (fig. 9).

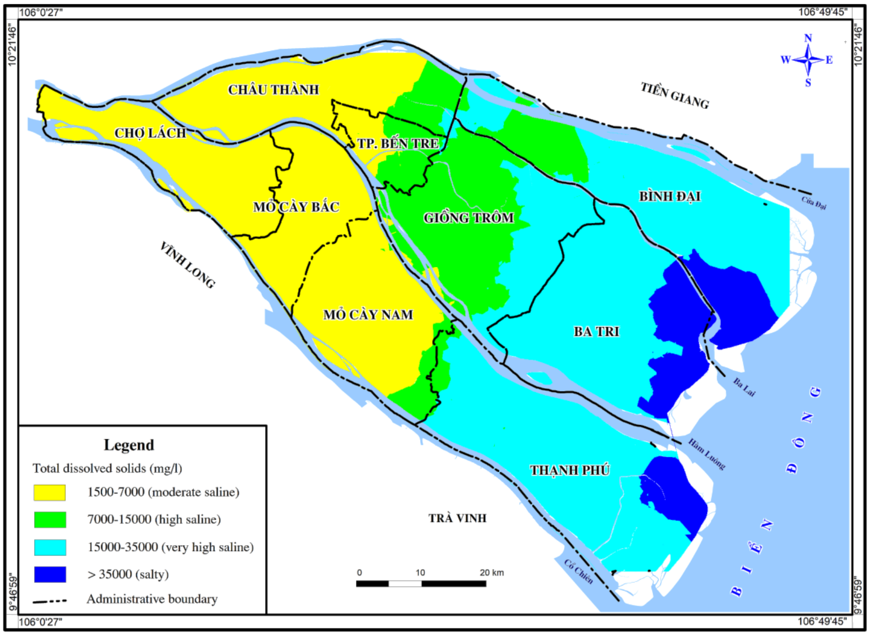

Fig. 9. Map of *TDS* distribution at depth of 10–100 cm in Ben Tre province in 2018

CONCLUSION

Using EM31-MK2™ electromagnetic instrument in combination with collecting and analyzing soil and water samples identified the correlation between soil and soil-water salinity with apparent soil electrical conductivity. Applying GIS and geostatistical techniques, the maps of soil and soil-water salinity spatial distribution in Ben Tre province have been established.

From the obtained results the following conclusions can be drawn:

Apparent soil electrical conductivity EC_a from ground surface to a depth of 6 m increases gradually from inland to the sea in northwest-southeast direction. It should be noted that the high electrical conductivity zone is distributed along Tien and Co Chien rivers from the sea to Mo Cay Nam district boundary. It is a vestige of saline intrusion into the river bed and infiltration to both banks.

Apparent soil electrical conductivity is closely related to soil salinity from ground surface to a depth of 30 cm and to soil-water salinity at a depth of 10–100 cm.

Current status of soil and soil-water salinity in 2018 was assessed with a 4-fold increase in information, from 16 km^2/data point to 4 km^2/data point. On this basis four maps were established, consisting of two maps of EC_e and *TSS* distribution and two maps of σ_w and *TDS* distribution.

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