

Experimental study of impact of a certain polluted river on groundwater along river bank in Southeast China

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Abstract: Based on the large scale land and resources survey project--groundwater contamination survey in southeast China, a certain polluted river and its typical sites along its bank were selected as research objectives. Such river is a comprehensive sewage channel for certain provincial capital city, with complicated types of pollutants. Based on the analysis on water level of horizontal and vertical hydrogeologic profile and water quality monitoring data, the impact and range of the polluted river on local groundwater were evaluated. Data show that the polluted river supplies water to underground aquifers throughout the year, which has great impact on groundwater horizontally, but different ions have different responses. Major influential indexes such as inorganic component 3-nitrogen, sulphate, chloride *etc.* present an obvious relevance, while iron, manganese, fluoride, arsenic and heavy metal and so on are less impacted. The first four indexes in groundwater are less impacted by the surface sewage because of their protogenesis, and heavy metal components become less due to sediment filtration. Data also show that deep groundwater is less influenced, on the contrary, ammonia nitrogen ion is obviously impacted. On the basis of influence degree as well as range of evaluation, some factors that caused the existing influence were discussed and proposes feasible study direction.

Keywords: Southeast China; Polluted river; Groundwater; Influence

Along with fast development of social economy, various environmental issues occur successively, which affect people's physical and mental health gradually. Surface water is one of the problems. Due to the complex hydraulic connection between surface water and groundwater, long-polluted surface water will impose an impact on the quality of groundwater to different degrees. The impact is a complex reaction of physical, chemical and biochemical properties, and it varies greatly with the environment, pollutants, geological conditions and soil conditions (ZHAO Xia, CHEN Jian-sheng, 2005; FAN Wei *et al.* 2012), which determines that the test study on the impact of surface water on the quality of groundwater is a complex subject with notable individual characteristics.

A test study on the interactive impact between

the surface water and the groundwater was conducted by the Nanjing Survey Center, China Geological Survey Bureau in Guzhen County and Suixi County in Huaihe River Basin, with rich experience and result obtained (YE Nian-jun, GE Wei-ya, 2008; YE Nian-jun, GONG Jian-shi, 2012). Based on the study, researchers selected heavily-polluted river for the study on the impact of surface water on the quality of groundwater, relying on the project of survey and evaluation of groundwater in Southeast Region. The purpose of this study is to find out the range, degree and primary components impacted by the river on the groundwater along the banks, and to provide scientific bases for the exploitation of the groundwater along the banks.

1 Background and conditions of study area

1.1 Natural conditions and sewage river

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of the region

The polluted river is distributed in the alluvial and lacustrine plain. Located at mid-latitude zone between Yangzi River and the Huaihe River, the river falls into the subtropical humid monsoon climate, characterized by cold winter and hot summer as well as mild spring and autumn. It is of the type transiting from the warm temperate zone to the subtropical zone, with annual average temperature of 15.7 °C, annual precipitation of nearly 1 000 mm and over 2 100 h duration of sunshine. With distinct raining season, the strongest raining period is from late May to mid-August every year, accounting for 80% precipitation of the whole year. The rivers within the region are in Chaohu Lake Basin. The groundwater is mainly fed from precipitation, with water level being largely affected by inter-annual precipitation and urban sewage. The loose bed of the region is relatively thin, about 20-80 m, thinning from north to south. The underlapped lithology is a wave-type undulating red bed.

The river basin is the main sewage channel for one provincial city consisting of nine districts and one county on the upper reach, therefore, a great deal of water are discharged into a lake on the lower reach through the channel. The sewage stems from urban industry and domestic water.

There is a barrage at the lake entrance for blocking river water, regulating water level and discharging sewage at different times.

1.2 Selection of study site

The site is located on the east bank in the lower reach of the sewage river, 3 km away from the barrage. The site crosses the river levee and agricultural field transversally. The levee is about 60 m wide and 3 m higher than the field. The field outside the levee is mainly paddy field and the groundwater level is lower than the ground. In order to find out the range impacted by the surface water on the quality of groundwater in horizontal and vertical directions, 5 drill holes (see Fig. 1) are perforated, covering horizontal width of 116 m and vertical depth of 60 m to reveal two water-contained beds. Among these drill holes, 3 holes (H1, H2 and H5) are located within the river levee, and 1 hole (H4) is positioned within the field and the last 1 hole (H3) is set on the boundary between the base of slope and the field. H1, H2 and H4 holes reveal phreatic stratum. H3, H5 holes reveal confined aquifer. H6 reveal phreatic stratum, is 37 m. H1, H2, H3, H4, H5 and H6 holes are 13 m, 34 m, 84 m, 116 m, 23 m and 37 m from the river boundary, respectively.

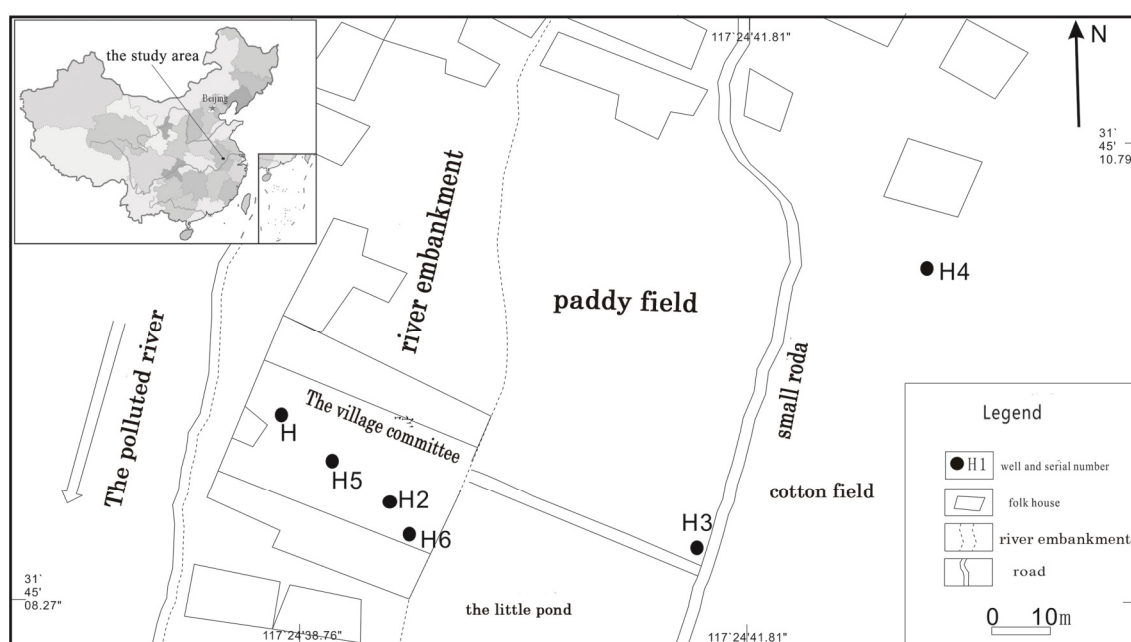


Fig. 1 Plan of experimental area

1.3 Hydrogeological condition of the site

The perforation indicates that, generally, within 4 m from the monitored cross section is artificial backfilled soil; within about 4-19 m from the monitored cross section is the interbedding of muddy sandy silt, fine sand, silt and sandy loam, which is the first water-contained bed with groundwater being phreatic water; within about 19-22 m from the monitored cross section is a layer of muddy sandy silt; within 22-50 m from the monitored cross section is the interbedding of sandy silt and silt, which is the second water-contained bed with pressure-bearing function. 50 m below the monitored cross section is the red bed.

The muddy sandy silt between the two water-contained beds is relatively continuous. According to the collected data, the muddy sandy silt is not continuous on a large scale because of human activity, hence, the second water-contained bed is the one with weak pressure-bearing capability.

2 Monitoring and analysis

2.1 Dynamic monitor of water level

Since June, 2012, we started monitoring the level of surface water and groundwater dynamically five times per week at an interval of six days. The number of data we have adopted for the paper is 144.

2.2 Monitoring of water quality

Since December, 2011, we started taking samples of water during dry season, normal season and wet season for one group of surface water and five groups of groundwater. There are 7 indexes for site test, twenty seven indexes of inorganic component for lab test, and 71 indexes of volatile organic compound and semi-volatile organic compound for lab test. All samples are tested and analyzed by the East China Supervision and Inspection Center of Mineral Resources, Ministry of Land and Resources. The data adopted by the paper is 24 sets of data in 4 batches (including one resident's well data), where inorganic test occupies the most.

3 Results

3.1 Relations between the supply and drainage of river and groundwater

The level of groundwater is lower than the surface water in the test site throughout the year (see Fig. 2), with water level difference ranging from 1.5 m to 2 m. On account of the function exerted by the barrage on the lower reach of the river, the level of surface water is less impacted by the change of raining season. The level is relatively low during June to early September, and rises 1 m - 1.8 m and stabilizes in the region after September. The level of phreatic water (H1, H2 and H4) is changed less, generally identical with that of surface water. With greater distance from the river, the level of H1, H2 and H4 decreases gradually. Basically identical with the level of phreatic water, the weakly-confined water (H3 and H5) is always lower than the level of phreatic water during observation period.

Comparison of levels between the surface water and groundwater: greater distance from the river, the lower level of the groundwater will be (see Fig. 3). The difference between the levels of river level and starting point is relatively great; that between H1 and H2 is small; that between H2 and H4 is the smallest. On the horizontal distribution of drill holes, the distance between H1 and H2, H1 and the river water are both small, while the distance between H2 and H4 is relatively great. It can be known from the comparison that, with greater distance from the river, the slope is decreasing gradually.

3.2 Relevance between the river and groundwater

3.2.1 Overview

The monitored data shows that, in groundwater along the river section, all samples are HCO_3^- -CaMg type except H3 hole which is SO_4^{2-} -CaMg, and Na and K contents are rising slightly in the busy season of sewage discharging (see Fig. 4).

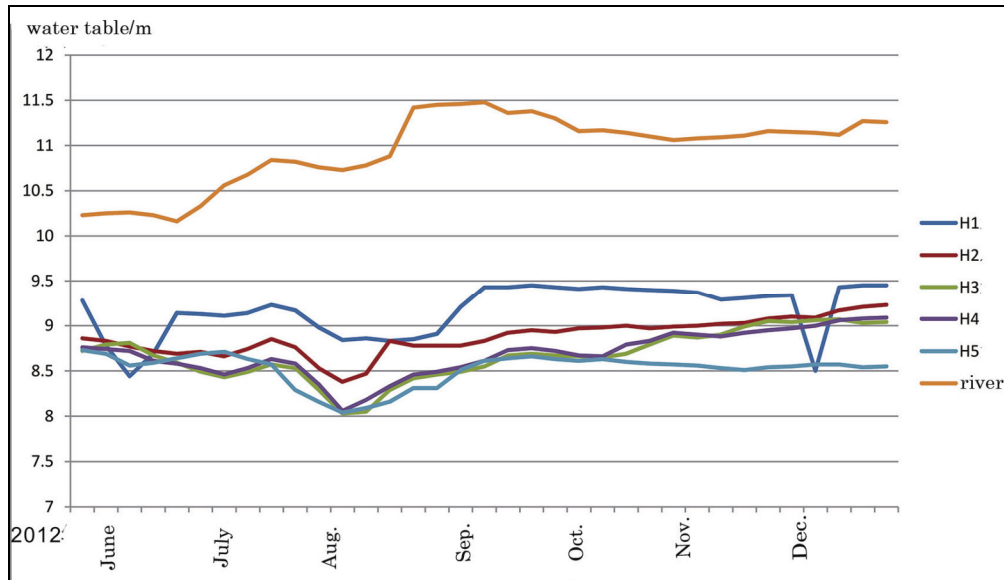


Fig.2 Water table of polluted river and groundwater in the experimental section

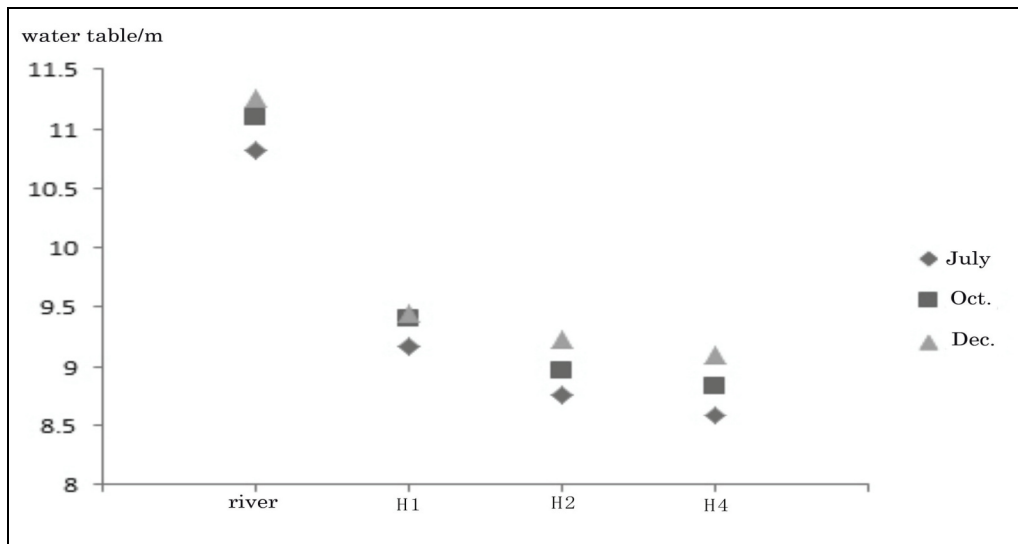


Fig. 3 Statistical graph of river table and groundwater table in typical time interval

Table 1 Water quality and factor of influence in experimental hydrogeological section

PT	Main factors	Water quality
River	Fe; Mn; As; NH_4^+ ; NO_2^- ; COD_{Mn} ; Benzol; Methylbenzene	V
H1	Mn; As; NH_4^+	V
H2	Mn; NH_4^+	V
H3	Mn; NH_4^+ ; NO_2^- ; COD_{Mn}	V
H4	Mn; As	IV
H5	Al; Fe; Mn	V

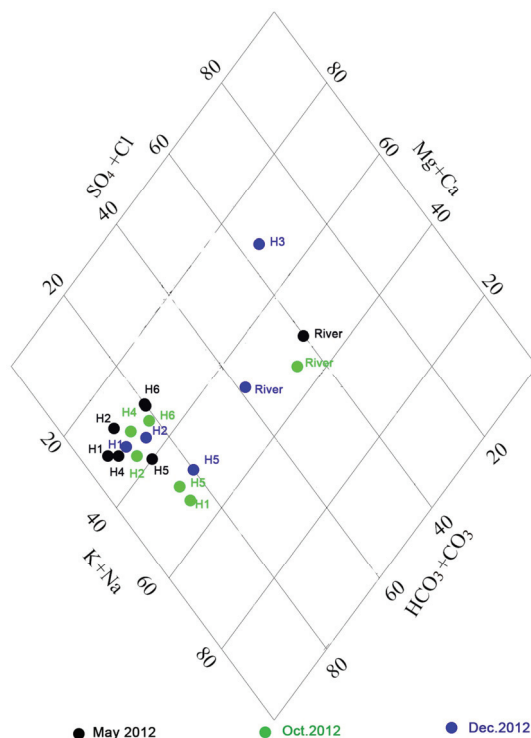


Fig.4 Piper line of groundwater and surfacewater

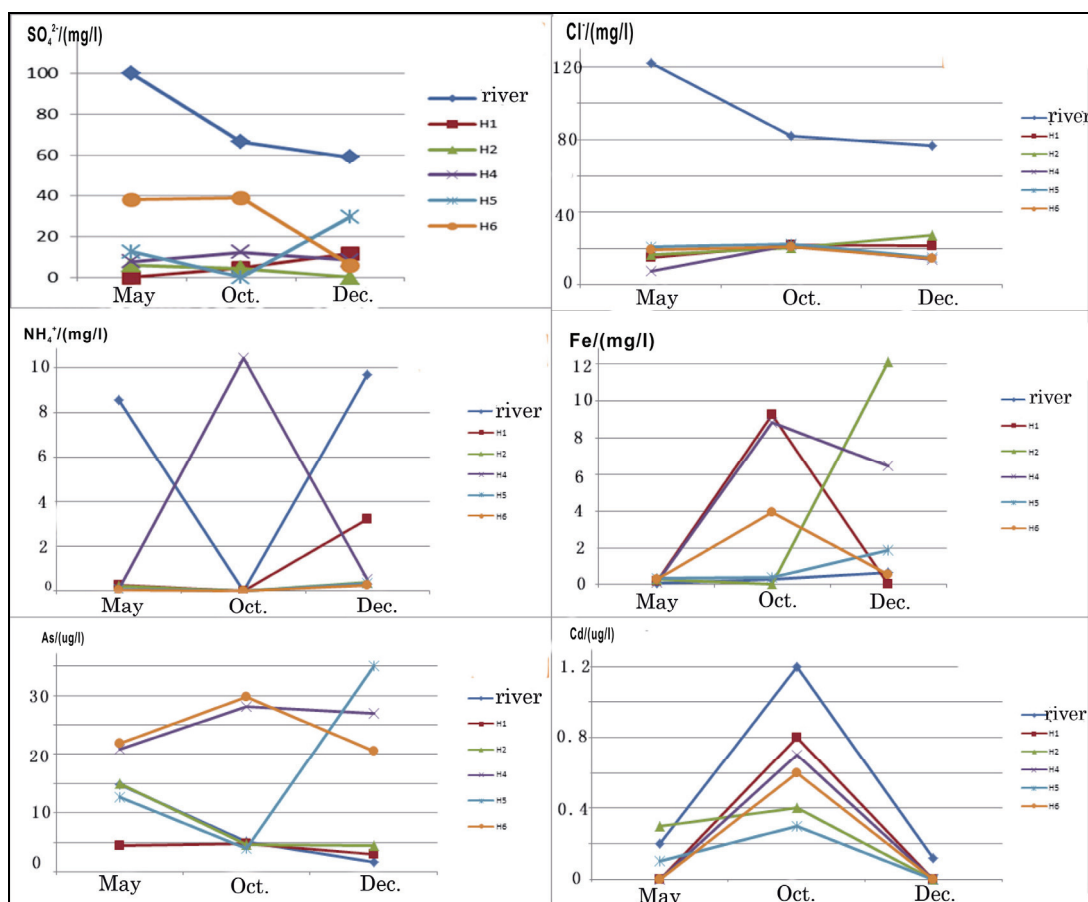


Fig.5 Schematic diagram of ion concentration in experimental section

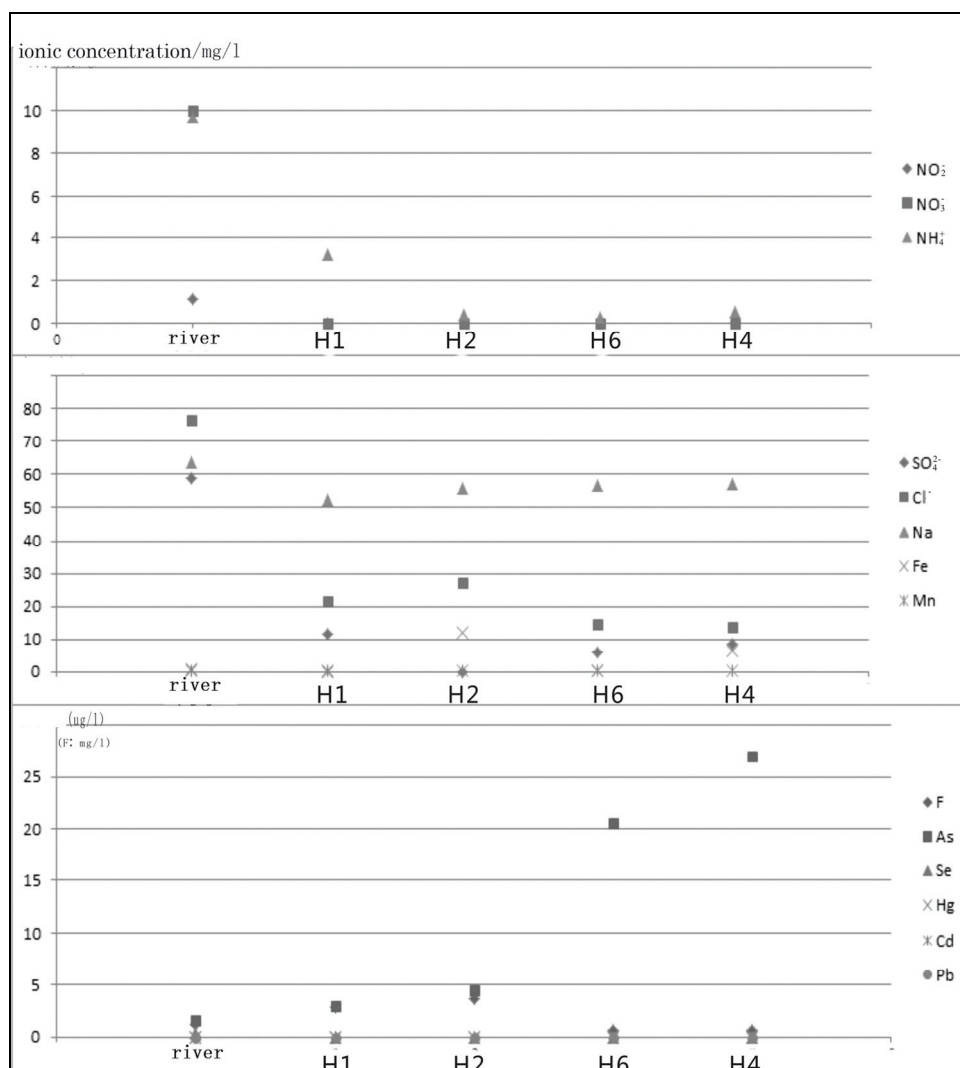


Fig.6 Content of certain ion in horizontal hydrogeological section

The data is subject to the statistics and evaluation in accordance with GB/T14848-2007 Standard for the Quality of Groundwater. H1 is categorized into IV category for once, while all other samples are evaluated with the same result (see Table 1). The quality of surface water falls into V category, and H1 and H2 of phreatic water are classified into V category, while H4, the farthest one, and H3 and H5 in weakly-confined groundwater is categorized into IV category. The primary factors impacting the surface water are Fe, Mn, As, NH_4^+ , NO_2^- , COD_{Mn} , benzene and toluene; the primary ions impacting the phreatic water are Mn, As, NH_4^+ , etc. the primary factors impacting the weakly-confined water vary greatly: the primary factors impacting H3 that is far away from the river are Mn, NH_4^+ , NO_2^- , COD_{Mn} , and factors impacting H5 that is near from the river are Al, Fe and Mn. As a whole, the primary factors impacting the phreatic water are relatively identical to those

of the surface water (Mn , NH_4^+).

3.2.2 Seasonal features of main ions

Organic components such as toluene and benzene in the surface water are tested exceeding the standard, nevertheless, the benzene is tested in only two wells of the groundwater but not exceeding the standard. The primary factors impacting the groundwater are inorganic components.

Fig. 5 reveals the tendency of change of some ions in the surface water and groundwater with seasons (H6 is one resident's well within the site, 37 m, and phreatic well). For sulfate, chloride and Cd concentration, either deep or shallow well is keeping the same pace with the surface water in terms of the change with seasons while the phreatic water has a different change. The change of various ions in the weakly-confined water H5

differs much with those of the surface water and the groundwater, and the concentration of these ions varies slightly in different periods of time. There is no obvious relevance among other ions, such as ammonium ion, iron element and arsenic element, *etc.* with significant diversity in all holes. The iron element may be related to the natural conditions, and the ammonium ion is largely affected by the oxidation reduction conditions and has strong instability while migrating (LI Zhi-ping, FENG Cui-hong, 2004; LI Zhi-ping, ZHANG Jin-bing, *et al.* 2004; HUANG Jian-feng, ZHANG Yi-zhang, *et al.* 2012; DING Hui, LI Xin-gang, *et al.* 2007).

3.2.3 Features of the spatial distribution of main ions

According to the data monitored for three times, it shows that ions remain the same in the horizontal and vertical distribution basically. In this paper, the

data of the dry season are sampled for analysis. Statistics for ionic concentration distribution on the horizontal (ion concentration in surface water and shallow groundwater) and vertical (surface water, unconfined water and weakly-confined water) directions are shown in Fig. 6 and Fig. 7, respectively, as follows:

Horizontally, in addition to heavy metals, the surface water has the highest content of various ions. However, with the greater distance from the ground, the concentration of stable and soluble ions, such as sulfate, chloride, sodium, *etc.* decreases gradually, while that of the iron, manganese and fluoride basically remains the same, and the arsenic concentration increases in tendency. No heavy metals are tested other than Cd. Since iron, manganese and fluoride can be determined as ions which have high background values, they are less likely to suffer pollution.

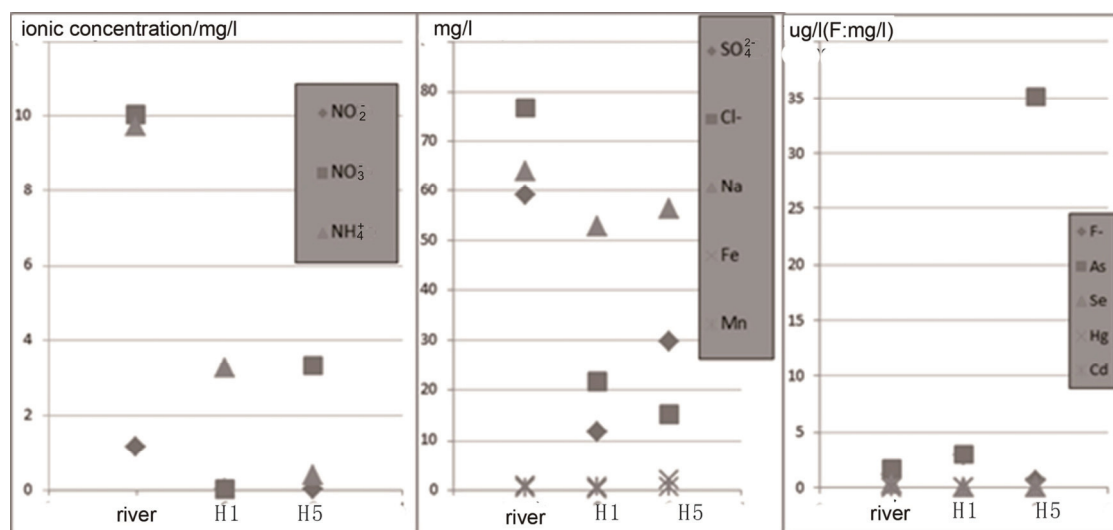


Fig.7 Content of certain ion in vertical hydrogeological section

On the vertical profile (surface water, phreatic water H1 and weakly-confined water H5), as the depth increases, the ammonium nitrogen, chloride, and sodium ion concentration decrease (Fig. 7), while the fluoride, selenium element, cadmium ion, mercury element, iron and manganese element remain unchanged generally, and the arsenic increases gradually.

4 Discussion

Known test and analysis data show that some

ionic concentration distribution statuses can clearly indicate the degree of pollution on groundwater from surface water and the affected area. However, there are also many ions that can not visually represent such the interactive relation between the surface water and groundwater due to their own physical and chemical characteristics, adsorption characteristics of water-contained lithology, redox environment and other factors (HUAN Huan, WANG Jin-sheng, *et al.* 2011; HU Hong-yan, CHEN Hong-han, *et al.* 2012; GU Li-ming, ZHANG Sheng, *et al.* 2012), which requires more

and deeper research as well as interpretation. Based on the preliminary data obtained this time, more data and in-depth research are required for the following questions.

(1) As an important pollutant, the heavy metals are tested few in this cross section, possibly resulting from deposition and isolation in the river sludge, which plays a decisive role (WU Guang-hong, ZHU Zhao-zhou, *et al.* 2008; FENG Dan, TENG Yan-guo, *et al.* 2010; HUANG Guan-xing, SUN Ji-chao, *et al.* 2011).

(2) Few samples of arsenic are tested within the horizontal and vertical range near the river; on the contrary, many types of arsenic are tested in the deep weakly-confined water and phreatic water. According to the results of previous studies, As is often adsorbed by Fe, Al and other sediments, in which is related to the decrease of As in the cross section near the river sections in this study (FENG Dan, TENG Yan-guo, *et al.* 2010).

(3) NH_4^+ concentration is low in the phreatic water, but very high in the weakly-confined water. However, other stable ions visually show that there is a weak relation between the surface water and weakly-confined groundwater. This preliminarily indicates that a part of NH_4^+ enters the weak confined layer, but also some of them are transformed from NO_2^- in reducing environment.

5 Conclusions

It is complicated to research the impact of Sewage River on coastal groundwater. Due to characteristic differences of hydraulic cycle, difference between artificial lining and sediment isolation conditions along the bank, differences in transmission lithology, *etc.* there is an exception for interactive relation between the surface water and groundwater without a law. In this paper, since the water level of the test river is always higher than the groundwater level, it is a one-way interaction for the surface water and groundwater, that is, the groundwater is mainly affected by the surface water. Therefore, on researches of relation between them, the key is to research the range of impact from the surface water on the quality of groundwater. By analysis of obtained test data, we can draw the following conclusions:

(1) Sewage usually flows into groundwater

from the sewage river. One-way pollution on phreatic water by surface water obviously appears within 116 m-wide test bank, and reduces as distance increases.

(2) As deep groundwater connects to shallow aquifer and thus indirectly suffers pollution from surface water via phreatic water, its water quality is poor. The pollution belt ranges less than 50 m upwards vertically, but is less than that of phreatic aquifer.

(3) Among factors affecting groundwater quality, sulfate, chloride, ammonia nitrogen and other major pollutants are seriously affected by surface water. In particular, ammonium nitrogen usually converges in the weakly-confined layer near the reducing state as the major factor for the pollution of weakly-confined water.

(4) Fe, Mn and other elements tested in groundwater have the same characteristics with those of local groundwater, almost native-based, less affected by surface water. And the concentration in phreatic and weakly-confined water remains the same.

(5) Except Cd, most heavy metals in groundwater are less affected by the surface as the test and analysis show, possibly resulting from deposition and isolation of sediment.

(6) Benzene and toluene are the main organic substance tested in surface water and phreatic water near the river. Benzene, as a raw material for synthetic organic solvent for pesticides, its derivatives are widely used in the chemical industry, and the waste water containing such organic pollutants is drained into the river, and then pollutes phreatic groundwater nearby through supplementing groundwater, but the pollution is limited in range.

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References

- DING Hui, LI Xin-gang, *et al.* 2007. Characteristics of sediments of Dagou Drainage River. *Haihe Water Resources*, 2: 44-48.
- FENG Dan, TENG Yan-guo, *et al.* 2010. Natural attenuation of arsenic and metals in river-

- groundwater hyporheic zone. *Earth and Environment*, 48(4): 456-461.
- GU Li-ming, ZHANG Sheng, *et al.* 2012. Research of exchange relationship of surface water and groundwater pollutants-taking Old City zone of Changzhou as an Example. *Environmental Science and Technology*, 25(2): 4-8.
- HU Hong-yan, CHEN Hong-han, *et al.* 2012. Contamination of groundwater along banks of Jindi River in northeast Puyang. *Water Resources Protection*, 28(2): 12-16.
- HUAN Huan, WANG Jin-sheng, *et al.* 2011. Chemical characteristics and evolution of groundwater in the Yongding River Alluvial Fan of Beijing Plain. *Acta Geoscientica Sinica*, 32(3): 357-366.
- HUANG Guan-xing, SUN Ji-chao, *et al.* 2011. Content and relationship of heavy metals in groundwater of sewage irrigation area in Pearl River Delta. *Journal of Jilin University (Earth Science Edition)*, 41(1): 228-234.
- HUANG Jian-feng, ZHANG Yi-zhang, *et al.* 2012. Characteristics and potential sources of nitrate pollution in surface and groundwater in Xitiaoxi River, Taihu Lake Basin. *Research of Environmental Sciences*, 25(11): 1 229-1 235.
- LI Zhi-ping, FENG Cui-hong, *et al.* 2004. Research on the influence of adjacent shallow groundwater by COD in long-term polluted river. *Journal of Irrigation and Drainage*, 24(1): 47-51.
- LI Zhi-ping, ZHANG Jin-bing, *et al.* 2004. Influence on shallow groundwater by $\text{NH}_4\text{-N}$ in polluted river. *Earth Science-Journal of China University of Geosciences*, 29(3): 363-368.
- WU Guang-hong, ZHU Zhao-zhou, *et al.* 2008. Concentrations and distribution of heavy metals in urban sewage discharge channel of Tianjin. *Environmental Science*, 29(2): 413-420.
- YE Nian-jun, GE Wei-ya, *et al.* 2008. Research report of environmental geology in Huaihe River Catchment. Nanjing center, CGS.
- YE Nian-jun, GONG Jian-shi, *et al.* 2012. The typical study and status report of groundwater contamination in Huaihe River Plain. Nanjing center, CGS.
- ZHAO Xia, CHEN Jian-sheng. 2005. Queries on the conversion between surface water and groundwater within the Heihe River Drainage. *Acta Geoscientica Sinica*, 26(z1): 309-311.