Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 16	No. 1	pp. 115-124	2017

Original Research Paper | Open Access

Effects of Porous Confined Groundwater Depth of Yancheng Coastal Alluvial Plain on Water Quality

Ma Junting*†, Chen Suozhong, He Zhichao* and Zhu Xiaoting***

*Key Laboratory of Virtual Geographical Environment, Ministry of Education (National Education Administration), College of Geographical Sciences, Nanjing Normal University, Nanjing, 210023, China

**Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing, 210023, China

†Corresponding Author: Ma Junting

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 15-01-2016
Accepted: 18-03-2016

Key Words:
Confined aquifer
Water quality factor
Aquifer depth
Correlation
Dynamic evolution

ABSTRACT

The space structure of aquifer (group) does not only determine the spatial distribution pattern of groundwater, but also impose some effects on the groundwater quality. Based on the internal hydrogeological borehole data in hydrogeological division of Yancheng Coastal Plain and water quality factor monitoring data during 2005~2014, geographic information science (GIS) and analysis of variance (ANOVA) method etc., are applied to the research response characteristics of aquifer roof depth changes in time-space dimension for the quality of porous groundwater of confined aquifer III in experiment sample area. This paper analyses the dynamic evolution laws of groundwater quality and proposes suggestions on groundwater management and protection in the research area. The research result shows that the depth of confined aquifer III in this area mostly goes between -118.9 ~-85.45 m. Due to hydrogeological conditions of groundwater with different depths and exploitation and utilization differences, there is some correlation between a typical water quality factor of groundwater and aquifer depth. Mineralization, total alkalinity and total bacterial count have the strongest correlation strength with the depth (relevancy: 69.67 %, 75.76 % and 58.09 %). The strength of total hardness is at an intermediate level (49.18 %). $KMnO_4$ index is less affected by the depth (35.27 %). It is also found that the correlation strengths between factors and depth in various depth classification areas are significantly different, indicating different dynamic evolution characteristics.

INTRODUCTION

Porous confined groundwater is widely distributed in the central sections of a plain or basin. Normally, it has a deep burial depth and closed geological structure. It is little affected by climate, featuring stable flow, good water quality and no pollution. It is an important water supply source for human being (Xueyu & Xiaoxing 2005). With rapid development of society and economy, the demand for groundwater is increasingly urgent. As the groundwater exploitation is intensified, the groundwater environment will change significantly, which results in a series of groundwater environment problems and bring serious harm to ecology and human activities (Hao et al. 2010). Yancheng Coastal Plain is located in the middle of the east coast of China. As the population increases and industry and agriculture develops rapidly, the porous confined groundwater buried in deep ground surface is becoming a main water supply source for many towns (Yuxi et al. 2015, Suozhong et al. 2005). The area contains sedimentary strata in tertiary quaternary systems and forms a very thick and loose gap aquifer system. In particular, unconfined groundwater and confined aquifer I contains relatively high groundwater salinity. Confined aquifers II and III have good water quality and serve as applied water. With the rapid development of industry and agriculture since 1990s, the groundwater exploitation has increased, and the concentrated exploitation in some local areas has caused the decline of water level, saltwater intrusion, ground subsidence and other geological environmental problems (Yanling 2005). At present stage, the research on porous confined groundwater distribution and evolution laws in the coastal plain area is of some practical significance to the protection of groundwater resources and production guidance in this type of area.

The current research on the groundwater in this area is mainly conducted from the perspective of survey and analysis on groundwater. For example, Cheng Hongwei took testing data for 21 representative wells in Yancheng to analyse the distribution trend of mineralization, ammonia nitrogen amount and other water quality factors in space and time (Hongwei 1998). Based on the water quality monitoring data, Bian Jinyu et al. adopted main control factor analysis method to analyse the control factors of groundwater quality in Yancheng (Jinyu & Rui 2003). This research has described and analysed time-space dynamic change characteristic quantification for groundwater, but the researches on the effects of this area on groundwater quality changes are few. As a matter of fact, there are lot of researches on the quality changes and effects at home and abroad. For example, Liao Zisheng et al. analysed the effect factors for water quality change trend in groundwater system of Songnen Basin (Zishen & Xueyu 2004). Han Yinli et al. took deep groundwater exploration of Yinchuan Plain as guidance and established a mathematic model for groundwater mineralization and aquifer resistance of fluvial and pluvial deposition of Yinchuan Plain and lake-river deposition to obtain the correlation between groundwater quality in this area and resistance (Yinli et al. 2008). Tang Changyuan et al. researched the effects of the wetland in upstream of Chiba, Japan on groundwater quality and pointed out that the wetland had certain inhibitive effects on the nitrate content in groundwater (Changyuan et al. 2005). Serhal Hani researched the effects of fertilizer and pollutant on groundwater quality in Cambrai, France (Hani & Daniel 2009). The above researches adopt various means to obtain the effect mechanism of time-space distribution characteristics for groundwater quality from different factors. The research on dynamic changes of hydrogeological division in Yancheng Coast provides a useful reference. However, the current researches on effect factors for groundwater quality of hydrogeological division in Yancheng Coastal Plain are very few. How to analyze the correlation between different effect factors and groundwater quality by combing hydrogeological characteristics of Yancheng Coastal Plain is of important significance to revealing groundwater evolution laws and mechanism in this area. In view of the fact that the depth of aquifer is a typical characteristic of aquifer spatial distribution and it has a certain effect on time-space evolution characteristics of some groundwater quality factors, this paper carries out a research on the correlation between the content of groundwater quality factor and aquifer depth from the perspective of the spatial distribution pattern aquifer. Based on the hydrogeological borehole data in the research area and aqueous dynamic monitoring data, hierarchical information of objective confined aquifer in boreholes are extracted, aquifer roof depth digital elevation model (DEM) is constructed. GIS and ANOVA statistical analysis methods are applied to reveal the effects of the depth of confined aquifer III in the hydrogeological area of the Yancheng Coastal Plain on pore groundwater quality and provide a reference for scientific management and protection of pore groundwater resource in Yancheng Coastal Plain.

STUDY AREA

Study area is located in the north of hydrogeological division of Yancheng Coastal Plain, bordering Northern Jiangsu Main Irrigation Canal in the north and Doulong Port in the south and lying between 33°15'~34°12' N and 119° 34'~120°41' E. It totals an area of about 6,177.11 km^2, as shown in Fig. 1. The plain is formed by continual alleviation of seawater and rivers for nearly 2,000-3,000 years. The water networks in the area are densely distributed, forming a plain geomorphic type of coastal water network and extending to the sea nowadays (Zujiang et al. 2005). The terrain in the area is low, flat, slanting from southeast to northwest. The terrain in Dafeng is relatively high, with an altitude of about 3~5 m. It goes lower northwards and extends to the Sheyang River by about 1~1.5 m.

The confined groundwater in the research area is in the pore of loose sediment strata, and its depth goes between 50~350 m (Fig. 2). Aquifer is mainly a loose sediment strata sandstone, gravel or limestone, containing abundant and stable water content (Zujiang 2005, Suozhong 2004). An aquiclude is formed by clay or silt clay layer among different aquifers. According to sediment age, formation cause, strata structure and hydrogeological characteristics, the area has five aquifer groups: aquifer I, aquifer II, aquifer III, aquifer IV and aquifer V. In particular, porous unconfined groundwater and micro-confined water mainly receive atmospheric precipitation, surface water and agricultural irrigation water infiltration recharge. Discharge mode is evaporation and exploitation. The confined groundwater I and II are saline water, brackish water and salt water. The underlying Neogene System strata contains aquifer groups IV and V which receives upside leaking recharge and lateral recharge of western and central mountains. Main discharge mode is artificial exploitation. Aquifer III is composed of fine sand and medium-coarse sand in lower pleistocene series, and its thickness mostly goes between 20.00~35.00 m. With rich water yield property, it is the main exploitation bed for groundwater in the research area, sharing a close relation with human beings. Therefore, confined aquifer III in the research area is selected in this paper as a research object (Feng 2003).

DATASETS UTILIZED

Research data acquisition: Research data includes exploration data of 60 hydrogeological boreholes in Yancheng City. The aquifer distribution diagram is prepared by extracting information of roof depth of the confined aquifer III in hydrogeological boreholes. According to groundwater dynamic change laws and thematic map for aquifer depth

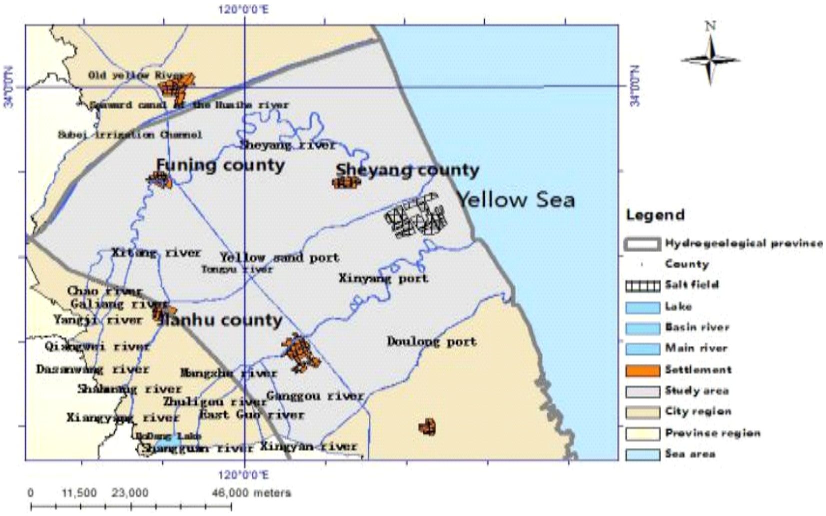

Fig.1: Location and extent of study area.

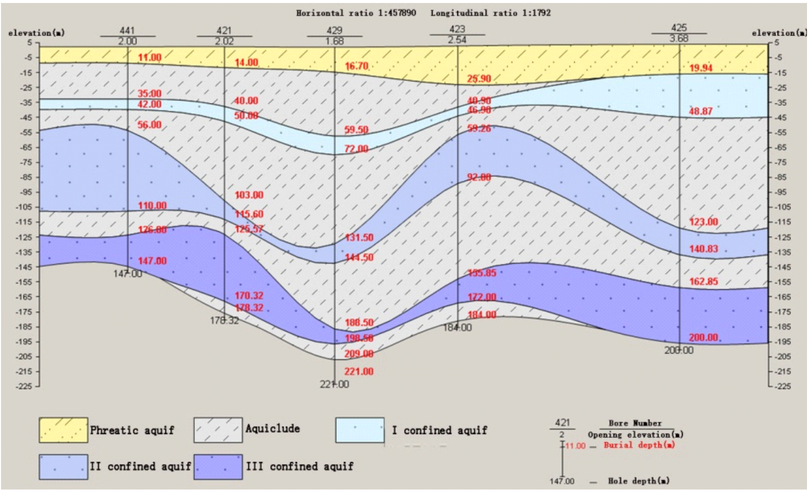

Fig. 2: Confined groundwater burial conditions schematic.

classification, 18 dynamic monitoring wells are selected within the research scope, and their water quality monitoring data during 2005~2014 are extracted. The position information of each borehole and monitoring well is extracted by GPS. Xi'an 80 ellipsoid with 3° belt dispersion and Gauss Kruger projected coordinate system is adopted. The spatial distribution for the selected groundwater monitoring wells and hydrogeological boreholes is shown in Fig. 3.

Classification of water quality factor: There are many kinds of groundwater quality monitoring factors in Yancheng Coastal Plain. According to area groundwater distribution characteristics, refer to water quality factor classification standard of *Groundwater Environment Quality Standard* (GB/T14848-93). According to actual water quality monitoring in this area and the effects of different indexes on industrial and agricultural production and human life, 5 factors (mineralization, total hardness, total alkalinity, $KMnO_4$ index and total bacterial count) are selected as water quality indexes for analysis of effect factors for groundwater quality.

Aquifer depth DEM generation and treatment: Original data of hydrogeological borehole exploration in the research area is interpreted to generate standardized cards for hydrogeological boreholes. After that, database for hydrogeological boreholes is established. The database structure is shown in Fig. 4.

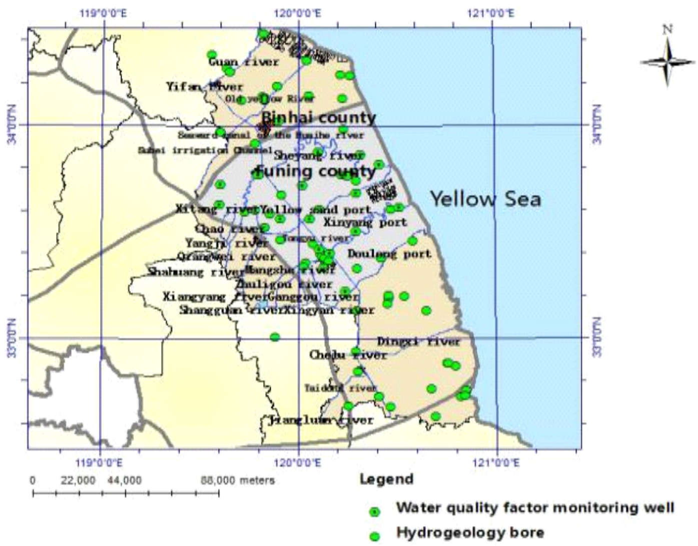

Fig. 3: Spatial distribution map of hydro-geological bore and groundwater monitoring well.

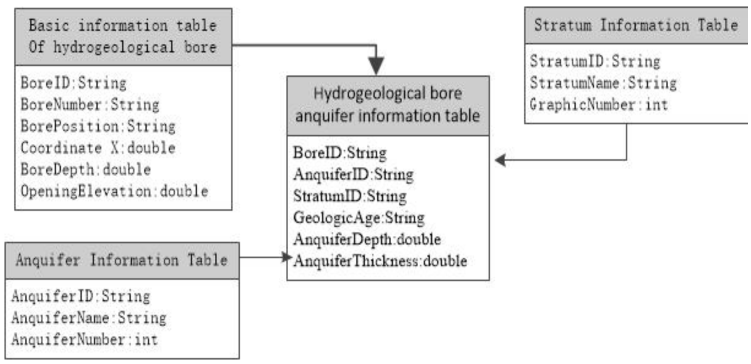

Fig. 4: Hydro-geological bore database structure.

Based on the above data structure, strata depth data extraction algorithm is designed. Position coordinate of each borehole and strata depth information are read from the borehole database to form original strata interface sampling points. The sampling points are imported to ArcGIS, spatial interpolation tool is used to establish a triangular irregular network (TIN) of strata interface, cap is conducted with coverage in the research area after the model is rasterized. Then, aquifer roof elevation DEM in the research area can be obtained. According to modelling area and differentiation of depth values, DEM cell size is set as 500 × 500 m. To research the correlation between the depth and water quality, the continual depth values are classified. The maximum and minimum roof elevations of confined aquifer III are -55.19 m and -160.87 m respectively. Classification test is conducted based on the spatial distribution diagram for water quality monitoring wells. Spatial distribution characteristics for aquifer can be completely displayed by dividing 10 equal spaced sections to make water quality factor distribution laws have good discrimination. Aquifer depth DEM in this research area and classification result are shown in Fig. 5.

Analysis and treatment of water quality factor monitoring data: The confined groundwater III in the research area has a deep burial depth and closed geological structure. Groundwater environment and water quality changes are stable. Since 2005, the local water conservancy administration department has sampled water quality for 1~ 2 time(s) every year, but only sampled water quality once in most years. Considering stability and seasonality and to facilitate the analysis, the sampling is conducted once a year in default. If sampling is conducted for 2 times in a certain year, it is agreed that the average value of the two sampling values will be used as the sampling value in the current year. Table 1 gives the monitoring data for water quality factors in 1# monitoring well after treatment.

Table 1: Monitoring well 1# data structure.

Monitoring factor	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Salinity (g/L)	0.78	0.67	0.53	0.55	0.86	0.61	0.54	0.91	0.87	0.82
Total hardness (mg/L)	244	185	169	141	147	159	208	210	207	96.9
Total alkalinity (mg/L)	436	448	433	554	392	421	485	491	446	474
$KMnO_4$ Index (mg/L)	1.20	0.30	1.60	0.80	0.80	0.40	0.90	0.70	0.80	1.20
Total bacterial count	20	10	13	20	10	30	15	20	15	10

Table 2: Valid burial depth classification interval and equivalent water quality sample data structure.

	-160.8~ -150.30	-150.30~ -139.74	-139.74~ -129.17	-129.17~ -118.60	-118.60~ -108.03	-108.03~ -86.89	-86.89~ -76.32	76.32~ -65.76	65.76~ -55.19
2005	Q_{11}	Q_{12}	Q_{13}	Q_{14}	Q_{15}	Q_{16}	Q_{17}	Q_{18}	Q_{19}
2006	Q_{21}	Q_{22}	Q_{23}	Q_{24}	Q_{25}	Q_{26}	Q_{27}	Q_{28}	Q_{29}
2007	Q_{31}	Q_{32}	Q_{33}	Q_{34}	Q_{35}	Q_{36}	Q_{37}	Q_{38}	Q_{39}
2008	Q_{41}	Q_{42}	Q_{43}	Q_{44}	Q_{45}	Q_{46}	Q_{47}	Q_{48}	Q_{49}
2009	Q_{51}	Q_{52}	Q_{53}	Q_{54}	Q_{55}	Q_{56}	Q_{57}	Q_{58}	Q_{59}
2010	Q_{61}	Q_{62}	Q_{63}	Q_{64}	Q_{65}	Q_{66}	Q_{67}	Q_{68}	Q_{69}
2011	Q_{71}	Q_{72}	Q_{73}	Q_{74}	Q_{75}	Q_{76}	Q_{77}	Q_{78}	Q_{79}
2012	Q_{81}	Q_{82}	Q_{83}	Q_{84}	Q_{85}	Q_{86}	Q_{87}	Q_{88}	Q_{89}
2013	Q_{91}	Q_{92}	Q_{93}	Q_{94}	Q_{95}	Q_{96}	Q_{97}	Q_{98}	Q_{99}
2014	Q_{101}	Q_{102}	Q_{103}	Q_{104}	Q_{105}	Q_{106}	Q_{107}	Q_{108}	Q_{109}
Sampling count	20	30	20	10	20	10	10	10	10

Note: Q_i is a variable to describe a water quality factor detected in the buried depth of j during the year of i.

Table 3: Aquifer III burial depth height classification and percentage.

Number	Elevation interval/m	Area/km^2	Percentage/ %	Number	Elevation interval/m	Area/km^2	Percentage %
1	-160.8~-129.31	267.47	4.33	6	-99.12~-92.91	1324.76	21.45
2	-127.31~-118.19	398.72	6.45	7	-92.91~-85.45	872.8	14.13
3	-118.9~-111.14	650.46	10.53	8	-85.45~-75.09	453.5	7.34
4	-111.14~-104.92	975.63	15.79	9	-75.09~-55.19	173.62	2.81
5	-104.92~-99.12	1060.15	17.16				

Table 4: ANOVA result table of water quality monitoring data.

Monitoring factors	Sum of squares (SS)		Mean square (MS)		F value	P value	Critical value F-Script
	Burial depth (SSA)	others (SSE)	Burial depth (MSA)	others (MSE)			
Salinity	8.71	9.24	1.09	0.07	15.44	0.0000071	2.01
Total hardness	204499.1	627479.3	25562.4	4789.92	5.34	0.0000083	2.01
Total alkalinity	465455.3	345592.0	58181.9	2638.11	22.054	0.0000054	2.01
$KMnO_4$ Index	7.03	49.40	0.88	0.38	2.33	0.023	2.01
Bacterial count	26551.98	52141.82	3319.00	398.03	8.34	0.0000042	2.01

Various depth classification areas and distribution are significantly different, and the number of monitoring wells is different. Therefore, all of historical monitoring data for these monitoring wells are used as a sample. To ensure the continuality of elevation value of depth classification, a few depth classification sections, excluding monitoring wells are included in the adjacent sections. After treatment, 9 valid classification sections (Table 2) are obtained. GIS overlay analysis tool is used to obtain the monitoring wells in every classification section. The monitoring data struc-

Table 5: Multiple comparative analysis result.

	Salinity		Total hardness		Total alkalinity		KMnO4 Index		Bacterial count	
	$\lvert \bar{x}_i - \bar{x}_j \rvert$	LSD	$\lvert \bar{x}_i - \bar{x}_j \rvert$	LSD	$\lvert \bar{x}_i - \bar{x}_j \rvert$	LSD	$\lvert \bar{x}_i - \bar{x}_j \rvert$	LSD	$\lvert \bar{x}_i - \bar{x}_j \rvert$	LSD
Test 1	0.149	0.152	73.665	39.584	41.23	29.358	0.045	0.351	20.433	11.40
Test 2	0.224	0.152	57.790	39.584	68.86	29.358	0.025	0.351	13.083	11.40
Test 3	1.001	0.204	106.88	53.073	144.20	39.387	0.185	0.471	17.85.	15.29
Test 4	0.780	0.204	71.045	53.073	138.91	39.387	0.045	0.471	8.500	15.29
Test 5	0.139	0.204	69.185	53.073	2.090	39.387	0.095	0.471	2.900	15.29
Test 6	0.191	0.235	38.770	61.284	33.200	45.481	0.690	0.544	14.400	17.66
Test 7	0.245	0.235	25.140	61.284	75.200	45.481	0.250	0.544	1.100	17.66
Test 8	0.128	0.235	29.430	61.284	189.80	45.481	0.630	0.544	11.200	17.66

ture for water quality factors is formed, as shown in Table 2.

METHODOLOGY AND RESULTS

Basic characteristics of depth distribution for confined aquifer III: The data of hydro-geological boreholes in the research area and the characteristic analysis of aquifer roof depth DEM show that the depth of confined aquifer III within the whole research area has a significant difference in space. The deepest roof elevation in the area is about -160.88 m, and the shallowest roof elevation is about -55.19 m. The depth changes are significant. In the wide coastal area in the east and west of the research area, the aquifer has a mild trend and a shallow depth due to the aquifer deposition. The narrow zone in the west of the research area has Xitang River and Jialiang River to form a plain water network. The river cutting is obvious, which causes significant changes of aquifer depth. In general, the aquifer elevates from the southwest to the northeast, showing a distribution characteristic of being basically opposite to the ground elevation. The groundwater depth changes of Mangshe River and East Guohe River are significant with deep burial depth. It tends to be mild at the influx of Northern Jiangsu Main Irrigation Canal, and its aquifer depth is relatively shallow. As shown in Table 3, the roof elevation is located at an area of -99.12 ~ -92.91 m, which occupies the largest area and 21.45 % of the total research area. The roof elevation in an area of below -129.31 m and above -75.05 m only occupies 7.14 % of the total research area. Most of them are distributed in the mountainous areas in the middle and west of research area.

Significance analysis on effects of aquifer depth on water quality factor: To test whether the aquifer depth has a significant effect on the water quality factor, a hypothesis that "there is no significant correlation between depth and content of water quality factor" is proposed. As for whether (total) average value of equivalent monitoring values for 10 years from the tested nine sections, the following hypothesis is proposed:

$$H_0 : \mu_1 = \mu_2 = . . \mu_i = . . . = \mu_9$$
$$H_1 : \mu_i (i = 1,2, . . 9) not all equa \qquad ...(1)$$

In Formula (1), μ_i is the total average value for water quality monitoring sample in number i^{th} classification section. H_0 is defined in the original hypothesis as: The total average values for water quality factor monitoring in various depth classification areas are equal, and the depth has no significant effect on water quality. H_1 means that a correlation exists between aquifer depth and water quality. If original hypothesis is refused, it will indicate that the depth has a significant effect on water quality and a significant correlation exists between them. If the original hypothesis is not refused, it cannot fully prove that a significant correlation exists between them.

ANOVA (analysis of variance) is a statistical method which uses sampling data to test whether multiple total average values are equal. Testing statistics are built by calculating Sum of Squares for Total (SST), Sum of Squares for Factor A (SSA) and Sum of Squares for Error (SSE) for sampling data. The research on the effects of specified-type independent variable on numeric-type dependent variable is realized (Manga & Morelli 1997). After its time and space are treated, the water quality sampling data is imported to SPSS, ANOVA analysis module is used, and relevant significance testing is conducted for H_0 hypothesis. Supposing the significance level α is 0.05, the analysis result is shown in Table 4.

The above table provides the sum of squares for factor A (SSA) caused by the depth (independent variable) and measures the effects of depth on water quality factor. SSE reflects the error sum of squares caused by other factors. These factors include sampling error, groundwater flow velocity, aquifer lithology, saltwater intrusion and aquifer thickness. As SSA is larger compared with SSE, the effects of depth on water quality factor will be more significant. Otherwise, the effects of other factors on water quality factor will be more significant. The following formula (Yue 2014) can be

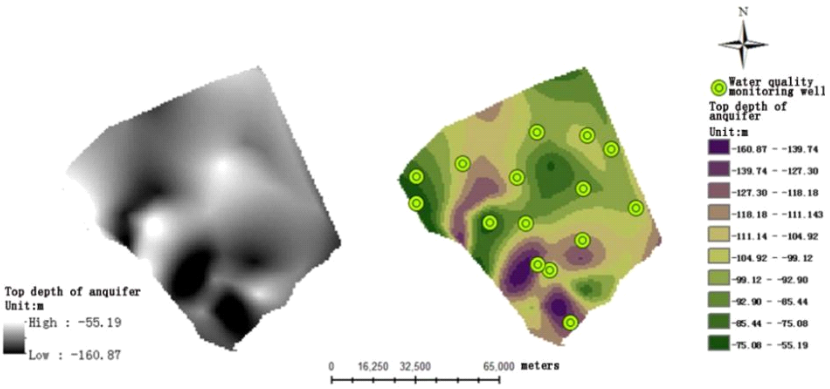

Fig. 5: Aquifer III roof burial depth DEM and its classification.

adopted to measure the relationship strength between depth and content of water quality.

$$R^2 = \frac{SSA}{SST} = \frac{SSA}{SSE + SSA} \quad ...(2)$$

In formula (2), R^2 refers to the error sum of squares of depth and its proportion in total error sum of squares. Its square root R measures the relationship strength between the two variables.

According to the variance analysis principle and analysis result, when the significant level $\alpha = 0.05$, the molecular degrees of freedom in F distribution table is 8, and the critical value for denominator degrees of freedom 131 is $F_\alpha = 2.01$. Formula (3) is applied to calculate the test statistics F for sampling distribution, which is compared with the critical value F_α.

$$F = \frac{MSA}{MSE} = \frac{SSA/(k-1)}{SSE/(n-k)} \quad ...(3)$$

If $F>F_\alpha$, the original hypothesis H_0 will be refused. It can be concluded that the aquifer depth has a significant effect on the content of water quality factor. If $F<F_\alpha$, the original hypothesis H_0 will not be refused. At this moment, it cannot be considered that the aquifer depth has an effect on the water quality. It can be known from the calculation result in Table 4 that the statistical values for sampling data of three water quality factors (mineralization, total alkalinity and total bacterial count) are 15.44, 22.054 and 8.34 respectively, which are relatively high and far more than the test critical value F_α. This indicates that these water quality factors are significantly affected by the depth. The statistical values for $KMnO_4$ index and total hardness are 2.33 and 5.34 respectively, which is slightly higher than F_α. This indicates that these two factors are less affected by the aquifer depth, but there is still a certain effect. The relationship strength between water quality factor and depth can be calculated by substituting the calculation result in Table 5 into formula (2). In particular, R^2 values of mineralization, total alkalinity and total bacterial count are 48.53 %, 57.39 % and 33.74 % respectively. That is, the proportions of aquifer depth on the content of these three factors in total effect are 48.53 %, 57.39 % and 33.74 % respectively. R^2 value of total hardness is 24.58 %. This indicates that the proportion of variation explanation of aquifer depth for total hardness is only 24.58 %. Compared with mineralization and total alkalinity, this proportion is not high, but R value for the relationship strength between total hardness and depth is 49.18 %. This indicates that there is a nearly intermediate correlation between them. R values for mineralization, total alkalinity and total bacterial count are 69.67 %, 75.76 % and 58.09 % respectively. This indicates that there is an above intermediate correlation among them. Correspondingly, R^2 values for $KMnO_4$ index is 12.44 %, and its square root R value is 35.27 %. This indicates that the aquifer depth has an insignificant effect on $KMnO_4$ index, and their correlation is relatively weak.

It can be known from the above analysis that the relationship between the selected five water quality factors and the depth is up to the significant degree in statistics. However, it is still unclear about the most significant differences of water quality factors among elevation classification sections. Therefore, multiple comparisons method (Benjamini & Liu 2003, Hochberg & Tamhane 1987) is introduced to further analyze the monitoring data of the above five water quality factors: total average values are conducted with pair comparison and the difference significance among the average values of various contents of water quality factors are tested. What is mostly applied in multiple comparisons method is the least significant difference (LSD). t is used to test pair comparison among all grouped data. With high sensitivity, it can test the slight differences among various total levels (Zhou et al. 2008). Based on LSD, the monitoring data for water quality factor is analysed in this paper as follows:

Step 1: Suppose the test significance level $\alpha = 0.05$. Considering that the research is divided into 9 different elevation classifications and the elevations among different classification are continually distributed from low to high, 8 groups of test hypotheses are proposed. The test hypothesis for group *i* can be described as:

$$H_0 : \mu_i = \mu_j, H_1 : \mu_i \neq \mu_j; (j = i + 1) \qquad ...(4)$$

Step 2: Calculate test statistics of water quality factors ($|x_i$-'$x_j|$) and least significant difference (LSD). The computational formula for LSD value is as follows (Junping 2006):

$$LSD = t_{\alpha/2}\sqrt{MSE(\frac{1}{n_i} + \frac{1}{n_j})} \qquad ...(5)$$

In the above formula, n_i is the monitoring sample capacity in number i^{th} classification section, $t_{\alpha/2}$ is the critical value for *t* distribution of degree of freedom (*n-k*), *n* is the total number of monitoring samples, and *k* is the number of depth classifications. It can be known from the calculation result in Table 5 that MSE and sample capacities for 5 kinds of water quality factors are different, so they need to be calculated respectively. The degree of freedom for *t* distribution is 131. It can be known by checking *t* distribution table that the critical value is $t_{\alpha/2} = t_{0.025} = 1.980$. According to Formula (6) and test statistics, the multiple analysis result for water quality factors is shown in Table 5.

Step 3: Decision and analysis: Compare test statistics and LSD values. If the statistical value is higher than LSD value, the original hypothesis will be refused. In this test, there is a significant different in the contents of water quality factors between the two depth classifications. Otherwise, the original hypothesis will not be refused. It is considered that the difference in water quality between the two depth classifications is insignificant. It can be known from the result in Table 5 that the following groups have significant test differences: groups 2, 3, 4 and 7 for mineralization test, the first 5 groups for total hardness test, groups 1~4, 7 and 8 for total alkalinity test, groups 6 and 8 for $KMnO_4$ index test and groups 1~3 for total bacterial count test. It can be known by contrasting the elevation classifications in Table 3 that the effect of the depth on 3 kinds of factors (mineralization, total hardness and total alkalinity) in deep aquifer area -160.8 m ~ -99.12 m is significant. Its spatial distribution area occupies 54.26 % of the whole research area. Total alkalinity is in the deep or shallow aquifer (about 47.26 % of total area), showing the characteristics of depth changes. $KMnO_4$ index only shows a significant difference for the specific depth between -99.12 m ~ -92.91 m and -85.45 m ~ -75.09 m. However, its distribution area in space occupies 31.6 % of the total area, being nearly 1/3 of the research area. There is some correlation between the content of $KMnO_4$ index and the aquifer depth in this position.

Distribution and evolution characteristics of water quality factors with depth changes: To reflect the characteristics of water quality factors with depth changes in space and time, firstly make statistics on the monitoring wells contained in each depth classification section, and calculate the average value of all monitoring data during specified years in the same depth classification section. Use the above value to represent the water quality this year in the above depth section to draw a statistical curve chart for 5 water quality factors (mineralization, $KMnO_4$ index, total hardness, total alkalinity and total bacterial count) with depth classification changes during 2005~2014, as shown in Fig. 6.

It can be seen by analysing Fig. 6 that in terms of water quality factors of confined groundwater III in the research area, $KMnO_4$ index, total bacterial count and mineralization have big changes during 2005~2014, while total alkalinity and total hardness have small changes. In shallow aquifer area, $KMnO_4$ index and total bacterial count reached the peak during 2005~2014, which indicates that water pollution is becoming serious. It can be known by contrasting Table 4 that (-92.91, -85.45) is an advantage distribution depth section for $KMnO_4$ index. The shallow area (-85.45, -75.09) is an advantage distribution depth section for total bacterial count. During 2005~2014, $KMnO_4$ index showed an upward tendency in most sections, while total bacterial count in the aquifer depth area less than 104.92 m showed a significant increase. As the shallow groundwater is further affected by domestic waste discharge in human life, the content of organic pollutants in groundwater will increase.

-118.9, -99.12 is an advantage distribution depth section for mineralization, total hardness and total alkalinity. Compared with $KMnO_4$ index and total bacterial count, the changes of the above three factors are not very significant during 2005~2014. As for the groundwater in the aquifer located above -104.92 m ~ -99.12 m, the groundwater exploitation strength in coastal area with shallow aquifer in the east in recent years is intensified, and saltwater intrusion is intensified. Due to alleviation of sea facies and high salt content of groundwater and especially shallow groundwater in reclamation and intertidal areas in the east, mineralization content has showed a significant increase in recent 10 years (increased by 1.5 mg/L within 10 years), which makes the water salty.

Similar to the mineralization, total hardness shows a slight increase in shallow aquifer area, which indicates that the underground industrial process water is threatened. Total alkalinity in shallow aquifer and the section (-111.14, -104.92) is high. The water buffer capacity in the area is strong with good metal dissolution and detoxication. It is suitable for farm irrigation. Due to decline of water level caused by groundwater exploitation and decrease of water yield, its content shows a slight decline in the whole stable trend. Attention should be paid to this.

CONCLUSIONS

Based on the actual water quality monitoring and groundwater utilization in the research sample area, this paper analyzes the response characteristics of spatial distribution and dynamic changes of typical water quality factors in confined porous groundwater against the aquifer depth. Several conclusions are obtained as follows:

1. Confined aquifer III in the research area is the main exploitation bed for groundwater in the area. Its depth is distributed unevenly in space, elevating from the west to the east. The depth changes in the southwest area are significant, and the depth changes in the central and northeastern areas are relatively mild. The aquifer depth in most areas goes between -118.9 m ~ -85.45 m, which occupies above 60 % of the research area.
2. There is a significant correlation between the groundwater quality and aquifer depth in confined aquifer III. Mineralization, total alkalinity and total bacterial count have the strongest correlation strength to the depth, and their *R* values are 69.67 %, 75.76 % and 58.09 % respectively. The correlation strength of the total hardness reaches a nearly intermediate level (R = 49.18 %). The effects of the depth on $KMnO_4$ index are limited, and *R* values for correlation strength between $KMnO_4$ index and depth is 35.27 %.
3. The effects of the depth on total hardness, mineralization and total bacterial count in deep aquifer area are relatively significant. Their depth elevations are distributed between -160.8 m ~ -99.12 m (about 54.26 % of the total area). The effects of the depth on total alkalinity in shallow aquifer area are significant (about 47.26 % of total area). $KMnO_4$ index in the specific depth section (-99.12 m ~ -92.91 m and -85.45 m ~ -75.09 m) has a significant difference, and its aquifer distribution scope occupies 1/3 of the total research area.
4. The groundwater content in the depth between -85.45 m ~ -75.09 m for $KMnO_4$ index and total bacterial count is relatively high. They are mainly distributed between Sheyang County and Huangsha Port. In recent years, it has shown an increase trend under the effects of human exploitation and waste discharge. The mineralization content reaches the peak in the aquifer in the middle and west of the research area. The development of coastal salt fields and the saltwater intrusion have intensified in recent years, which bring adverse effects on residents' domestic drinking water. In general, total alkalinity and total hardness have small changes. Their distribution advantage depth section is -111.14 m ~ -104.92 m. In shallow depth area, total alkalinity declines slightly, while total hardens shows a certain increase trend. This indicates the applicability or effects of groundwater in industrial and agricultural production. Some preventive and control measures should be taken.
5. The factors affecting groundwater quality include groundwater flow velocity, upside leakage, saltwater intrusion, lithology and hydrolytic weakening properties (Hudak 2010). Aquifer depth has been taken out in this paper, and the time-space characteristics of water quality factors under single effect are researched without considering multi-factors. To extract and quantize other factors in the research area and conduct conjoint analysis under the effects of multi-factors is an important direction for follow-up research in this paper.

ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China (No.41571386).

REFERENCES

Benjamini, Y. and Liu, W. 2003. A step-down multiple hypotheses testing procedure that controls the false discovery rate under independence. Journal of Statistical Planning and Inference, 82: 163-170.

Changyuan, T. and Yasuo, S. 2005. The characteristics of geochemistry in a headwater wetland, Chiba, Japan. IAHS-AISH Publication, 294: 167-175.

Feng, G. 2003. Water resources situation and problems in Yancheng City. Hydrology, 23(2): 53-55.

GB/T1 1994. Quality standard for ground water. Beijing, China: National Technical Supervision Bureau Version 4848-93, China.

Hani, S. and Daniel, B. 2009. Impact of fertilizer application and urban wastes on the quality of groundwater in the Cambrai Chalk aquifer, Northern France. Environmental Geology, 51(7): 1579-1592.

Hao, W., Chuiyu, L. and Dayong, Q. 2010. Advances in method and application of groundwater numerical simulation. Earth Science Frontiers, 17(6): 1-12.

Hochberg, Y. and Tamhane, A.C. 1987. Multiple Comparison Procedures. Addison-Wiley: NewYork.

Hongwei, C. 1998. Analysis of groundwater resource in Yancheng. Journal of China Hydrology, 28: 65-69.

Hudak, P. F. 2010. Principles of Hydrogeology. Higher Education Press: Beijing.

Jiarong, L., Qinglong, Q. and Zhixiag, F. 2000. Investigation and evaluation of groundwater resources in Yancheng City. Advances in Science and Technology of Water, 20(3): 48-50.

Jinyu, B. and Rui, F. 2003. Analysis of controlling factors of groundwater quality in Yancheng area. Hydrogeology and Engineering Geology, 20(5): 57-60.

Junping, J. 2006. Statistics. Tsinghua University Press: Beijing.

Manga, U. and Morelli, M. 1997. Data-aided frequency estimation for burst digital transmission. IEEE Transactions on Communication, 45(1): 23-25.

Suozhong, C. and Jiahu, H. 2004. 3D spatial dispersing method for interstitial geohydrology succession based on GIS. Advances in Water Science, 15(5): 64-69.

Suozhong, C., Benchun, C. and Jiazhu, H. 2005. Water Resource Management Information System. Science Press, Beijing.

Xueyu, Z. and Xiaoxing, Q. 2005. Groundwater Hydrology. China Environmental Science Press: Beiijing.

Yanling, F. 2005. Evaluation of groundwater resource forecast in Yancheng. Resource Survey and Environment, 26(1): 54-59.

Yinli, H., Bingxi, Y. and Qiusheng, Y. 2008. The application of electric characteristics to studying spat distribution of groundwater quality in Yinchuang plain. Geophysical and Geochemical Exploration, 32(3): 288-291.

Yue, X. 2014. High-Dimensional Variance Analysis. Northeast Normal University.

Yuxi, Z., Jingtao, L. and Yuanjing, Z. 2015. Hydro-chemical evolution of shallow and deep groundwater in Tongchuan city, China. Journal of Coastal Research, 73(5): 436-442.

Zhou, S., Qianshi, X. and Chengyi, P. 2008. Probability Theory and Mathematical Statistics. Higher Education Press: Beijing.

Zishen, L. and Xueyu, L. 2004. Chemical characteristics and variations of groundwater quality in Songnenbasin. Earth Science Journal of China University of Geosciences, 15(1): 96-102.

Zujiang, L. and Yongxia, W. 2005. Three-dimensional numerical model for groundwater resource evaluation and plan in Yancheng. Water Resource Protection, 21(5): 37-41.