Science in China Series D: Earth Sciences

© 2008 SCIENCE IN CHINA PRESS

Springer

www.scichina.com
earth.scichina.com
www.springerlink.com

Isotopic characteristics of groundwater in Changzhou, Wuxi and Suzhou area and their implications

JIANG YueHua†, JIA JunYuan, XU NaiZhen, WANG JingDong & KANG XiaoJun

Nanjing Institute of Geology and Mineral Resources, Nanjing 210016, China

Based on the study of groundwater isotope(^2H and ^{18}O, ^{34}S, ^{15}N, ^3H, ^{14}C) in Changzhou, Wuxi and Suzhou area, it is found that the deep confined groundwater has no pollution on the whole, whereas the shallow groundwater is polluted to a different degree in the area. The deep confined aquifers (main exploitation aquifers) in Changzhou area and in Wuxi and Suzhou area likely belong to two different aquifers. The main exploitation aquifers in Changzhou area are not connected with those in Wuxi and Suzhou area, or they are connected but not expedited. The lateral run-off of groundwater is at present directed to the exploitation center because of overexploitation of the deep groundwater for a long time, but the flowing speed of groundwater is still extremely slow. The deep confined groundwater is in a close to half close state. The ^{14}C age of groundwater varies from 10000 a BP to 38000 a BP, with the oldest groundwater found at the nearest exploitation center (along the line of three cities of Changzhou, Wuxi and Suzhou) and the youngest at the furthest exploitation center.

Changzhou-Wuxi-Suzhou area, groundwater, isotope

1 Introduction

It has been more than 50 years since the environmental isotopic techniques were first applied to solve problems of groundwater hydrology and water resources[1]. Owing to isotopic technical superiority over other technology, it was widely used in the research of hydrogeology conditions[2−7], the exploration of groundwater sources[8,9], evaluation of water resource[10,11], management of groundwater resource[12], identification of pollution source of groundwater[13−17], judgment of the sedimentary velocity[18] and information on change of sea water levels[19]. However, it is necessary to understand geological environmental setting in studied areas in applying isotopic techniques to analyze problems of groundwater hydrology, and at the same time, application condition of isotopes should be also considered, such as ^{14}C age which is theoretically no more than 50000 a BP. In recent years the International Atomic Energy Agency (IAEA) held regional trainings on Application of Isotope and geochemical Techniques to Groundwater Contamination Studies all over the world frequently and cooperated to study concerned projects with many countries, thus providing new opportunities for application of the environmental isotopic techniques.

Changzhou, Wuxi and Suzhou area is located in the southern part of Yangtze River delta with an area of 160000 km^2, including Changzhou, Wuxi, Suzhou cities and 11 counties. This area has good conditions on natural geography and belongs to water-net plain, and has well-developed economy and high degree of urbanization. In recent years the surface water are polluted, the water quality of the Taihu Lake and the Grand Canal have worsened, causing varying degree of groundwater pollution[20,21]. As a result of overexploitation of groundwater and poor scientific management, a series environmental geologic problems and hazards such as land subsidence, ground fissure[22−24] have occurred

Received October 23, 2007; accepted February 25, 2008
doi: 10.1007/s11430-008-0055-y
†Corresponding author (email: njjyuehua@cgs.gov.cn)
Supported by the China Geological Survey (Grant Nos. 200312300013, 1212010340106, 121201063400 and 1212010634404)

in Suzhou, Wuxi and Changzhou area with decreasing water table, which in turn have adversely influenced the people's quality of life and a sustainable development of local economy.

From 1980 up to now, two important works in the area have been done, which are the integrated appraisals of hydrogeology, engineering and environmental geology, and survey of groundwater resources and geologic hazards[1,2)], but the groundwater isotope research is rarely involved. In this paper, we will discuss the conditions of recharge, runoff, and discharge of groundwater and the flow field change due to overexploitation and pollution state of groundwater in Changzhou, Wuxi and Suzhou area, based on the study of the components of environmental and radioactive isotopes in groundwater. These also can provide background information and theoretical consideration for scientific development and management of groundwater resources and pollution disposal of groundwater in the area.

2 Sampling and testing

A total of 27 samples were collected for ^{14}C, 88 for ^{2}H, ^{18}O and ^{3}H, 56 for ^{34}S, 30 for $^{15}N\text{-}NO_3$ and $^{18}O\text{-}NO_3$ measurements. Moreover, 88 water samples were analyzed for water quality test. The sample locations are shown in Figure 1.

The majority of the samples were collected from groundwater and only a few from surface water and precipitation. Samples were primarily collected from the main exploitation aquifer (2nd confined aquifer) and the phreatic aquifer, at the same time we also collected other aquifer samples. The characteristics of the different aquifers are shown in Table 1.

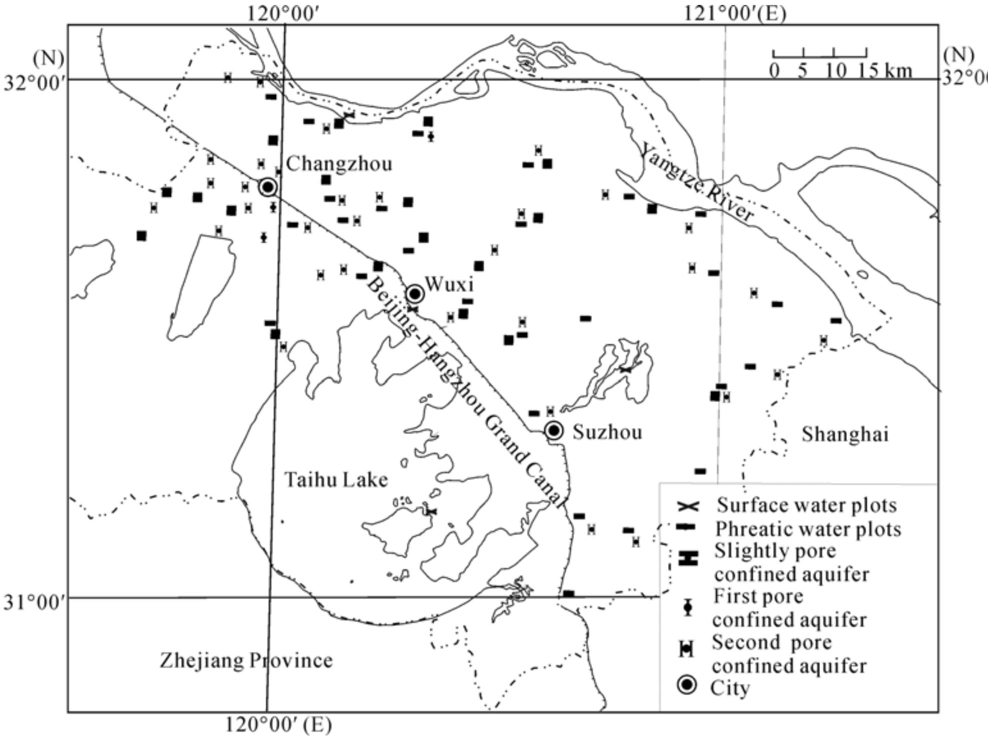

Figure 1 Distribution of sampling plots for the groundwater isotope study in Changzhou, Wuxi and Suzhou area.

Table 1 The characteristics of the different aquifers

	Depth (m)	Thickness (m)	TDS	Inflow (m^3/d)
Phreatic aquifer	0.5—10	6—10	<1 or >1	3—20
Slightly confined aquifer	15—18	5—30	<1 or >1	20—100
1st confined aquifer	38—50	30—50	<1	100—1000
2nd confined aquifer	94—123	30—55	0.6—0.9	1000—1500
3rd confined aquifer	110—176	5—35	0.7—0.9	1000—2000

1) Jiangsu, Zhejing and Shanghai Bureau of Geology and Mineral Resources. Integrated appraise of hydrogeology, engineering and environmental geology in Yangtze River delt, 1987

2) Nanjing Institute of Geology and Mineral Resources, Jiangsu, Zhejiang and Shanghai Institute of Geological Survey. Survey of groundwater resources and geologic hazards in Yangtze River delt, 2003

The radioactive isotope ^3H were tested by liquid scintillation spectrometer (type: Quantulus-1220) according to Chinese standard (GB 12375—90)[1)], standard source and background were synchronously tested in testing and the values compared with other developed nation's data. The radioactive isotope ^{14}C was also tested by liquid scintillation spectrometer, in which the preparation of carbides was adopted by Mg-method. ^{14}C ages are rectified by ^{13}C after calculating percentage of modern carbon (PMC%). ^{14}C standard made use of Chinese sugar carbon and background was synthesized by laboratory. ^{14}C half life used 5568 a BP, starting time was in 1950. ^{13}C analysis method was 100% phosphatic method and ^{13}C took PDB (Belemnitell americana from the Cretaceous PeeDee formation, South Carolina) as standard and was tested by mass spectrograph (type: MAT 251 EM), with ±0.2‰ analysis precision. ^2H was analyzed by zinc-method and took SMOW (Standard mean ocean water) as standard and was tested by mass spectrograph (type: MAT 251 EM), with ± 2.0‰ analysis precision. ^{18}O analyzed by equilibrium method, SMOW as standard, tested by mass spectrograph (type: MAT 251 EM), with ± 0.2‰ analysis precision. ^{34}S analysis method was as following: $BaSO_4$ was purified by half melting carbonate-zinc oxide from sulphate minerals at first, and then SO_2 was prepared by V_2O_5 oxygenation, at last ^{34}S was tested by mass spectrograph (type: MAT 251 EM) and took CDT (Canyon Diabio Trolite-Arizona, USA) as standard, with ±0.2‰ analysis precision. Before mensurating ^{15}N-NO_3 and ^{18}O-NO_3, nitrogen must be produced by burning method which used CaO solder tube and CO_2 produced by burning method which used $AgNO_3$ + C (plumbago), whereafter ^{15}N and ^{18}O were tested by mass spectrograph (type: MAT 251), in which ^{18}O took SMOW (Standard mean ocean water) as standard, with ±2.0‰ analysis precision. Water samples for water quality check were tested based on water and waste water (State environmental protection administration of China) analysis method of DZ/T 0064.51-1993 and HJ/T 84-2001, testing instruments are inductance coupling plasm spectrumeter, ultraviolet/visible spectrophotometer, atom absorb spectrometer and atom fluorescent spectrometer. Therefore, the testing data in this article are deemed credible.

3 Results and discussion

3.1 Hydrochemical characteristics of groundwater

(1) The deep confined aquifers. It is suggested that hydrochemical types of the deep confined aquifers in Changzhou, Wuxi and Suzhou area belong to HCO_3-Na type water on the whole (Figure 2), $SO_4^{2-}+Cl^- \leqslant 20\%$, $45\% \leqslant Na^++K^+ \leqslant 84\%$, in which samples of 1st confined aquifer and parts of 2nd confined aquifer drop into the area of HCO_3-Ca-Mg type water.

The chemical composition of the deep confined aquifers typically shows it is formed by dissolution of aluminum silicate minerals. A part of samples of the deep confined aquifers drops into the area of the shallow confined aquifers because of cut hole techniques, suggesting that they were mixed with the shallow groundwater. It is obvious that two samples of the deep confined aquifer wells in Taichang and Shaxi of the eastern area are salt water, $SO_4^{2-}+Cl^- \geqslant 70\%$ (Cl^-, 428 and 1370 mg/L, respectively), and the main reason is that the old close brine (ancient transgression) in the upper stratum penetrated downwards, which may be certificated by Cl^- < 150 mg/L and SO_4^{2-}<93 mg/L of the deep and shallow confined aquifer wells around this two wells.

(2) The shallow phreatic aquifers and slightly confined aquifers. Figure 2 shows that hydrochemical types of the shallow phreatic aquifers and slightly confined aquifers principally belong to HCO_3-Ca, HCO_3-Mg and HCO_3-Na type water, $10\% \leqslant SO_4^{2-}+Cl^- \leqslant 50\%$, $20\% \leqslant Na^+ + K^+ \leqslant 70\%$, and that the shallow groundwater is recharged by precipitation with abundant CO_2 and O_2 in oxidation environment. The chemical composition of the shallow groundwater typically shows it is formed by precipitation or surface water recharge.

3.2 Recharge, transportation and discharge condition of groundwater

(1) δ^2H and $\delta^{18}O$. Based on the study of ^2H and ^{18}O isotope in the different aquifers of Changzhou, Wuxi and Suzhou area, we discovered that there are both same characteristics and distinct differences in ^2H and ^{18}O isotopic composition between Changzhou area and Suzhou-Wuxi area. The sample points of phreatic, slightly confined and confined aquifers in Changzhou area and phreatic, slightly confined aquifers in Suzhou-

1) National Standard of the People's Republic of China. Anaytical method of Tritium in Water. GB12375-90, 1990-12-01

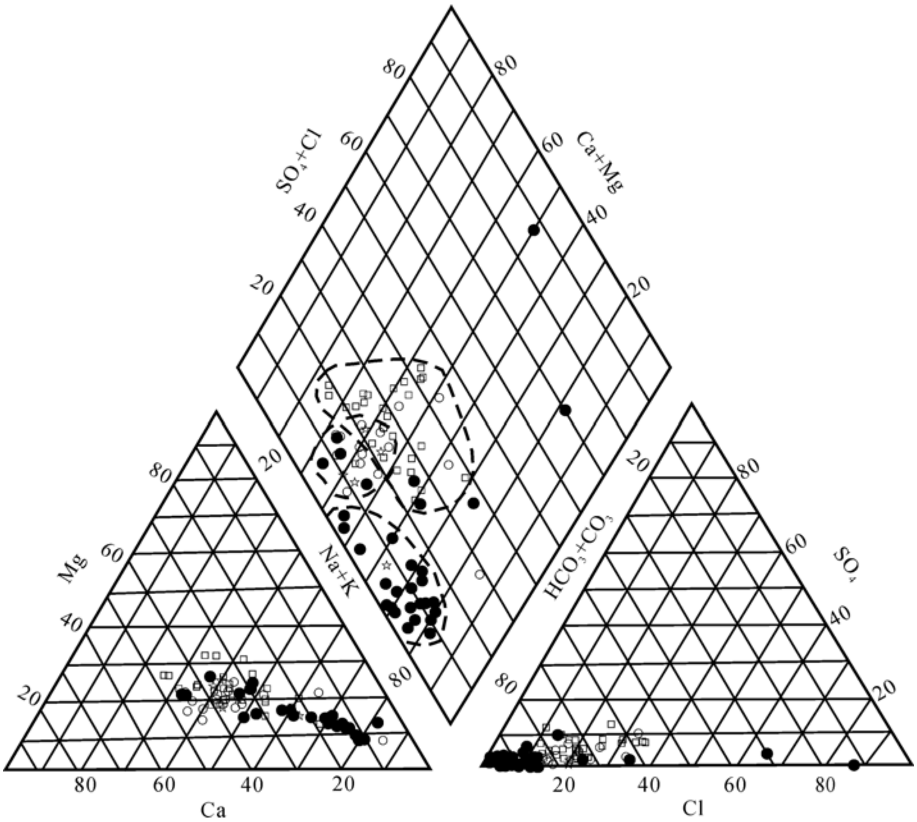

Figure 2 Piper diagram of groundwater in Changzhou, Wuxi and Suzhou area. □, Phreatic water; ○, slightly pore confined aquifer; ☆, first pore confined aquifer; ●, second pore confined aquifer; ▲, third pore confined aquifer.

Wuxi area are plotted below the meteoric water line (Figure 3), suggesting that groundwater gets recharge from precipitation or surface water that has evaporated to some extent before being recharged, which is consistent with Relly Model. But the deep confined aquifers and part of phreatic and slightly confined aquifers in the Suzhou-Wuxi area are plotted on or near the meteoric water line. This is explained by water-rock interaction which results in ^{18}O isotope depletion.

Figure 3 shows that the groundwater based on δD and δ^{18}O in the study area can be divided into four groups. Group A covers 2nd and 3rd confined aquifers of Changzhou area, in which the value of δD is −64.3‰—−71.2‰, δ^{18}O −8.3‰—−6.4‰. Group C covers phreatic aquifer and slightly confined aquifer, in which δD is −55‰—−41‰, δ^{18}O −3.0‰—−5.0‰ and also of present precipitation (snow, water), suggesting that the samples of Group C are modern water. Group B includes the samples from all the aquifers in the Changzhou and Suzhou-Wuxi area, with the values of δD being −62‰—−42‰, δ^{18}O −6.5‰—−5.0‰. Group D covers deep confined aquifers and part of the phreatic & slightly con-

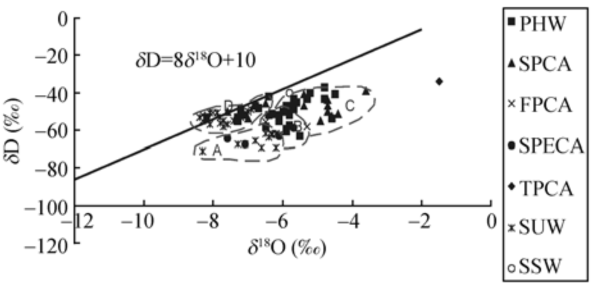

Figure 3 δD-δ^{18}O relationship diagram showing groundwater of the different aquifers in Changzhou, Wuxi and Suzhou area. PHW, Phreatic water; SPCA, slightly pore confined aquifer; FPCA, first pore confined aquifer; SEPCA, second pore confined aquifer; TPCA, third pore confined aquifer; SUW, surface water; SSW, snow water.

fined aquifers in the Suzhou and Wuxi area, in which the value of δD is −58‰—−41‰, δ^{18}O −8.4 ‰—−6.0‰.

The temperature of group A and D is lower than that of group B and C when recharging, which indicates that the groundwater in group A and D is older than that of group B and C. Group B is between group A and C, suggesting that the distribution of each aquifers is not continuous or aquifers are connected as a result of opening wells. The groundwater of group B is distinctly influenced by modern water.

It is confirmed by this study and the former research1) that the groundwater in the study area is mainly recharged by precipitation and part of surface water while it is discharged by exploitation and evaporation. The flow speed of the groundwater, especially of the deep groundwater is very slow in Changzhou, Wuxi and Suzhou area because of the flat landform and low hydraulic gradient. The groundwater is in a close to half close state. It is suggested that the deep confined aquifers (main exploitation aquifers) likely belong to two different aquifers. The main exploitation aquifers in the Changzhou area are either not connected to those in Wuxi and Suzhou area, or they are connected but not expedited, which is consistent with the characteristic of radioactive tritium and carbon isotopes and paleogeographic background at that time.

(2) ^{3}H and δ^{18}O. This study shows that tritium in phreatic water in Changzhou, Wuxi and Suzhou area varies from 3.74—27.43 TU, in slightly confined aquifer 1.98—26.68 TU, in 1st confined aquifer 6.05—13.52 TU, in 2nd and 3rd confined aquifer 0.04—23.27 TU. The degree of mixing in Phreatic and slightly confined aquifers and 1st confined aquifer with precipitation and surface water is higher than 2nd and 3rd confined aquifers. Based on the relation of ^{3}H and δ^{18}O shown in Figure 4, the groundwater can be divided into three groups in the area. The value of ^{3}H in the samples from group A (mainly deep groundwater samples from Wuxi and Suzhou area) is less than 3 TU and δ^{18}O varies from −6.2‰—−9.0‰, showing that groundwater is in relation to the old recharge and has no relation with the modern current water containing system. The value of the ^{3}H in group C varies from 19 TU to 28 TU (these data are close to Yangtze River water 21.87 TU and Beijing-Hangzhou Grand Canal water 27.88 TU in Wuxi section and the Taihu Lake water 12.96 TU in this study) and δ^{18}O ranges from −3.8‰ to −6.1‰, indicating that the groundwater originates as surface water and precipitation fallen after 1950. The value of ^{3}H in group B varies from 4 TU and 18 TU and δ^{18}O ranges from −4.5‰ to −8.5‰, suggesting that the groundwater is affected by modern water to some extent.

It must be noted that the concentration of ^{3}H in groundwater decreased with the increase of depth, but

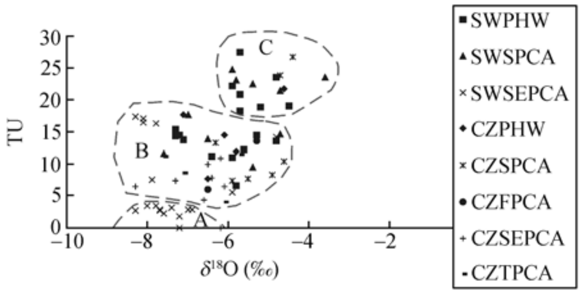

Figure 4 Relation between δ^{18}O-TU (tritium isotope) showing groundwater of the different aquifers in Changzhou, Wuxi and Suzhou area. SWPHW, Phreatic water in Suzhou and Wuxi; SWSPCA, slightly pore confined aquifer in Suzhou and Wuxi; SWSEPCA, second pore confined aquifer in Suzhou and Wuxi; CZPHW, phreatic water in Changzhou; CZSPCA, slightly pore confined aquifer in Changzhou; CZFPCA, first pore confined aquifer in Changzhou; CZSEPCA, second pore confined aquifer in Changzhou; CZTPCA, third pore confined aquifer in Changzhou.

the average value of ^{3}H in phreatic water in Suzhou-Wuxi area is 15 TU while it is 24 TU in slightly confined water, showing the abnormal phenomenon that the concentration of ^{3}H at the lower part is higher than that at the top. The study indicates that this phenomenon is caused by scarcely exploiting the slightly confined groundwater and good close condition in comparison with phreatic water. The slightly confined groundwater was recharged after the fastigium of the nuclear explosion. The high concentration of ^{3}H has being retained up to the present, while the phreatic water has lower concentration of ^{3}H than slightly confined water because of yearly dunking and washing by flood and quick water recycle, which is consistent with results of the shallow groundwater (collecting 27 samples) in the same area studied by Lu et al.[25].

(3) ^{14}C. Based on the study of ^{14}C of the deep confined groundwater in the area of Suzhou, Wuxi and Changzhou, the age of the groundwater ranges from 10000 a to 38000 a. The age of the groundwater in the center of the land subsidence in the Changzhou area ranges from 20000 a to 30000 a, while it ranges from 30000 a to 38000 a in the center of the land subsidence in the Suzhou-Wuxi area. The ^{14}C isolines shown in Figure 5 demonstrate that the nearest exploitation center (along the line of three cities of Changzhou, Wuxi and Suzhou), the oldest the age of groundwater; the furthest exploitation center, the newest the age of groundwater. Owing to the biggest exploitation quantities of ground-

1) Wang R J, Wu S L. Study on prevention and cure of using groundwater resources and important geological environmental problems. Technical Report, China Institute of Geo-Environment Monitoring, 2004

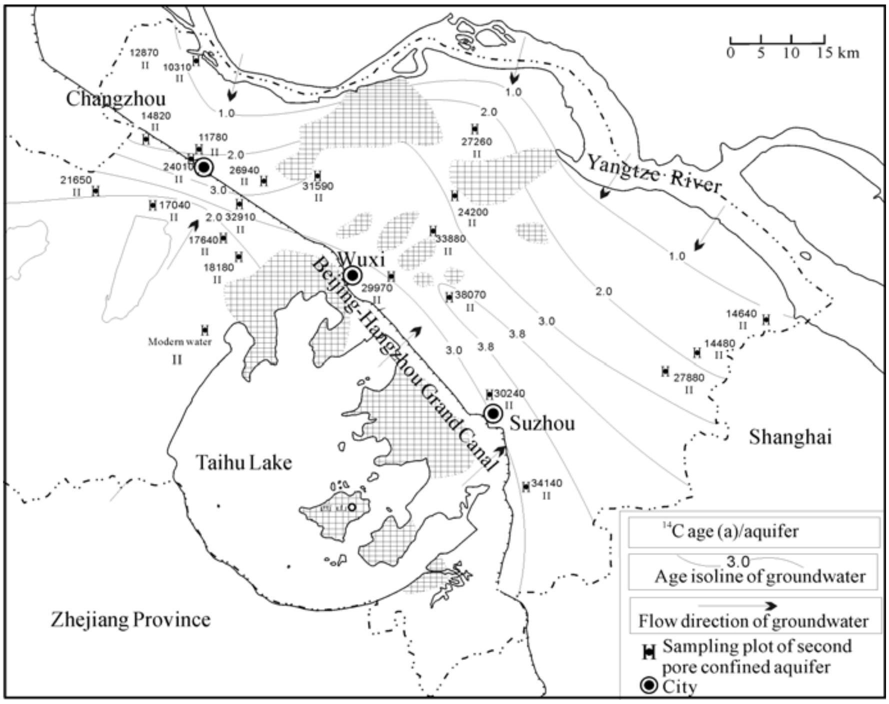

Figure 5 ^{14}C age contour in groundwater of the second confined aquifer in Changzhou, Wuxi and Suzhou area.

water and the severest area of land subsidence along the line of three cities of Changzhou, Wuxi and Suzhou, this age variation of groundwater in fact reflects flow field changes of the regional groundwater, namely, the lateral run-off of groundwater is at present directed to the exploitation center because of overexploitation of the deep groundwater for a long time, but the flowing speed of groundwater is still extremely slow.

The distribution of the relative concentration of ^{14}C, namely the percentage of modern carbon (Figures 6 and 7), shows that the values of the percentage of modern carbon (pmc) are very low in the deep groundwater, especially in Suzhou-Wuxi area; only in two samples the percentage of modern carbon reaches 16% while others vary from 0.8% to 4%, suggesting the deep aquifers are in a close to half close state without mixing with modern water. It is consistent with the fact that the values of ^{3}H of most samples in deep groundwater from this area are less than 3TU and groundwater was not mixed with modern water. The percentage of modern carbon is clearly high in the shallow groundwater. For example, it is about 105% in three samples of the slightly confined groundwater from Changzhou area and 60% in one sample of 1st confined groundwater, suggesting that the shallow groundwater has been mixed with modern water to some extent.

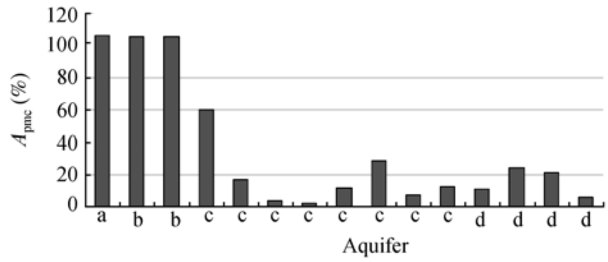

Figure 6 Sketch of ^{14}C (pmc) of the different aquifers in Changzhou area. a, Slightly confined aquifer; b, first confined aquifer; c, second confined aquifer; d, third confined aquifer.

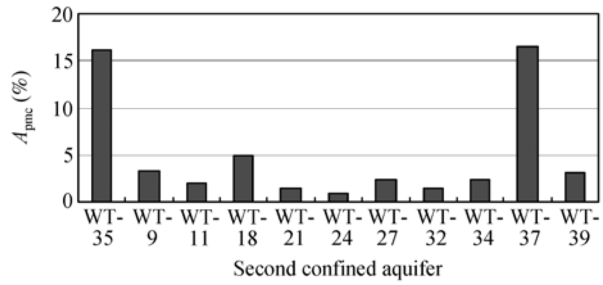

Figure 7 The percentage of modern carbon (pmc) of the second confined aquifer in Wuxi and Suzhou area.

3.3 Pollution of groundwater

The water quality of the surface water has gradually worsened because of rapid economic development in Changzhou, Wuxi and Suzhou area, resulting in different degree of groundwater pollution. $\delta^{15}N$ was studied in the Changzhou area and $\delta^{34}S$ in the Suzhou-Wuxi area in order to define the state of the groundwater pollution.

(1) $\delta^{34}S$. On the basis of ^{34}S in 58 samples from all aquifers in the Suzhou-Wuxi area, there is an obvious difference of the $\delta^{34}S$ values between the shallow groundwater and the deep groundwater. The highest values of $\delta^{34}S$ occur in the deep confined aquifer, where they vary from 50‰ to 75 ‰. The lowest values of $\delta^{34}S$ occur in phreatic and surface water, where they vary from 5‰ to 19‰. The values of $\delta^{34}S$ in slightly confined and 1st confined aquifers vary from 20‰ to 45‰. Clearly, the values of $\delta^{34}S$ increase with depth from phreatic and surface water to 1st confined water and to 2nd confined water (Figure 8). Figure 8 shows that the values of $\delta^{34}S$ are in an inverse correlation to that of the SO_4^{2-} content, that is to say, in phreatic and surface water the higher content of SO_4^{2-}, the lower values of $\delta^{34}S$; while in deep confined water the lower contents of SO_4^{2-}, the higher values of $\delta^{34}S$ (the content of SO_4^{2-} were not detected in 10 samples because of its low concentration in deep confined water).

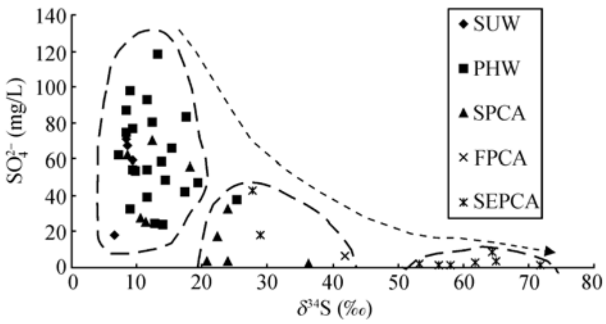

Figure 8 $\delta^{34}S$ versus SO_4^{2-} in groundwater of the different aquifers from Changzhou, Wuxi and Suzhou area. SUW, Surface water; PHW, phreatic water; SPCA, slightly pore confined aquifer; FPCA,first pore confined aquifer; SEPCA, second pore confined aquifer.

As commonly known, the value of $\delta^{34}S$ of water vapor from modern sea surface is +20 ‰. If $\delta^{34}S$ of precipitation or groundwater are close to +20‰, it can be concluded that there is no pollution from modern atmosphere. Accordingly it is confirmed that the deep confined groundwater and part of the slightly confined groundwater in the Suzhou and Wuxi area has not been polluted (the value of $\delta^{34}S$ in the most samples are less than +20‰). The high contents of SO_4^{2-} and the low values of $\delta^{34}S$ in most phreatic and surface water show that phreatic and surface water are obviously polluted by the affection of acid rain which is a consequence of coal burning in the area.

(2) $\delta^{15}N$. The technology of $\delta^{15}N$ developed in 1920s can directly identify pollution source. The application principle of this technology is based on the different characteristics of $\delta^{15}N$ in three main pollution sources: the values of $\delta^{15}N$ in chemical fertilizer vary from –4‰ to 4 ‰, 4‰—8 ‰ in organic nitrogen from mineralized soil, and 8‰—20‰ in dejecta or sewage[16]. At present, many scholars can study nitrate contamination in groundwater by using $\delta^{15}N$ and $\delta^{18}O$ separately, but few can measure the $\delta^{15}N$ and $\delta^{18}O$ of NO_3^- simultaneously and carry out the corresponding researches[15].

The $\delta^{15}N$ and $\delta^{18}O$ of NO_3^- were measured simultaneously in 25 samples from the Changzhou area and the results indicate that:

1) $\delta^{15}N$ was detected in 9 out of the 10 group samples from the shallow groundwater (including phreatic and slightly confined water). Thus the percentage of detection is 90% for the shallow groundwater while it is only 40% (detected in 6 out of 15 group samples) from mid to deep groundwater (including 1st, 2nd and 3rd confined aquifers). This indicates that the content of NO_3^- in the shallow groundwater is higher than that in the deep groundwater and it is easy for the shallow groundwater to adsorb more NO_3^- by anion exchange resin, and hence the detection percentage of $\delta^{15}N$ in the shallow groundwater is much higher than that in the deep water. This is consistent with our results where the average content of NO_3^- in 10 samples from the shallow groundwater is 38.32 mg/L while it is only 0.52 mg/L in 15 samples from the deep groundwater. Half of the contents from the deep groundwater are less than 0.04 mg/L, demonstrating the obvious pollution in the shallow groundwater and almost no pollution in the deep groundwater.

2) In the Changzhou area the relation of the average $\delta^{15}N$ in all aquifers can be described as follows: phreatic water (18.27‰) > slightly confined water (12.13‰) > 2nd confined water (5.58‰) > 3rd confined water (4.95‰). There is a clear, normal correlation between $\delta^{15}N$ of NO_3^- and the NO_3^- concentration (Figure 9). The lower the $\delta^{15}N$, the lower the concentration of NO_3^-, and vice versa. Low $\delta^{15}N$ and NO_3^- concentration is observed in deep groundwater and high values in the shallow groundwater. Negative correlation is observed between $\delta^{18}O$ of NO_3^- and NO_3^- concentration, which is the higher the concentration of NO_3^-, the lower the $\delta^{18}O$

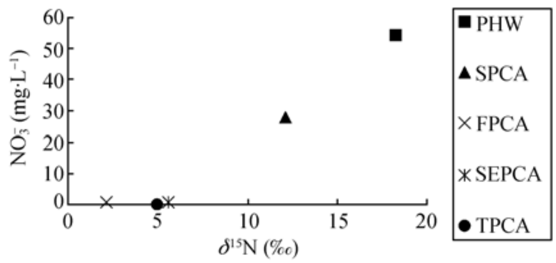

Figure 9 Correlative map of the average values of δ^{15}N in NO_3^- and NO_3^- in the different aquifers. PHW, Phreatic water; SPCA, slightly pore confined aquifer; FPCA, first pore confined aquifer; SEPCA, second pore confined aquifer; TPCA, third pore confined aquifer.

gets. Low δ^{18}O and high concentration of NO_3^- occur in the shallow groundwater and high δ^{18}O and low concentration of NO_3^- occur in the deep groundwater.

3) Because it is more reliable to identify the pollution source by using δ^{18}O and δ^{15}N of NO_3^- simultaneously than using them separately[16,17,26−30], the data in this study were projected on a δ^{18}O vs δ^{15}N plot1) (Figure 10). The data points can be classified into two groups. One group (consisting of samples collected from the phreatic and slightly confined aquifers) belongs to the distribution area of fertilizer and sewage. The values of δ^{15}N vary from 10.026‰ to 32.834‰ and those of δ^{18}O from 12.502‰ to 20.757‰, suggesting that the most phreatic and slightly confined groundwater was polluted by fertilizers and sewage. This is consistent with the conclusion that the concentration of NO_3^- is beyond the national standard. The second group consists of samples collected mainly from the mid and deep confined groundwater (1st, 2nd and 3rd confined water) and belongs to the distribution area of fertilizer and precipitation. The values of δ^{15}N vary from 2.163‰ to 6.208‰ and those of δ^{18}O are from 17.051‰ to 23.201‰. Phreatic and slightly confined groundwater can also be found within this group. The values of δ^{15}N change from 4.818‰ to 5.160‰, and those of δ^{18}O from 17.034‰ to 18.818‰. NO_3^- in mid and deep confined groundwater samples (1st, 2nd and 3rd confined water) may come from precipitation at the time the groundwater was formed, while it may come from fertilizer or modern or ancient precipitation in the phreatic and slightly confined groundwater because of the depth of mid-deep confined groundwater and the clay aquiclude overlain it.

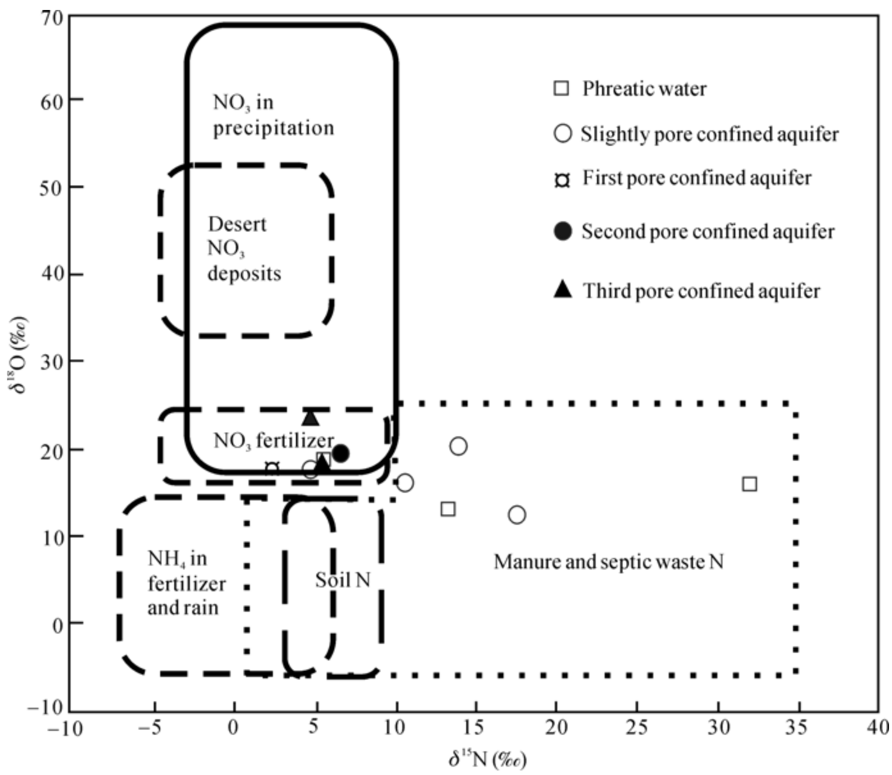

Figure 10 Relationship map of δ^{15}N and δ^{18}O in NO_3^- of the different aquifers in Changzhou area (Modified from Herczeg1))

1) Herczeg A L. Isotope tracers of groundwater pollution. Training Course information, 2003

4 Conclusions

(1) Hydrochemical types of the deep confined aquifers in Changzhou, Wuxi and Suzhou area belong to HCO_3-Na type water on the whole. The chemical composition of the deep confined aquifers typically shows it is formed by dissolution of aluminum silicate minerals. Hydrochemical types of the shallow phreatic aquifers and slightly confined aquifers principally belong to HCO_3-Ca, HCO_3-Mg and HCO_3-Na type of water. The chemical composition of the shallow groundwater typically suggests it is formed by precipitation or surface water recharge.

(2) Based on the study of groundwater isotope (^{2}H, ^{18}O, ^{34}S, ^{15}N, ^{3}H and ^{14}C) in Changzhou, Wuxi and Suzhou area, we discovered that the deep confined groundwater has no pollution on the whole, whereas the shallow groundwater is polluted in varying degrees in the area.

(3) It is suggested that the deep confined aquifers (main exploitation aquifers) in Changzhou area and in Wuxi and Suzhou area likely belong to two different aquifers. The main exploitation aquifers in Changzhou area are not connected with those in Wuxi and Suzhou area, or they are connected but not expedited.

(4) The lateral run-off of groundwater is at present directed to the exploitation center because of overexploitation of the deep groundwater for a long time, but the flowing speed of groundwater is still extremely slow.

(5) The deep confined groundwater is in a close to half close state. The age of groundwater varies from 10000 a BP to 38000 a BP, with the oldest groundwater found at the nearest exploitation center (along the line of three cities of Changzhou, Wuxi and Suzhou) and the youngest at the furthest exploitation center.

Heartfelt thanks are due to Ha Chenyou and Wang Ruijiu from the China Institute for Geo-Environmental Monitoring and two anonymous reviewers for their assistance.

1 Sheng X F, Yu J J. Conference summary of the international environmental isotopic hydrology and China countermeasures. Hydrogeol Eng (in Chinese), 2004, (1): 114－115

2 Man K Y. Investigation on movement of groundwater by environmental isotope ^{18}O, D, T. J Northern Jiaotong Univ (in Chinese),1994,18(1):50－55

3 Xiao F, Wang Z M, Li S. The application of isotopic technique to the hydrogeological condition research in a nuclear waste disposal site. Uranium Geol (in Chinese), 1995, 11(4): 244－253

4 Chen Z Y, Zhang G H, Nie Z L, et al. Groundwater Isotopic Stratification and Its Implicationsin Northern China. Earth Sci — J China Univ Geosci (in Chinese), 2002, 27(1): 97－104

5 Li W P, Hao A B, Zheng Y J, et al. Regional environmental isotopic features of groundwater and their hydrogeological explanation in the Tarim Basin. Earth Sci Front (in Chinese), 2006, 13(1): 191－198

6 Wang R J. Isotope hydrogeology in Xishan, Taiyuan. Acta Geol Sin (in Chinese), 1985, (4): 97－104

7 Liu C F, Wang P Y, Zhou L. The environment significance of H, O, C and Cl isotopic composition in groundwater of Hebei plain. Earth Sci Front (in Chinese), 1997, 4(1-2): 267－274

8 Wei Y M, Li J F, Sun J P. Application of environmental isotope to the prospecting of groundwater resources in a city. Expl Sci Tech (in Chinese), 2001, (1): 38－44

9 Zhuang J. Application of environmental isotopic methods to the prospecting of mining groundwater resources. Coal Geol China (in Chinese), 1997, 9(2): 47－48

10 Gao Z F. Evaluation of groundwater resource with the applied environmental isotopic method in Northwest, China. Acta Geol Gansu (in Chinese), 1995, 4(1): 62－72

11 Wu J F, Zhu X Y. Environmental isotope study and water resource evaluation in Kouquangounan water resource site. Coal Geol Expl (in Chinese), 1997, 25(3): 35－39

12 Weng D G. Groundwater resources attribute based on environmental isotopes. Earth Sci — J China Univ Geosci (in Chinese), 2002, 27(2): 141－147

13 Zhu L N, Wang R J, Ke C L. Application of environmental isotope in studying the influence of fly ash leaching on groundwater. Res Environ Sci (in Chinese), 2002, 15(4): 31－53

14 Zhang C Y, Zhong Z S, Shen Z L. The Progress in the study of oxygen isotopes in groundwater nitrate. Earth Sci Front (in Chinese), 2003, 10(2): 287－290

15 Zhou A G, Chen Y Z, Cai H S, et al. New way in NO_3^--N contamination study of water environment: Correlative method of ^{15}N & ^{18}O. Earth Sci — J China Univ Geosci (in Chinese), 2003, 28(2): 219－224

16 Heaton T H E. Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: A review. Chem Geol, 1986, 59: 87－102

17 North J C, Frew R D, Peake B M. The use of carbon and nitrogen isotope ratios to identify landfill leachate contamination: Green Island Landfill, Dunedin, New Zealand. Environ Inter, 2004, 30(5): 631－637

18 Wang Y H, Shen H T. Research methods of sedimentary rate in channel-mouth coast environment. Mar Geol Quat Geol (in Chinese),

2002, 22(2): 115－120

19 Ha C Y, Wang R J. The information about sea level changes inferred from groundwater. Earth Sci Front (in Chinese), 1996, 3(1-2): 177－181

20 Jiang Y H, Dai Q J, Wang Y P, et al. The negative environmental effects of groundwater exploitation in the Yangtze river delta and their preventive countermeasures. Volcanol Mineral Res (in Chinese), 2000, 21(3): 214－225

21 Hu J P, Wu S L. Groundwater environmental problems in Suzhou-Wuxi-Changzhou urbanized region. Hydrogeol Eng Geol (in Chinese), 1998, 25(4): 5－7

22 Xue Y Q, Zhang Y, Ye S J, et al. Land subsidence in China and its problems. Quat Sci (in Chinese), 2003, 23(6): 585－593

23 Guo K Y, Yu J, Fang Z, et al. Groundwater exploitation and geological hazard. Nature (in Chinese), 2005, (3): 17－18

24 Yu J, Wang X M, Su X S, et al. The mechanism analysis on ground fissure disaster formation in Suzhou-Wuxi-Changzhou area. J Jiling Univ (Earth Sci ed.) (in Chinese), 2004, 34(2): 236－241

25 Lu X R, Zhu J Q, Wang C H, et al. Explanation of the shallow groundwater cycle mechanism with isotope technology in Suzhou, Wuxi and Changzhou area. Hydrogeol Eng Geol (in Chinese), 2006, 33(4): 52－55

26 Wassenaar L. Evaluation of the origin and fate of nitrate in the Abbotsford aquifer using the isotopes of ^{15}N and ^{18}O in NO_3^-. Appl Geochem, 1995, 10: 391－405

27 Rademach J J, Young T B, Kanarek M S. Gastric cancer mortallity and nitrate levels in Wisconsinn drinking water. Archives Environ Health, 1992, 47: 292－294

28 Aravena R, Evans M L, Cherry J. Stable isotopes of oxygen and nitrogen in source indentification of nitrate from septic systems. Ground Water, 1993, 31: 180－186

29 Kendal L C, Silvas R, Chang C C Y, et al. Use of the $\delta^{18}O$ and $\delta^{15}N$ of nitrate to determine sources of nitrate in nearly spring runoff in forested catchments. Isotopes Water Res Manag, 1996, 1: 167－176

30 Bohlke J K, Erikseng E, Reves Z K. Stable isotope evidence for an atmospheric origin of desert nitrated posits in northern Chile and southern Califonia, USA. Chem Geol, 1997, 136: 135－154