Study on the freshwater boundary of the Pleistocene aquifer in the coastal zone of Nam Dinh province

Nguyen Thu Hang
Faculty of Environmental Sciences
VNU University of Science
Hanoi, Vietnam

Dinh Duy Chinh
Faculty of Environmental Sciences
VNU University of Science
Hanoi, Vietnam

Trinh Hoai Thu
Institute of Marine Geology and Geophysics
Vietnam Academy of Science and Technology
Hanoi, Vietnam

Vu Van Manh
Faculty of Environmental Sciences
VNU University of Science
Hanoi, Vietnam
fesvvm@yahoo.com

Abstract: *Saltwater intrusion has occurred in coastal aquifers in Nam Dinh province, Vietnam, which causes many negative effects on economic activities and especially residential life. Determining fresh-saltwater distribution is therefore necessary for authorities to have fundament to release policies and solutions timely to prevent this issue. Based on samples analyzing data, 3 regression equations of each couple of the conductivity, total dissolved solids (TDS) and chloride concentration were formulated and displayed on graphs, these can be applied to calculate TDS from available conductivity or chloride concentration values in any areas. Calculating all input data, a variogram was created, which indicates the spatial correlation between sampling points. Then, Kriging interpolation was applied in map-making process. Finally the spatial distribution of fresh and saltwater was delineated. Freshwater districts are located in the southern part of the Nam Dinh province and a small area in the north.*

Keywords: saltwater intrusion; Nam Dinh; Pleistocene aquifer

I. INTRODUCTION

Available water resources, including surface water and groundwater, play an important role in the growth of population as well as economy in Vietnam. In fact, the negative effects of climate change, untreated sewage water and industrial waste water on surface water have made it more and more vulnerable with the decreasing quality leads to the possibility that groundwater will become the major resource for the future water supply of Vietnam. However, during the last decades, the uncontrolled utilization and increasing exploitation of the finite groundwater resources in Vietnam have resulted into several negative effects, especially in coastal areas. One of the major concerns encountered in coastal aquifer is the induced flow of saltwater into freshwater aquifer caused by groundwater over-pumping, known as saltwater intrusion. (*IGPVN, 2011*).

Nam Dinh is an agricultural dominated province located at the southern of the Red River Delta (RRD) in the north of Vietnam. It has a 72-kilometers long coastline bordering BacBo gulf (Gulf of Tokin). Latest statistical data published by General statistics office of Vietnam state a total population of 1,833,500 (2011) persons and a population density of 1110 persons per km, ranked seventh in the whole country. Following this large population is the increasing demand for freshwater used for drinking and living. However, like many other coastal regions, the groundwater resources here also represent the negative effects of saltwater intrusion as mentioned above. According to National technical regulation on drinking water quality (QCVN 01:2009/BYT), acceptance limit for TDS is 1g/l while chloride standard for coastal zone is 0.3 g/l.

In Nam Dinh province, surface water is still used in northern and eastern areas, while in the south and the west, deeper groundwater resources has been increasingly exploited for domestic as well as economical utilization. According to report of IGPVN (2011), average water consumption per person is ~0.2 m^3 per day and a total groundwater extraction for domestic purpose has been calculated to be more than 180,000 m^3 per day. Figure 1 indicates the portion of groundwater used for communal water supply in Nam Dinh province with the salinity boundary in Pleistocene aquifer.

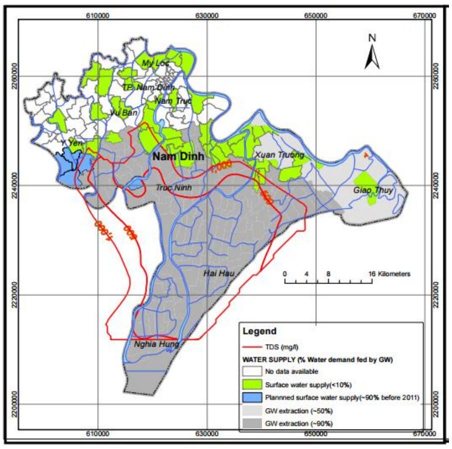


Figure 1. Portion of groundwater used for communal water supply in Nam Dinh province (IGPVN, 2011)

According to the Hydrogeological mapping of Nam Dinh (*Nguyen Van Do, 1996*) the Cenozoic formations in the RRD can be distinguished into 5 hydrogeological units, namely Upper Holocene (qh_2), Lower Holocene (qh_1), Upper Pleistocene (qp_2), Lower and Middle Pleistocene (qp_1) and Neogene (Pliocene, n). The research focuses on fresh–saltwater distribution in Pleistocene aquifer, which has a large potential deposit of freshwater, about 300,000m^3 per day (*Nguyen Van Dan et al, 2009*). If that intrusion is controlled and prevented efficiently, water in Pleistocene aquifer can be exploited and used in a long term.

II. MATERIALS AND METHODS

A. Water samples

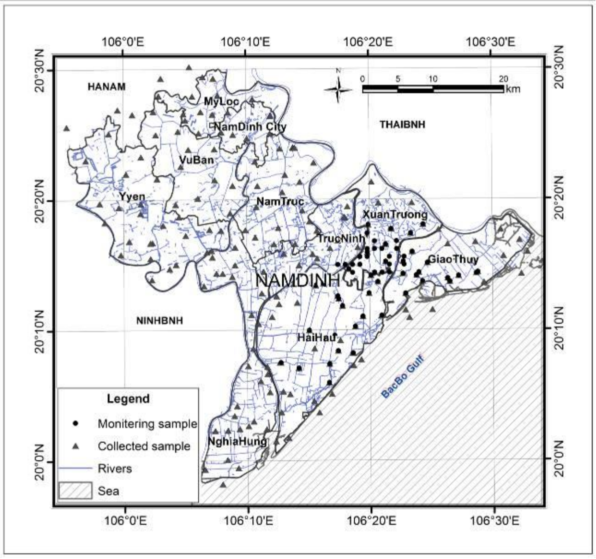


Figure 2. Location of study area and sample points

This study used 284 water samples in Pleistocene aquifer in research and mapping, where:

204 samples in all districts (triangle symbol in map) were collected from previous projects[1]. Those samples were analyzed by chemical or geophysical methods.

80 samples (circle symbol) were taken in July 2014[2] around the freshwater boundary of previous studies. The results of measurement and analysis were used to particularize and standardize the fresh-saltwater boundary of study area.

B. Chemical analysis

Chemical analysis had been conducted in laboratory for investigating the total dissolved solids (TDS), conductivity and chloride concentration. Hence, the regression equations between them were formulated.

TDS was measured by 2 chemical methods. The first one is evaporating water sample and weighing the remains after drying until the weight was unchanged at the temperature of 180 ± 2^{o}C. Hence, the formula:

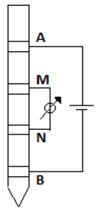
$$\text{TDS (g/l)} = (A-B)/V$$

where: A is mass of measuring cup + sample (g); B is mass of measuring cup (g); V is analyzed sample volume (l).

The second one is measuring the conductivity, using a Wenner microelectrode system. This system contains 2 sending electrode AB outside and 2 potential measuring electrode MN inside so that AM=MN=NB. The whole electrode system was dipped into sample water. Then, conductivity of water was defined by:

$$\sigma_w = 1/(K\Delta U/I)$$

where: K is Wenner electrode coefficient; ΔU is Voltage between M and N; I is electric current through AB.



With this method, TDS was calculated by the formula:

$$\text{TDS} = A\,\sigma_w$$

where: A is experimental constant; σ_w is conductivity of water.

C. Geostatistic

Geostatistics is a class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena.

The calculation of geostatistic is based on the sample data and on a variogram which characterizes the spatial continuity or roughness of a data set.

Variogram analysis consists of the experimental variogram calculated from the data and the variogram model fitted to the data. The mathematical definition of the variogram is:

$$\gamma(h) = \frac{1}{2}E\left[Z_{(x)} - Z_{(x+h)}\right]^2$$

Where: $Z_{(x)}$, $Z_{(x+h)}$ are the values of the variable of interest at 2 locations seperated by a distance h. E[ ] is the statistical expectation operator.

Furthermore, let N(h) equal the number of studied pairs, the experimental variogram by:

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z_{(x)} - Z_{(x+h)}\right]^2$$

The variogram model is chosen from a set of mathematical functions that describe spatial relationships. The appropriate model is chosen by matching the shape of the curve of the experimental variogram to the shape of the curve of the mathematical function (Spherical, Exponential, Gaussian, Power...)

[1] Nguyen Van Do, Doan Van Canh, BGI, IPGVN
[2] Trinh Hoai Thu, VAST06.06/14-15

Characteristic of variogram includes:

- Sill: value at which the variogram levels off.
- Range: The lag distance at which the variogram reaches the sill value.
- Nugget: In theory the variogram value at the origin should be zero. If it is significantly different from zero for lags very close to zero, then this variogram value is referred to as the nugget. The nugget represents variability at distances smaller than the typical sample spacing, including measurement error.

Geostatistical methods are optimal when data are normally distributed and stationary (mean and variance do not vary significantly in space). Significant deviations from normality and stationary can cause problems, so it is always best to begin by looking at a histogram or similar plot to check for normality and a posting of the data values in space to check for significant trends.

D. Kriging interpolation

The study used Kriging – a geostatistical analysis tool to interpolate TDS values from sample points.

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. The general formula is formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where:

$Z(s_i)$ is the measured value at the i^{th} location

λ_i = an unknown weight for the measured value at the i^{th} location

s_o = the prediction location

N = the number of measured values

Multistep process of Kriging includes: exploratory statistical analysis of the data, variogram modeling, creating the surface, and exploring a variance surface.

III. RESULTS.

A. The relationship between TDS, conductivity and Cl-

The relationship between TDS, conductivity and Chloride in couple is indicated by regression lines with equations attracted.

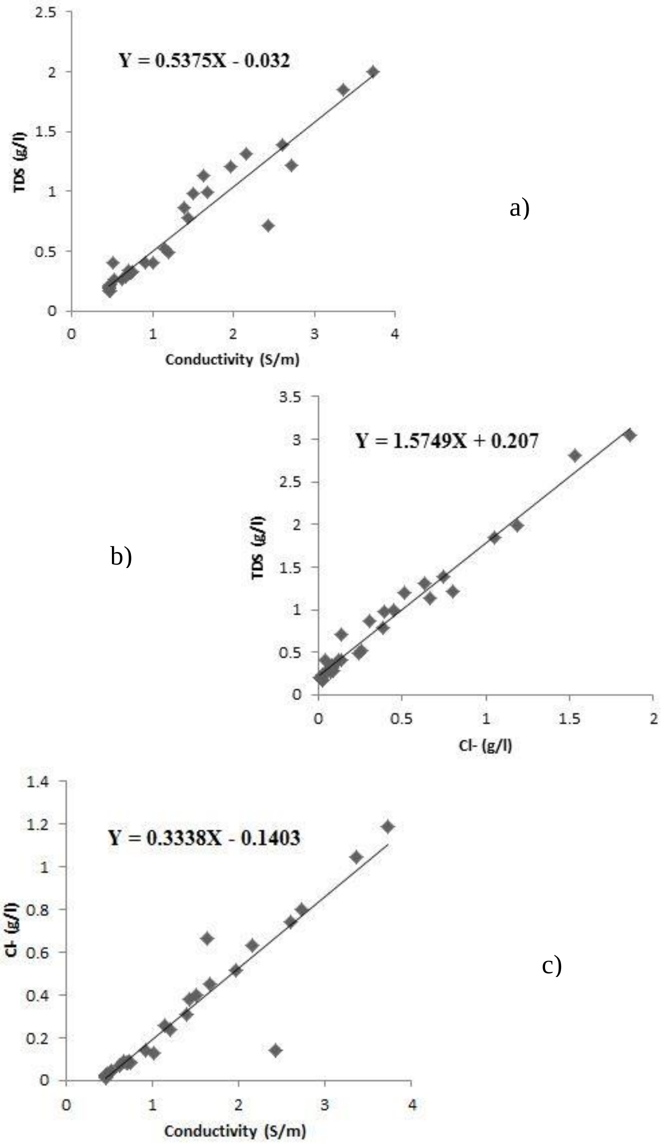


Figure 3. The relationship between:
a) TDS and conductivity; R^2=0.92; SD=15%
b) TDS and Cl-; R^2=0.98; SD=11%
c) Cl- and Conductivity; R^2=0.88; SD=11%

The three equations have the form of a linear regression with standard deviation (SD) is not over 15%. By those, if a value among TDS, Cl^- and conductivity is available, the others can be calculated without measurements.

B. Primary fresh-saltwater distribution map.

This section presents the fresh-saltwater distribution with the 1 g/l TDS boundary which was interpolated from water samples of previous studies.

Among 204 water samples, 3 ones that seemed to be abnormal were discarded in process of removing gross error with a 95% confidence interval.

Creating a histogram of TDS value, there was an abnormal distribution with the peak skewed to the left, mean and variance vary significantly. Therefore, it would be better to transform TDS data to logarithmic form with the nearly normal distribution (Figure 4) and the less significant deviation form stationary (mean = -0.221138; variance = 0.331773).

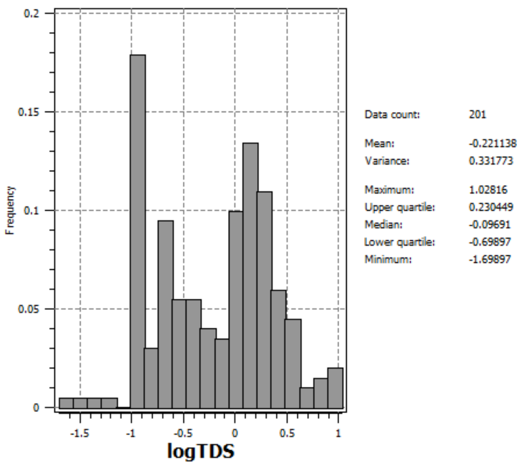


Figure 4*. Histogram of LogTDS*

Subsequently, the variogram of logarithm TDS was created with the direction of North East – South West, in which there are an major active fault (Van Ly) and some other faults (Nam Dinh, Yen Mo – Thai Thuy, Nghia Hung – Kien Xuong). Tested with azimuth from 40 to 50 degrees, the 45 degree situation gave the best result (Figure 5).

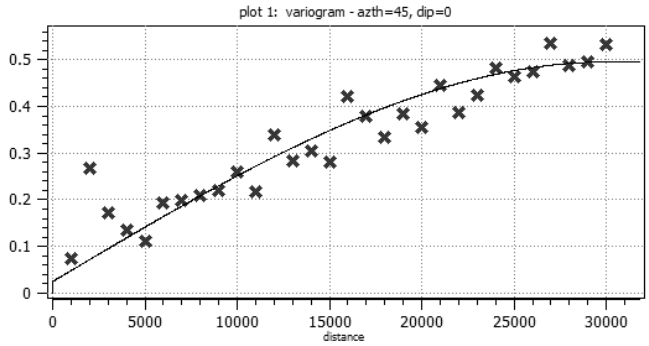


Figure 5. Variogram of logTDS.
Sill = 0.47; Range = 30000; Nugget =0.025

The chosen variogram model is Spherical model, which exhibits linear behavior at the origin, appropriate for representing properties with a higher level of short-range variability.

Using the variogram modeled above, a map of LogTDS was created by Odinary Kriging interpolation. Then, using Math tool to calculate the TDS. The TDS distribution was mapped with the fresh-saltwater boundary in Figure 6.

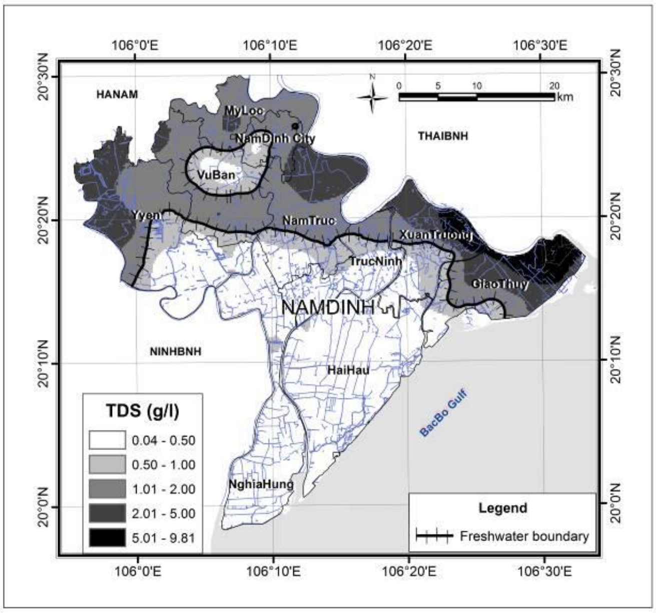


Figure 6. Primary fresh-saltwater distribution map.

C. Particularized fresh-saltwater distribution map

80 samples taken in July 2014 were added to combine with 201 samples above to particularize and standardize the primary map. To realize this task, mapping went through a similar process with the one above. The result is performed in Figure 7.

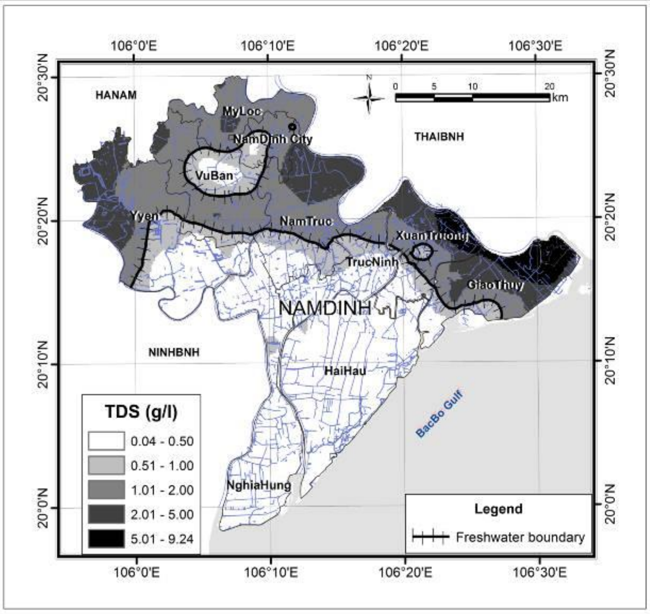
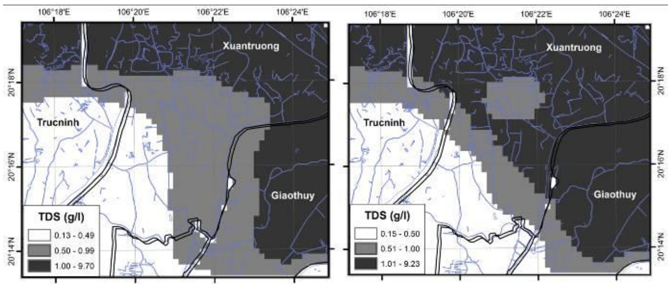


Figure 7. Spatial distribution of TDS of the Pleistocene aquifer in Nam Dinh Province.

According to the interpolation result, The TDS ranges from 0.04 to 9.24 g/l. The Eastern part of Nam Dinh Province, located in Giao Thuy and a part of Xuan Truong district, has the highest TDS content. Despite of bordering the sea, southern part of Nam Dinh Province has not got saltwater intrusion. This area is about 772.60 km^2, including the whole

Nghia Hung and Hai Hau districts, southern Y Yen, Nam Truc, Truc Ninh, Xuan Truong districts and a small part of Giao Thuy district. This can be temporarily explained by the available of remote water supply following tectonic fault, Karst zones of ancient stone pushed the saltwater far away to create quite great freshwater area. There is also a small fresh water area located in Vu Ban district and Nam Dinh city, covering about 58.73 km^2.

Put the two map created in comparison; there is a noticeable difference in the TDS distribution as well as fresh-saltwater boundary in Xuan Truong, Giao Thuy location, where is also the area gathering 80 new samples. Figure 8 zooms to this area and clarifies this difference.



a) Primary map b) Particularized map

Figure 8. Difference between 2 maps

In the two maps, the white area (TDS <0.5g/l) and the light grey area (0.5 – 0.99g/l TDS) represent water could be used for drinking and living. This freshwater area in primary map is continuous while that in the particularized is splitted and smaller. The total area of freshwater in Nam Dinh province in primary map is 859.76 km^2 while that in the second map is 831.33 km^2.

Attracted with interpolation map is the variance of prediction that was presented in Figure 9.

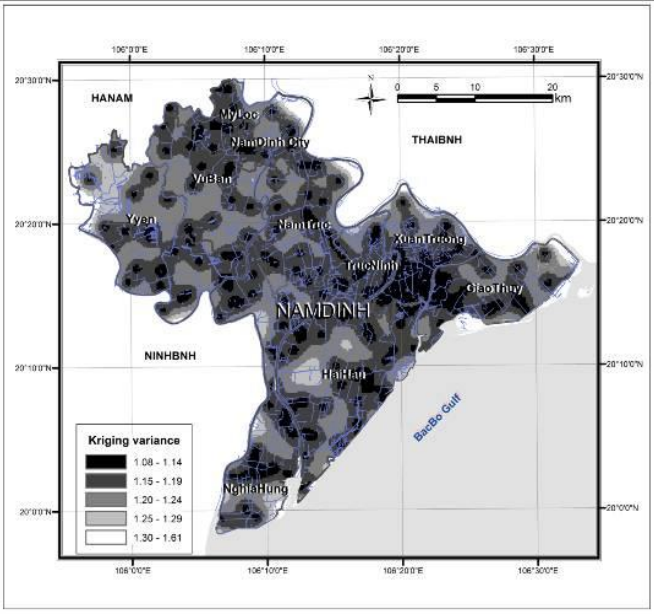


Figure 9. Variance of prediction map

It is obvious that at the locations having high density of sample points, variance value is lower, which also means the accuracy is higher. This variance of prediction map therefore could be used to evaluate the reliability of interpolation result.

D. Chloride concentration distribution map.

This map was created by calculating each cell of TDS distribution map (Figure 7), using the regression equation of TDS and Cl^- (Figure 3b).

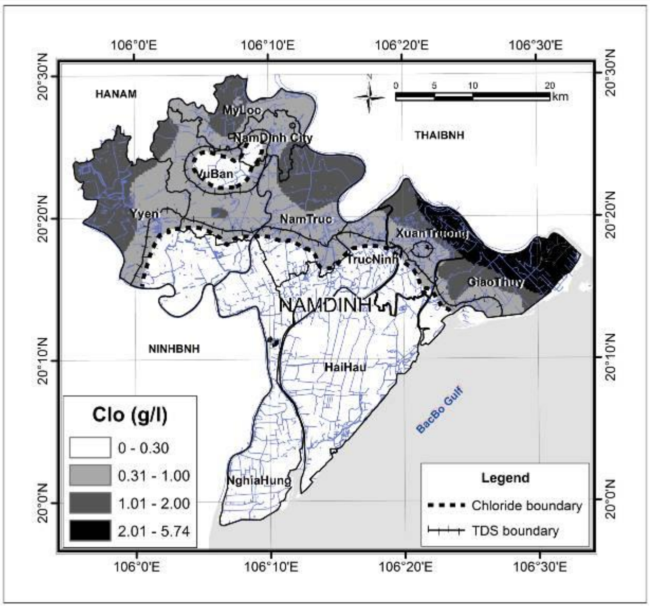


Figure 10. Chloride concentration distribution map

The 1g/l TDS boundary is also displayed in the map in order to compare with chloride boundary (0.3g/l, according to National technical regulation on drinking water quality for coastal zone). Then, it is obvious to see the areas meeting drinking water standard for TDS but not for chloride concentration.

IV. CONCLUSION

The TDS map with standard boundary of the Pleistocene aquifer was mapped, then particularized and standardized at Xuan Truong area. The TDS value ranges from 0.04 to 9.24 g/l. It defines the Pleistocene aquifer in Nam Dinh province containing 831.33 km^2 of freshwater with the great part located in the South and a small area in the center of the North. The investigating also delineated the vulnerable zones with high TDS content. Furthermore, the relationship between TDS, conductivity and chloride concentration formulated can be useful for studies and predicting models of Pleistocene in Nam Dinh province. The map of chloride distribution is created from the relationship formulated.

In fact, the accuracy of mapping depends on the distribution of sample points, the qualification of sample analysis and especially the interpolation, including which interpolation method was chosen and how it was applied. In this study, the accuracy was not really high, which could be realized from the incompletely normal distribution in histogram, in spite of transformation of TDS value into logarithm. However, the mapping result could provide authority and environmental managers with a general view of fresh-saltwater distribution in order to have efficient exploiting and using water polices.

Data of previous projects, especially in last century, may be obsolete, which is a crucial handicap for researching about the recent quality. Therefore, it would be better continuously conducting new investigations and get up-to-date data in order to update information about the groundwater extraction status as well as achieve high accuracy in studies, calculations and create highly reliable maps.

ACKNOWLEDGEMENTS

This paper was completed thank to the support of Vietnam Academy of Science and Technology (VAST) project: “Research of saltwater intrusion level in Pleistocene aquifer in Nam Dinh coastal zone due to overexploitation of groundwater”, code VAST06.06/14-15.

References

[1] Doan Van Canh *et al.,* ”Groundwater resource of Nam Dinh Province”, Journal of Geology, 2005.

[2] Frank Wagner *et al.,* “Assessment of Groundwater Resources in Nam Dinh Province”, Final Technical Report, Part A, Improvement of Groundwater Protection in VietNam, September 2011.

[3] Geoff Bohling, “Introduction to geostatistics and variogram analysis”, October 2005.

[4] Nguyen Van Dan *et al.,* “Research on the application of hydrogeological, geophysical and modelling methods for the investigation and assessment of salt intrusion and searching for fresh water lens or aquifers in the coastal area of Nam Dinh”, Center for Water Resources Planning and Investigation, Hanoi 2009.

[5] Nguyen Van Do, “Report on hydrogeological mapping at a scale 1:50.000 in Nam Dinh area”, Department of Geology, Hanoi 1996.

[6] Vincent Post, Elena Abarca, “Saltwater and freshwater interactions in coastal aquifers”, Hydrogeology Journal 18, 2010.