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Assessment of Groundwater Level and Quality: A Case Study in O Mon and Binh Thuy Districts, Can Tho City, Vietnam

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Abstract – **The objective of this study was to assess the current state of groundwater use and exploitation, groundwater level trends and groundwater quality changes in O Mon and Binh Thuy districts, Can Tho city. In this study the following methods were used: (i) descriptive statistics, (ii) spatial interpolation by Kriging method, (iii) trend analysis. The results show that groundwater exploitation is mainly from the Pleistocene aquifer, of which 85.6% is exploited for industrial production purposes and urban water supply. This has led to the decrease in groundwater levels of the aquifer at an average rate of 24.05 cm/year in the 2001-2013 period. There are higher rates of groundwater level decrease in industrial zones which have more diverse types of water-usage than other areas. Groundwater quality has been assessed to be good up to the present, but this is tending to reduce due to chloride, organic matter and microorganism contamination. In particular, total coliform remains a leading pollution indicator with average probability in overall observation samples of 75.5% (with 376 MPN/100ml). Tra Noc industrial zone is defined as one of the areas with the highest micro-organism contamination with average probability of 89.0%, which is 141 times higher than the standard (Vietnam technical regulation on groundwater quality - QCVN09:2008/BTNMT).**

Keywords – Groundwater level, Groundwater quality, Exploitation volume, Industrial zone, Kriging interpolation.

1. Introduction

As an urban area located at the center of the Vietnamese Mekong Delta, Can Tho city is currently undergoing a transformation into a more urbanised character. Urbanization and population growth has lead to higher demand for fresh water supply. Groundwater is the best option in context of decline both quantity and quality of domestic surface water. However, according to Can Tho city Department of Natural Resources and Environment's observation results, during the period 2000-2010 the groundwater level at Tra Noc industrial zone declined at an average rate of 41.24cm/year in the Middle-Upper Pleistocene aquifer (qp2-3), 37.64cm/year in the Upper Pleistocen aquifer (qp3), and 22.09cm/yearin the Holocene aquifer (qh). One possible result of the decreased groundwater levels is the subsidence of the natural ground surface in Can Tho city [1].

Groundwater resources management by the local authorities in the Tra Noc industrial zone has failed to control the exploitation of the ground water, leading to over-exploitation. There are many administrative problems in the local authoritites, including many legal documentation requirements, problems of registration guidance, failure to correctly issue well exploitation licenses in communities. The functions of the various responsible authorities overlap, particularly in regard to issuing sub-law document promulgation and regulations [2]. During the period of over-exploitation many wells were constructed which did not comply with construction standards. Damaged wells have not been filled in, which has led to groundwater pollution. In general, however, the groundwater in the Pleistocene, Pliocene and Miocene aquifers in Can Tho city is of relatively good quality. It is found that chlorides, iron-ion and nitrate concentrations in these three aquifers have been found to have a decreasing trend [1].

According to the master plan of Can Tho city (created under Decision No. 207/2006/QĐ - TTg of the Prime Minister), by 2025 the industrial areas will be expanded. Industrial and serviced urban areas will extend to the northwest of Thot Not District, along the Bassac river. High-tech zones will expand to the north of O Mon canal. Heavy industrial areas will expand to an international river port in the south of O Mon canal. The construction of the necessary infrastructures will bring some socio-economic prospery, but they might have significant negative impacts on groundwater resources.

The objectives of the current study were: (i) to identify the current state of groundwater use and level of aquifer exploitation; (ii) to assess groundwater level trends in the 2001-2013 period, and groundwater quality changes in the 1999-2012 period based on QCVN 09:2008/BTNMT (Vietnam national technical regulation on groundwater quality) [3].

2. STUDY AREA AND DATA COLLECTION

2.1 Study Area

Can Tho city, a city directly under the central authorities, is the fourth-largest city in Vietnam and the largest city in the Mekong Delta. It is located in the centre of the Mekong Delta. Being dubbed as "the capital city of Southwestern Vietnam", more than one hundred years ago, Can Tho city has become the level-1 city and one of the four provinces and cities of the Mekong River Delta Key Economic Zones – the fourth key economic zone of Vietnam. Can Tho city has advantages concerning agricultural and aquatic products as well as being in a geographical position that helps the city develop in areas such as urban infrastructure, traffic infrastructure, hi-tech agriculture, agricultural–aquatic products and the seafood processing, tourism and supportive industries (figure 1).

The city is nicknamed the "western capital" and is located 169-kilometres (105 miles) from Ho Chi Minh city. Can Tho city's climate is tropical and monsoonal with two seasons: the rainy season, from May to November; and the dry season, from December to April. Average annual humidity is 83%, rainfall is 1,635 mm and temperature is 27 °C (81 °F).

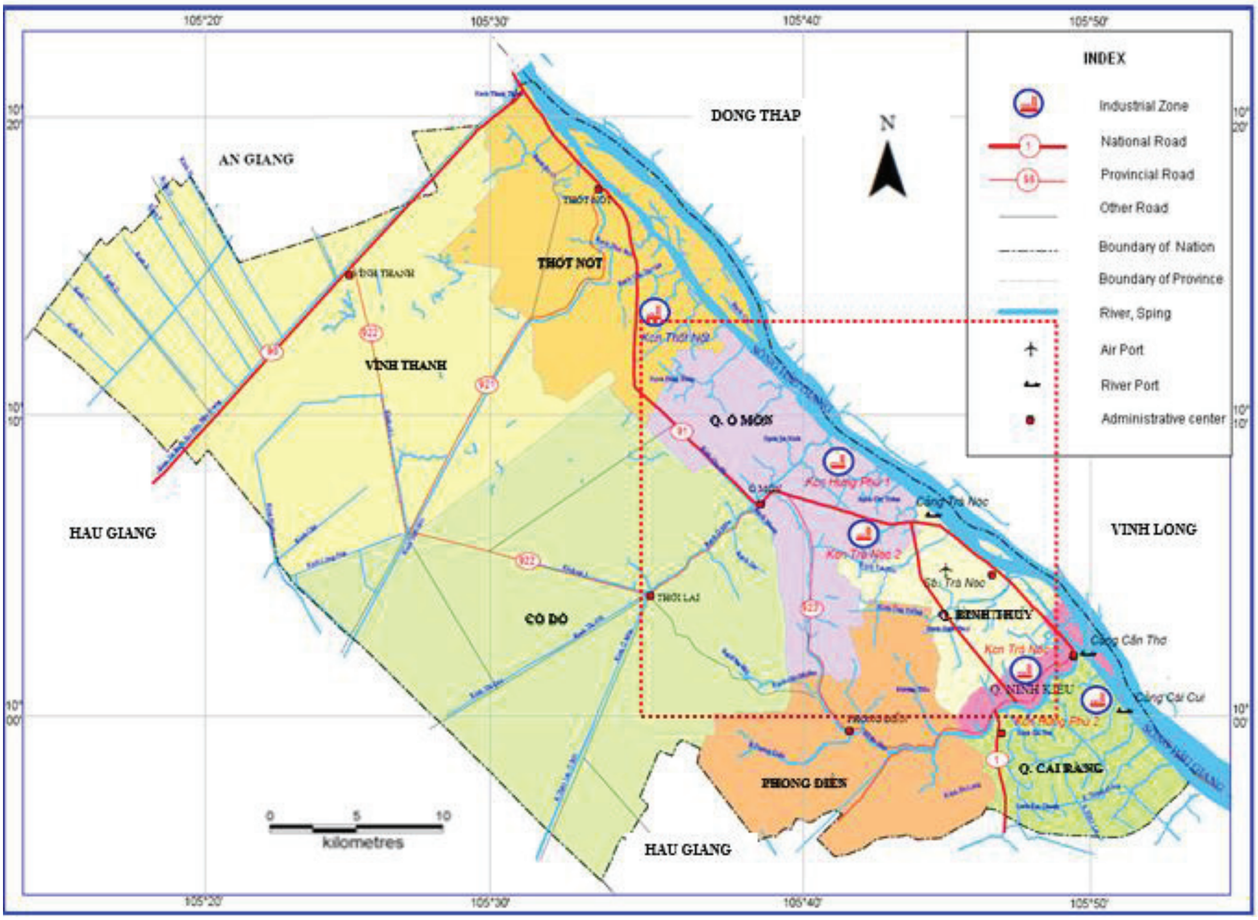

Figure 1 Can Tho city map and O Mon, Binh Thuy distrits map

(Can Tho city Department of Natural Resources and Environment, 2014)

Table 1 Data collection

Data	Duration	Notes
Groundwater qualityobservation data	1999-2012 period	- 9 monitoring wells - Frequency: 1 time/ 6 months
Groundwater level observation data	2002-2013 period	- 5 monitoring wells - Frequency: 1time/ 5 days
Groundwater exploitation data	2002– 2013 period	

Data Collection

The series of groundwater data was collected from Can Tho city Department of Natural Resources and Environment, and Division for Water Resources Planning and Investigation for the South of Vietnam. Specific information about data collection is shown in table 1.

3. METHODOLOGY

The framework of the methodology is presented in figure 2. Details are explained in the following sub-sections.

3.1 Descriptive Statistics Method

In this study, probability, mathematical statistics and the Kriging interpolation method were used. Groundwater quality observations were collected from 1999-2012; sampling frequency was 2 times/year. The probability is calculated by:

$$p(x_i) = \frac{x_k}{n}$$

where: $p(x_i)$ is probability value; x_k is total samples which have higher values than standard values (compared to QCVN 09:2008/BTNMT); and n is total observation samples.

3.2 Interpolation Method (Kriging Method)

The Kriging interpolation method is an effective tool to assess groundwater levels. Groundwater level elevation data was collected in 2007 and 2013. In this research, 16 groundwater level observation-wells were selected in the mathematical Kriging model. The rule of variation relationship of data with distance has been approximately equal to one of these predetermined functions (Spherical function, Gaussian, Exponential, Power). The Kriging model was calculated in Arcgis 10.2 version. All Kriging estimators are variants of the basic linear regression estimator Z*(u) [4, 5] defined as:

$$Z^*(\mathbf{u}) - m(\mathbf{u}) = \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha \left[Z(\mathbf{u}_\alpha) - m(\mathbf{u}_\alpha) \right]$$

where: u, uα are location vectors for estimation point and one of the neighboring data points, indexed by α, n(u) is the number of data points in the local neighborhood used for estimation of Z*(u).m(u), and m(uα) is expected values (means) of Z(u) and Z(uα). λα (u) is the Kriging weight assigned to datum z(uα) for the estimation location u; the same datum will receive a different weight for different estimation location. Z(u) is treated as a random field with a trend component, m(u), and a residual component, with R(u) = Z(u) - m(u).

Kriging estimates residual at u as weighted sum of residuals at surrounding data points.

Kriging weights, λα, are derived from covariance function or semivariogram, which should characterize residual component. Distinction between trend and residual is somewhat arbitrary, varying with scale.

3.3 Geological Characteristics of Research Area

The two districts selected for this study have relatively low and flat terrains. Surface soil derives from alluvial soil of the Bassac River and regular sediment deposition. There are two main kinds of deposits, namely: Holocene (new alluvial) and Pleistocene (old alluvial). A hydrogeological cross-section of the aquifers across O Mon - Thot Not – Can Tho city is presented in figure 3.

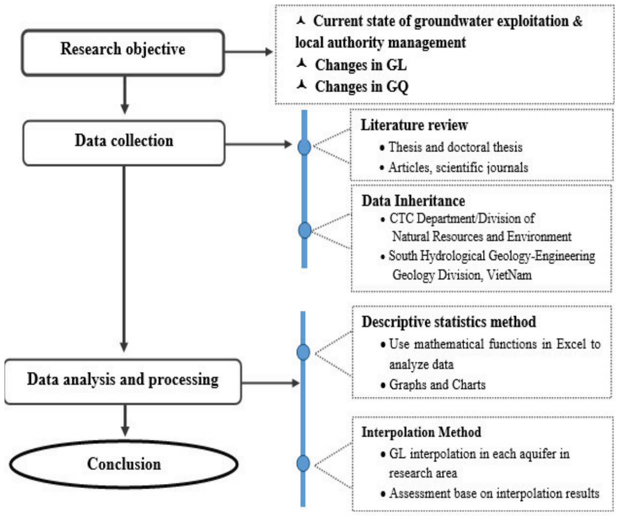

Figure 2 Study design

4. RESULTS AND DISCUSSIONS

4.1 State of Groundwater Abstraction

The statistical results of groundwater exploitation license issuance in Can Tho city by November, 2013 show that there are 70 exploitation-wells with large capacity in the area. Particularly, O Mon district has 54 wells that are registered, which account for 77% of the total. The highest exploitation volume rate is 14,284 m3/day in this district, accounting for 62% of the total volume extracted (figure 4).

Groundwater resources are mainly exploited in the Pliocene and Pleistocene aquifers. The total exploitation volume is 14,952 m^3/day. Currently, exploitation volume of groundwater resources in O Mon district primarily serves the purpose of water supply in urban areas and in industrial production and account for 99% of the total exploitation volume. Elsewhere, this figure in Binh Thuy district is only 62%.

Table 2 shows the exploitation volume (Total Q) for different purposes. Table 2 (combined with figure 4) shows that Binh Thuy district has no planto develop various types of water-uses with large groundwater exploitation volumes. Thus, O Mon district may be more significantly impacted by industrial activities in urbanization and industrialization process of Can Tho city.

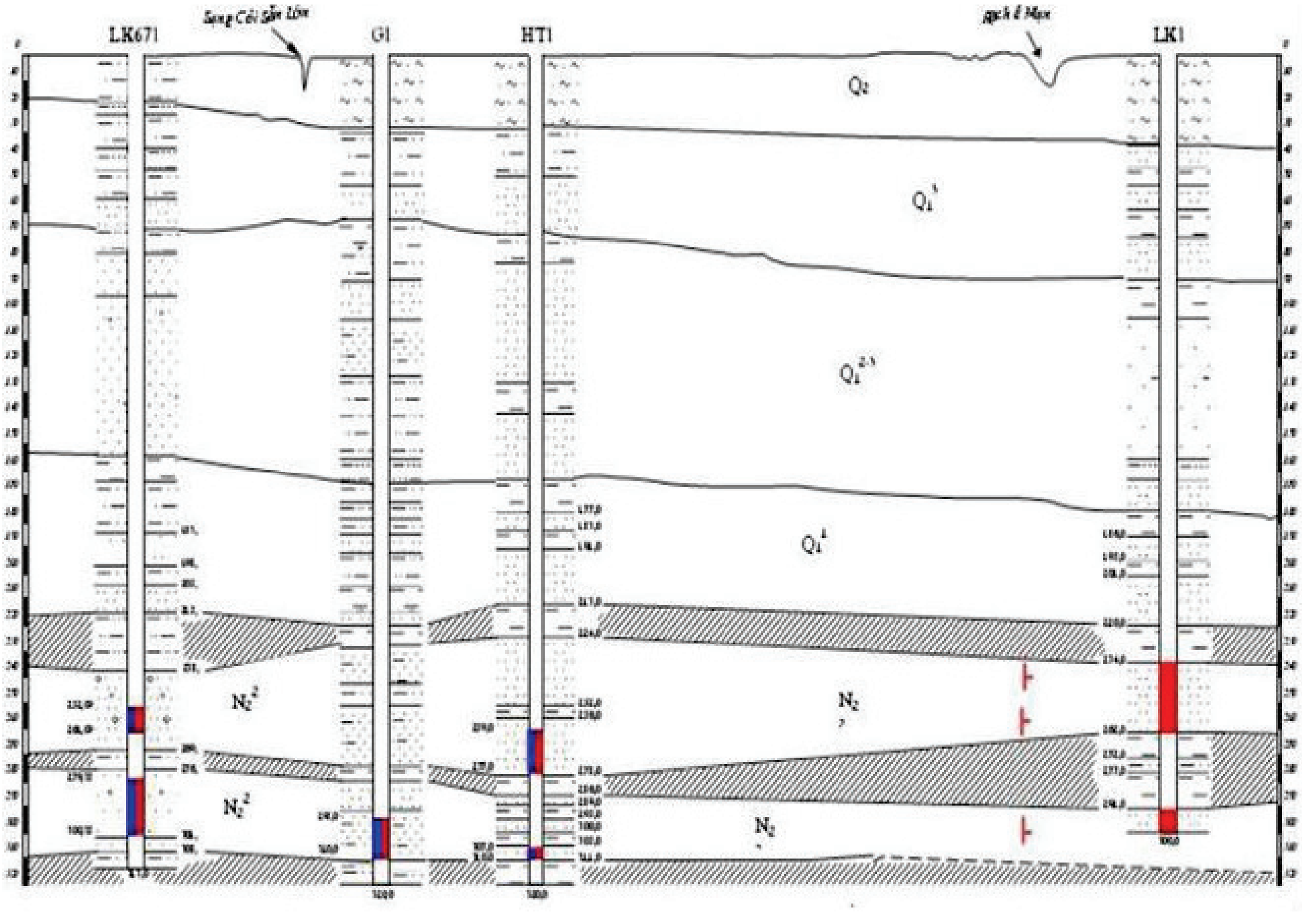

Figure 3 Hydrological Geology section of aquifers in O Mon - Thot Not – CTC

(Can Tho city Department of Natural Resources and Environment, 2014)

Table 2 Exploitation volume (Q) in different purposes (Unit m^3/day)

Purpose of use	**Aquifers**		**Total Q**
	Pleistocene aquifer	**Pliocene aquifer**	
Water supply	4.872	5.784	10.656
Construction	50	0	50
Service	800	0	800
Household production	2.430	0	2.430
Industrial production	6.800	2.000	8.800
Total Q	14.952	7.784	22.736

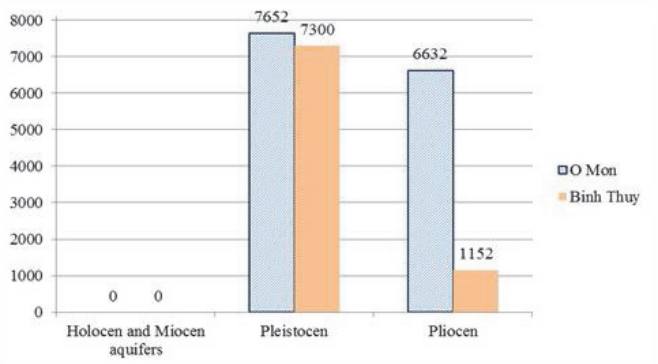

Figure 4 Exploited volume of groundwater resources in different aquifers

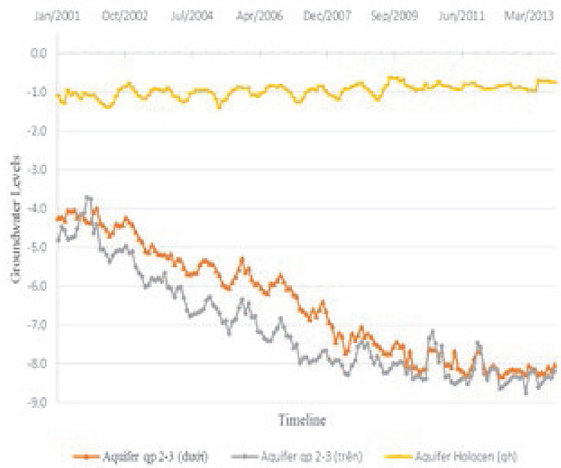

Figure 5 Trending of GWL at QT8 monitor

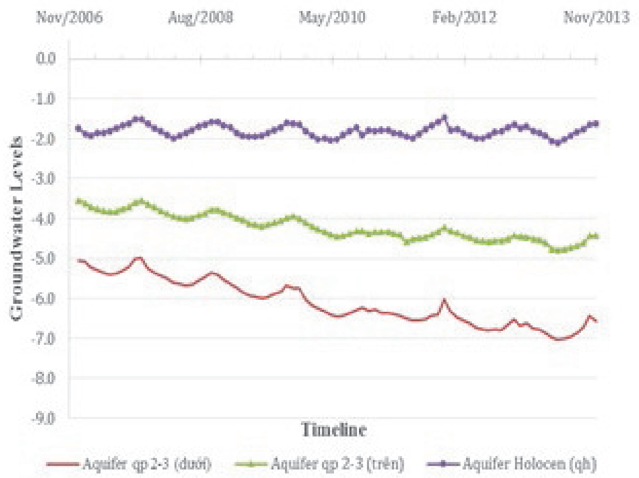

Figure 6 Trending of GWL changes at BS02 monitor

4.2 Changes in Groundwater Level

Static groundwater level has declined due to the expansion of the radius of exploitation-wells. Meanwhile, groundwater level fluctuation in Holocene aquifer has been relatively stable. Data from the QT8 and BS02 monitoring stations (figure 7), show that groundwater levels have risen 2.68 cm/year and 2.39 cm/year, respectively. In brief, the groundwater level in Pleistocene and Pliocene aquifers in the industrial zone has dropped. Although groundwater level in Holocene aquifer has not had a big change, it still needs to be monitored for a longer period.

The observations from 2002 to 2013 have shown that groundwater level both upper and lower-Pleistocene aquifers have been lowered considerably. In 2002–2013 period, the groundwater level has been declining with an average speed of -26.32 cm/year at QT8 monitoring well and of -12.96 cm/year at BS02 monitoring well in upper-Pleistocene aquifer (figures 5 and 6). However, the highest groundwater level drawdown of these two monitoring wells appeared in the first period when industrial zone was newly established. Tra Noc industrial zone has many exploitation-wells with large capacity, from 50-80 m3/hour. Thus, this affects natural static groundwater level.

4.3 Changes in Groundwater Quality

The results showed that groundwater quality in some monitoring wells is relatively good. However, the groundwater quality has been decreasing over years in 1999-2012 period due to chloride pollution, organic matter and micro-organism contamination. Particularly, coliform has the probability of 75.5% in total observation samples, followed by COD (Chemical Oxygen Demand) of 25.9% (figures 8 and 9). When groundwater quality observation data were compared with QCVN09:2008/BTNMT, such as iron, N-NO3-, SO42-, pH and most heavy metals, all of these parameter values were seen to be below standard values. However, groundwater hardness and salinity are still found to exceed standard values with a mean probability of 8.6% and 16%, respectively.

Figure 9 showed that the Tra Noc industrial zone has a total coliform parameter with mean probability of 89% that exceeds the standard value in most of areas (wards/villages). O Mon market area has the highest COD with probability of 41.2%. The results also show large differences and changes in the concentration of pollutants in the dry season and the rainy season (figure 10).

The calculated probability of both the total coliform and COD parameters in the rainy season are always higher than those in the dry season. In particular, the total coliform probability is 67.7% in the dry season and 89.7% in the rainy season. These of COD is 20.83% in the dry season and 37.78%, in the wet season. The groundwater hardness and manganese-ion content have fluctuated with a probability of less than 20% in different seasons.

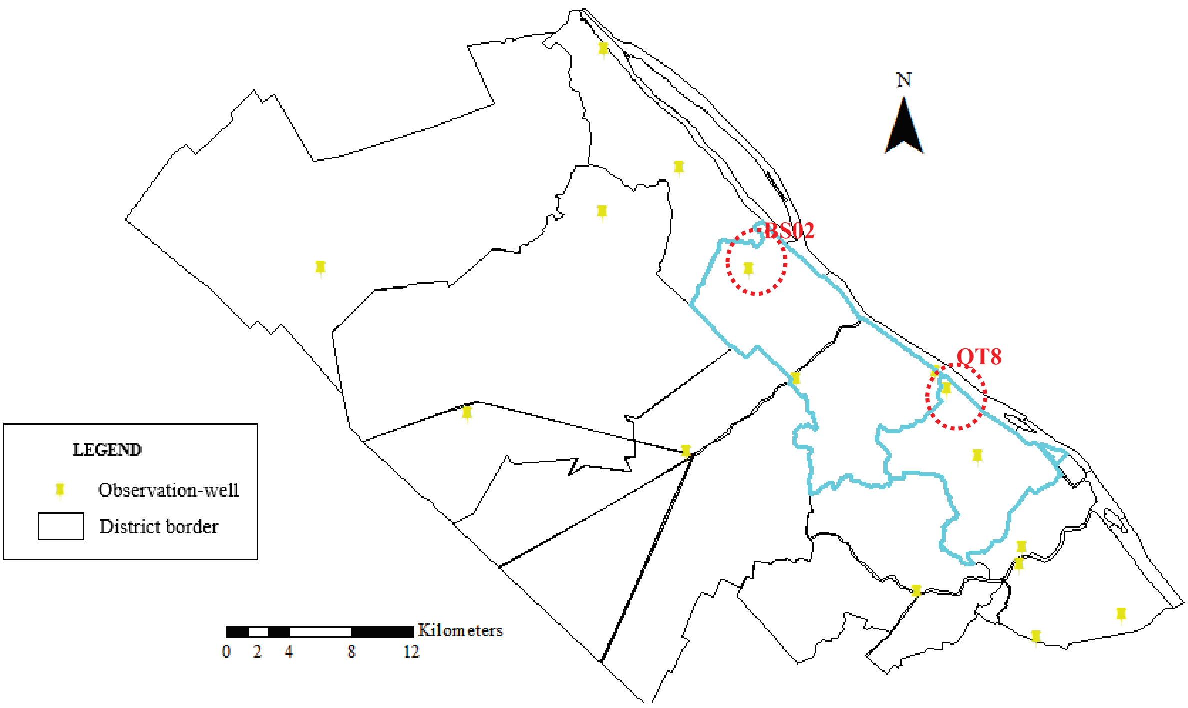

Figure 7 Locations of groundwater level observation-wells in the study area

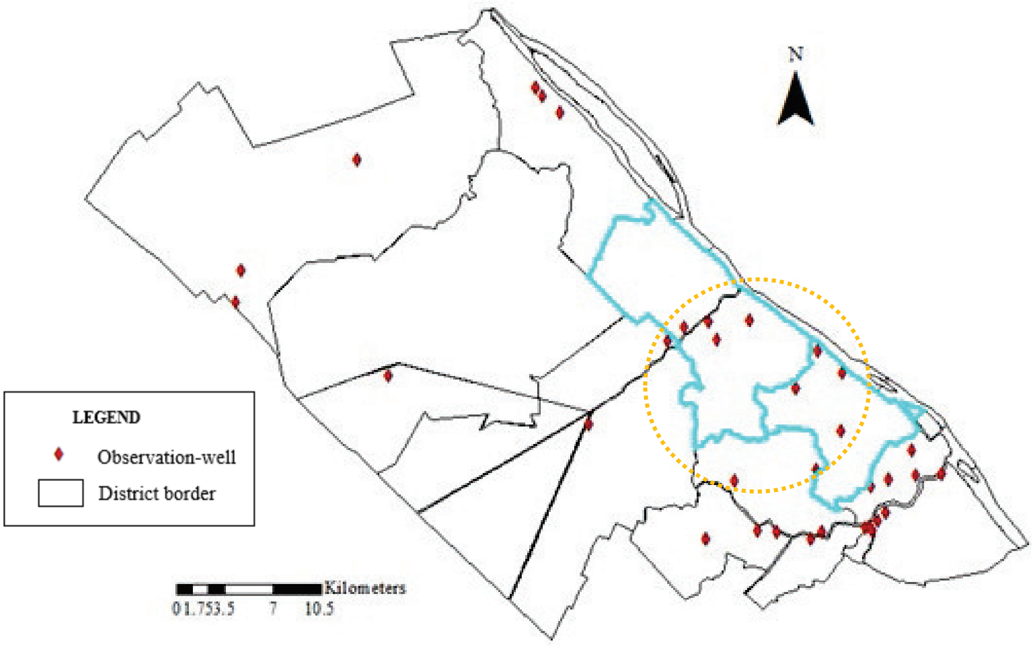

Figure 8 Groundwater quality observation-wells map in research area

Figure 9 Probability in some groundwater quality parameters compared with QCVN 09:2008/BTNMT

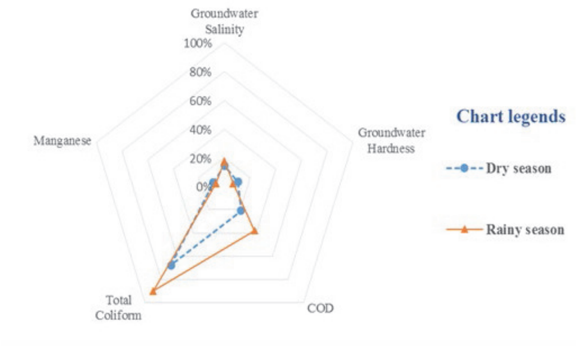

Figure 10 Probability of parameters compared with QCVN 09:2008/BTNMT in different season in 1999-2013 period

4.4 Results of Groundwater Level Interpolation

To visualize groundwater level changes over space and time, geostatistical methods and spatial interpolation analysis have been applied. The relationship between data on the groundwater level in each aquifer has been established. The construction of a semi-variogram diagram reflects the relationship between the variability of the data and the distance of groundwater level points in all observation wells. The selection of a semi-variogram model is then fitted to the set of data blocks (figure 11).

Interpolation methods were applied with values of data blocks on the the groundwater level in the lower-Pleistocene aquifer in 2007. These points have been distributed along the broken lines in the Q-Q plot graph (figure 12). The input data was divided into four groups corresponding to the distribution weight in the top and bottom groundwater levels in 2007 and 2013.

For the semi-variogram chart shown in figure 11, a Gaussian function was applied with the following parameters: Nugget = 0.00174; Partial Sill = 1.0323; Range = 56632.29. The interpolation results from this model have been aggregated for the groundwater level map for the entire region of the lower-Pleistocene aquifer in 2007 and 2013 (figure 13). Similar manipulation of these interpolation results of the groundwater level for both the upper-Pleistocene aquifer and Holocene aquifer in this region are shown in figures 14 and 15.

The interpolation results of groundwater levels in the space showed that both lower and upper-Pleistocene aquifers have relatively large fluctuations. In 2007, static groundwater levels were slightly higher than that in 2013. The results also showed that in these areas the groundwater level has been declining rapidly focusing on the industrial zone of the research area.

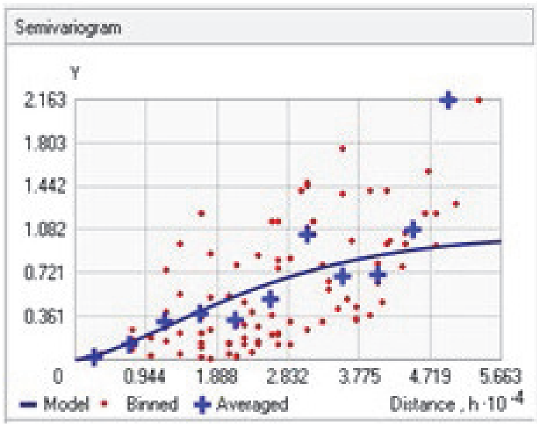

Figure 11 Semi-variogram diagramof spatial interpolation method

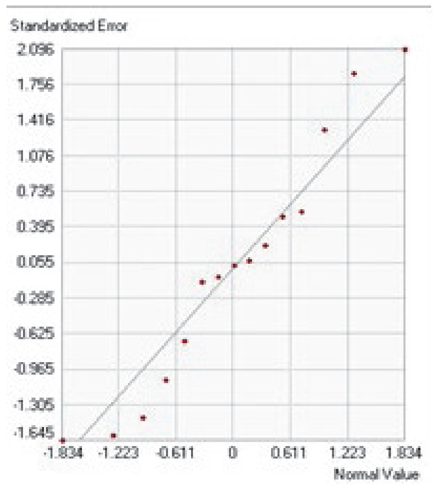

Figure 12 Q-Q plot graph of the data groups of lower-Pleistocene aquifer in 2007

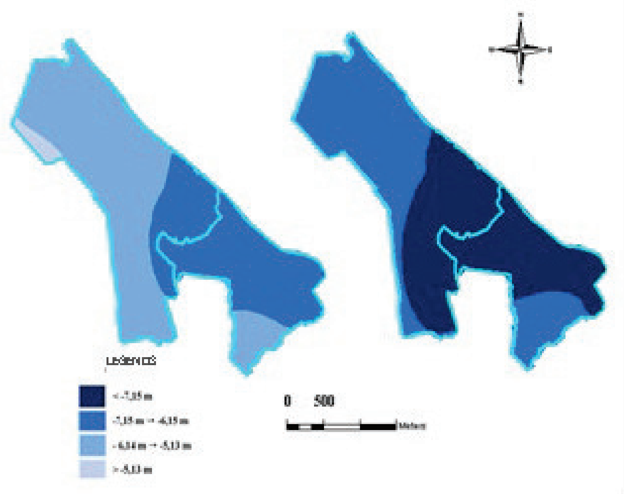

Figure 13 Equal groundwater level contour map in lower-Pleistocene aquifer 2007 (left) and 2013 (right)

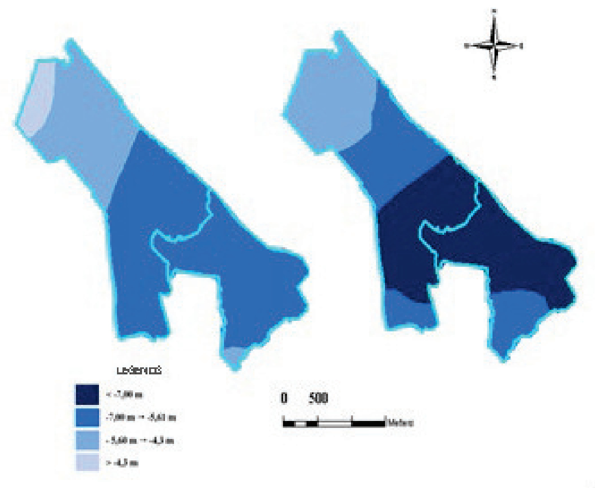

Figure 14 Equal groundwater level contour map in upper-Pleistocene aquifer 2007 (left) and 2013 (right)

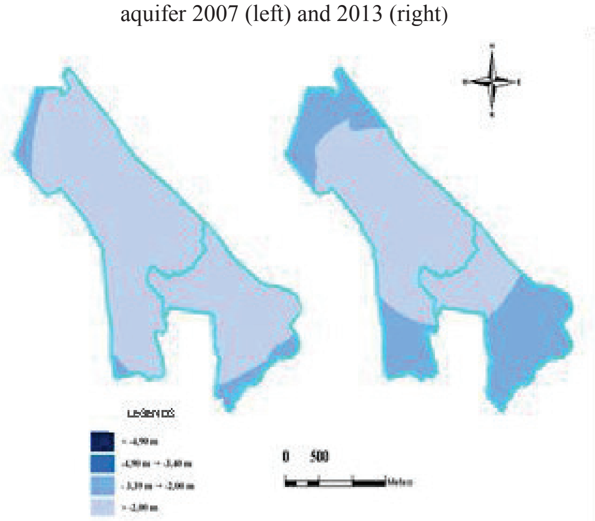

Figure 15 Equal groundwater level contour map in Holocen aquifer 2007 (left) and 2013 (right)

5. CONCLUSIONS

The analysis of the data of current groundwater exploitation shows that 85.6% of groundwater resources are exploited to serve industrial production purposes and urban water supply. The groundwater which has been most exploited is in the Pleistocene aquifer where the groundwater level has been declining with an average speed of -24.05 cm/year. These results reflect the current rate of exploitation and explain the main reason that groundwater level has been declining rapidly. Spatial interpolation results of groundwater levels in 2007 and 2013 also have shown differences across the research region in the space. The groundwater levels in the industrial zone and services areas have been relatively deeper than in other sub-regions. In terms of long-time period, this over exploitation is a serious matter.

Pollutants in the groundwater, such as chlorine, organic matter and microorganism contamination, have degraded the quality of the groundwater over the period 1999 to 2012, In particular, total coliform still remains the leading indicator with average probability of 75.5% (with 376 MPN/100ml). Especially, the Tra Noc industrial zone is shown to have the highest microbial contamination concentration with average probability of 89%, exceeding by 141 times the Vietnam national technical regulations on groundwater quality with limit concentration: 3 MPN/100 ml (QCVN09: 2008/BTNMT). In addition, COD, groundwater hardness and chloride were detected to exceed the standard with average probability of 16.8%.

6. ACKNOWLEDGMENT

This research is one output from the recent project named ‘Assessment of groundwater resources in Can Tho city’ including 2 chapters: (i) Current state of local authorities management for exploitation license insurance of groundwater resources; (ii) Application Visual Modflow model for assess trending of groundwater level in O Mon and Binh Thuy districts, which was jointly conducted by Can Tho University and Viet Nam Brewery Limited Company. The project was funded by the research program Security Water Resources formation by Viet Nam Brewery Limited Company. We gratefully acknowledge the significant contribution of all local agencies from Can Tho city, especially Vietnam Brewery Limited and the Can Tho Department of Natural Resources and Environment. In addition, many thanks to Mr. Roy Morien of the Naresuan University Language Centre for his editing assistance and advice on English expression in this manuscript.

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