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*Full Length Research Paper*

# The impacts of groundwater heat pumps on urban shallow groundwater quality in Shenyang China

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**In order to assess the impacts of groundwater heat pumps on urban shallow groundwater quality in Shenyang China, the urban groundwater samples from pumping and recharging wells of groundwater heat pumps were collected during heating season in the months of November, September, January, February and March in 2007 and 2008. 17 groundwater quality parameters were analyzed using Chinese state or professional standard laboratory methods and procedures. The results show that temperature, pH and the concentrations of total dissolved solid (TDS), total mineralization of groundwater (TMG), chloride (Cl), total hardness (TH), zinc (Zn), petroleum-related pollutants (PRP) and ferrum (Fe) in pumping water were lower than that in recharging water, while the turbidity, $SO_4$ and fluoride showed crosscurrent. There were no changes in Mn, Cu, nitrite nitrogen and total coliforms. The total bacterial count was 1/ml average in pumping water and 0/ml average in recharging water. The sampling of urban groundwater quality is higher than Chinese groundwater quality standard grade III. The groundwater heat pumps showed little impacts on urban shallow water quality during the heating season.**

**Key words:** Urban shallow ground water quality, ground source heat pump, groundwater heat pumps, pumping wells, recharging wells, Shenyang.

## INTRODUCTION

Groundwater heat pumps (GWHPs) were applied to the thermal transfer systems that use the ground water as a heat source and sink (Yang et al., 2009). The energy crisis and greenhouse gases (GHGs) emission reduction are critical not for China, but for the world. The GWHPs have evolved as one of the most attractive energy efficient technology for space heating and cooling, which makes it one of the most popular energy-saving and emission reduction air-conditioning systems in many countries (Lohani and Schmidt, 2010). It is predicted that worldwide application of the systems will exponentially increase in the next decades (Fridleifsson et al., 2008). Most studies, related to GWHPs, are about technologies (Bi et al., 2009; Koyun et al., 2009; Nagano et al., 2006; Tarnawski et al., 2009), the water sources selection (Xue et al., 2003), energy-saving (Dickinson et al., 2009; Kikuchi et al., 2009; Tolga et al., 2008) and GHGs reduction (Blum et al., 2010; Saner et al., 2010). There was lack of studies about the environmental impacts of GWHPs, especially in urban shallow groundwater quality. Klotzbücher et al. (2007) analyzed biodegradability and groundwater pollutant potential of organic anti-freeze liquids in GWHPs. They recommended that betaine was not to be used in borehole heat exchanger fluids because it has the potential of complex metal ions and thus may mobilize toxic metals in groundwater. Zheng et al. (2005) studied bacterial growth of recharging wells. There was little microbes' growth except at the border area of the cold and warm water, where a ring of high concentration was mixed with microbes. The GWHPs application in

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**Abbreviations: GWHPs,** Groundwater heat pumps; **GHGs,** green house gases; **PRPs,** petroleum-related pollutants; **TDS,** total dissolved solid; **TMG,** total mineralization of groundwater; **SO4,** sulphate; **Cl,** chloride; **TH,** total hardness; **NN,** nitrous nitrogen; **TC,** total coliforms; **TBC,** total bacterial count.

**Table 1.** Applied area of ground water heat pumps technology from 2006 to 2010.

| **Year** | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| **Areas ($Mm^2$)** | 3.1 | 14.3 | 22.5 | 32.3 | 45.5 |

USA had showed changes of the total mineralization of groundwater (TMG), chloride (Cl) and electrical conductivity in the recharging well (Hatten and Morrison, 1995). The total bacterial count and transfer distance were important for the water quality of the recharging well (Bales et al., 1997). Unfortunately, there is lack of comprehensive analysis about the impacts of GWHPs' running process on urban shallow groundwater quality in China.

The study was aimed at determining the biochemical parameters and heavy metal changes of groundwater in the running process of GWHPs, which revealed water quality changes in the pumping well, heat exchanger and extraction, and recharging well. The water quality changes in GWHPs running process could also give helpful information related to system performance and management, especially in urban shallow groundwater quality protection. The purpose was to explore the impacts of the running process of GWHPs on groundwater quality. Furthermore, scientific suggestions to technology improvement engineering and running management of GWHPs were given.

## MATERIALS AND METHODS

Shenyang is located in northeast China with a total administrative area of 12,980 $km^2$ (41°11´45" to 43°2´13"N, 122°25'9" to 123°48´24"E) and is the capital city of Liaoning province. Shenyang has a semi-humid continental climate with four distinctive seasons. The average annual temperature is about 8.1°C and the winter heating season is up to 5 months. Shenyang is in the middle and lower reaches of Liaohe River, with better hydrogeological conditions for groundwater heat pump technology application. Shenyang had applied the ground source heat pump technology since 1997, and the accumulative applied heating area was about 3.1 million $m^2$ until 2006. By 2010, the accumulative applied area of the ground source heat pump technology reached 45.5 million $m^2$ (Table 1). There were mainly four ground source heat pump technologies in Shenyang, which referred to groundwater heat pumps (GWHPs), ground-coupled heat pumps (GCHPs), regenerated water heat pumps (RWHPs) and mixed water source heat pumps (MWHPs). GWHPs application, using urban shallow ground water, was dominant in Shenyang. GWHPs projects are mainly distributed in the central city (Figure 1). So far, groundwater heat pumps technology has been widely used in residential and public buildings.

Six groundwater sampling projects were selected in the study area. The sampling method was with reference to "groundwater environment monitoring technology standard" (HJ/T164-2004). The sampling projects accounted for topography, administrative division, heating area, running years and monitoring conditions (Alexander, 2010; An et al., 2005). A GWHPs project in the residential building, two GWHPs projects in scientific buildings, a GWHPs project in the educational building, and two GWHPs projects in the commercial building were selected. Three monitoring boreholes were dug for each project, one for the control point and the other two for the pumping and recharging wells, respectively. However, the depth of boreholes was 25 m. The monitoring time is the heating season in the months of November, September, January, February and March, in 2007 and 2008, while the monitoring frequency is a period of ten days. The monitoring parameters were water temperature, turbidity, pH, total dissolved solid (TDS), total mineralization of groundwater (TMG), sulphate ($SO_4$), chloride (Cl), total hardness (TH), nitrous nitrogen (NN), fluoride (F), petroleum-related pollutants (PRP), ferrum (Fe), manganese (Mn), copper (Cu), zinc (Zn), total coliforms (TC) and total bacterial count (TBC). The state standard monitoring and analysis methods and the professional standard monitoring and analysis methods were used in the 17 parameters analysis. The evaluation criterion implemented the quality standard for ground water (GB/T14848-93) grade III standard level. The 'quality standard for ground water' grade III was based on the reference values of the human health, which was mainly suitable for centralized domestic and drinking water sources and industrial and agricultural water in China. The minimum detectable concentration of the grade III water quality standard was used as compared to the evaluation criterion (Table 2).

## RESULTS AND DISCUSSION

The baseline conditions and standards setting for groundwater quality analysis were essential (Al-Kharabsheh, 1999; Ehiagbonare and Ogunrinde, 2010). The minimum detectable concentration of the grade III groundwater quality standard in Table 2 was used as compared to the evaluation criterion. The results of various parameters of groundwater quality of GWHPs are shown in Table 3. The monitoring and analysis results showed that although there were changes in some groundwater quality parameters, the groundwater quality sampled from recharging wells was higher than the Chinese groundwater quality standard III category. Water temperature, pH and the concentration of TDS, TMG, Cl, TH and Zn, petroleum-related pollutants (PRP) and Fe in pumping water were lower than that in the recharging water, while the turbidity, $SO_4$ and fluoride showed crosscurrent. However, there were no changes in Mn, Cu, nitrite nitrogen and total coliforms. The total bacterial count was 1/ml average in pumping water and 0/ml average in recharging water. There was a large concentration change in TBC, turbidity, Fe, oil pollutants, Zn and water temperature, when the pumping water was compared with the recharging water. The concentration change rates of Zn and water temperature were 30 to 50%, while the concentration change rate of petroleum-related pollutants (PRP), Fe and turbidity was 55.6, 67.7 and 84.3%, respectively. However, the total bacterial count was 1 MNP/ml in pumping well and 0 MNP/ml in

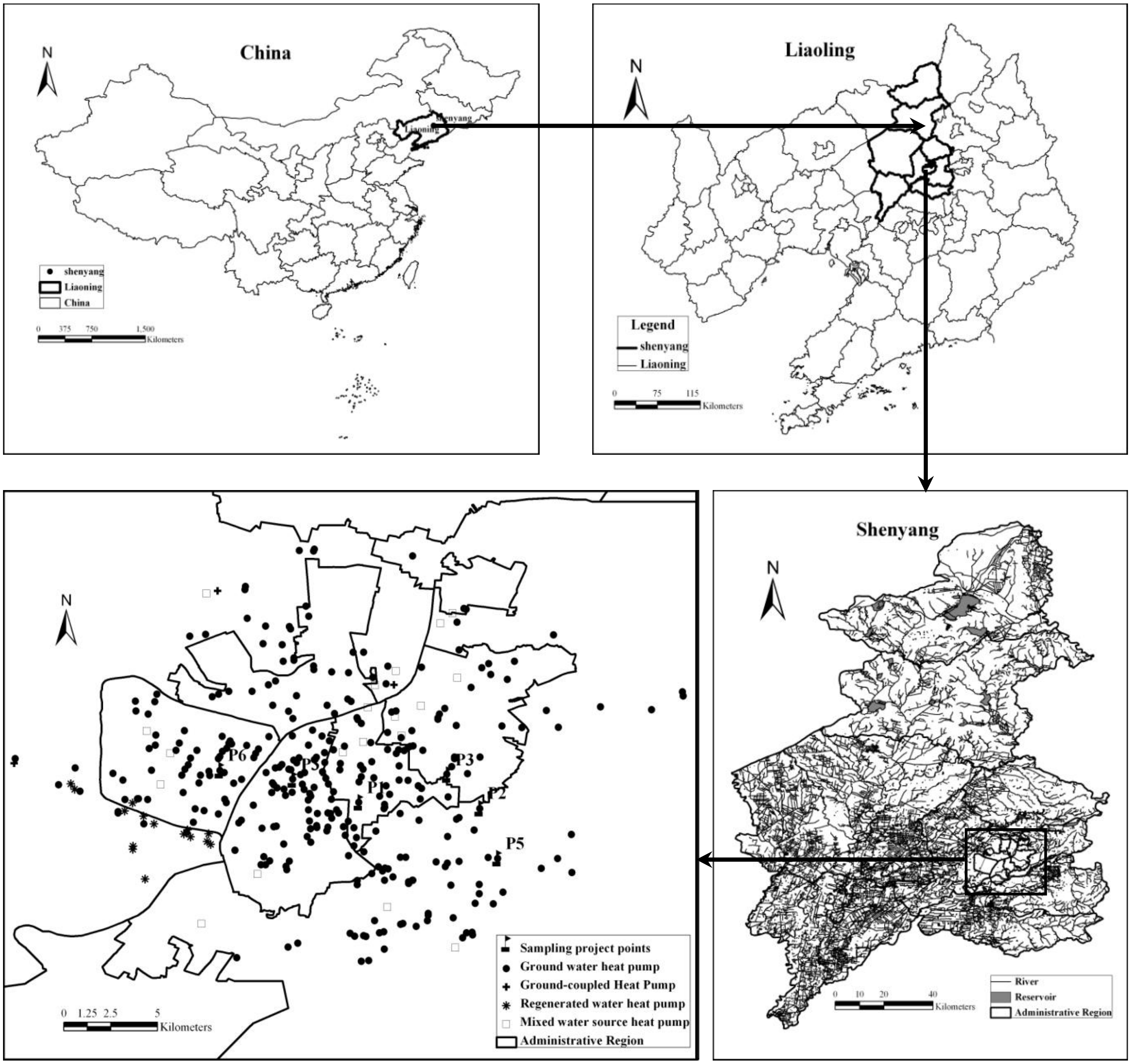


**Figure 1.** Location of Shenyang city and the types of ground source heat pump technologies and their spatial distribution. P1 is GWHPs project in the Institute of Metal Research, Chinese Academy of Sciences; P2 is GWHPs project in Shenyang Institute of Engine Design, Aviation Industry Corporation Group; P3 is GWHPs project in Chengjian Dongyi residential area; P4 is GWHPs project in Five Rings Sport Shop; P5 is GWHPs project in Shenyang Jianzhu University; P6 is GWHPs project in Tiexi General Merchandise Mall.

recharging well.

## Water temperature

The average temperature range of the six monitoring projects between pumping and recharging waters is 13.4 to 8.9°C, while the range of GWHPs in Five Rings Shangcheng residential area (P4) is 14.5 to 13.3°C, which showed low running performance of the GWHPs (Benli and Durmus, 2009).

## Turbidity

The average turbidity of recharging water increased to 84.3% when compared to the pumping water. The turbidity of recharging water was lower than that of pumping water in P1 and P3, while the other four projects showed crosscurrent, especially the GWHPs project of

**Table 2.** The monitoring and analysis methods used in the study.

| Monitoring parameter | Analysis method | Minimum detectable concentration | State standard monitoring and analysis methods (GB) and professional standard monitoring and analysis methods (HJ) |
|---|---|---|---|
| **Temperature (℃)** | Automatic display of GWSHPs | — | GB/T13195-1991 |
| **Turbidity (NTu)** | Nephelometer method | 0.01 NTu | GB/T13200-1991 |
| **pH** | Glass-electrodes method | 0.1 | GB/T6920-1986 |
| **TDS (mg/L)** | Gravimetric method | 3 mg/L | GB/T11901-1989 |
| **TMG (mg/L)** | Gravimetric method | 3 mg/L | GB/T11901-1989 |
| **$SO_4$ (mg/L)** | Chromatography of ions | 0.09 mg/L | Monitoring and analysis method of water and waste water (the 4th Edition) (HJ) |
| **Cl (mg/L)** | Chromatography of ions | 0.02 mg/L | Monitoring and analysis method of water and waste water (the 4th Edition) (HJ) |
| **TH (mg/L)** | EDTA titration | 5.00 mg/L | GB/T7477-1987 |
| **NN (mg/L)** | Spectrophotometric method with N-(1-naphthyl) echylenediamine | 0.003mg/L | GB/T7489-1987 |
| **F (mg/L)** | Chromatography of ions | 0.02 mg/L | Monitoring and analysis method of water and waste water (the 4th Edition) (HJ) |
| **PRP (mg/ L)** | Three wave-length Infrared spectrophotometry | 0.03 mg/L | GB/T11914-1989 |
| **Fe (mg/L)** | Flame atomic absorption spectrometry | 0.03 mg/L | GB/T11911-89 |
| **Mn (mg/L)** | Flame atomic absorption spectrometry | 0.02 mg/L | GB/T11911-89 |
| **Cu (mg/L)** | Flame atomic absorption spectrometry | 0.01 mg/L | GB/T7475-1987 |
| **Zn (mg/L)** | Flame atomic absorption spectrometry | 0.004 mg/L | GB/T7475-1987 |
| **TC (MPN/L)** | Multiple-tube fermentation technique | — | Monitoring and analysis method of water and waste water (the 4th Edition) (HJ) |
| **TBC (MPN/ml)** | Standard plate count method | — | Monitoring and analysis method of water and waste water (the 4th Edition) (HJ) |

Monitoring and analysis method of water and waste water (the 4th Edition) is the professional standard of Chinese Environmental Protection Ministry.

Tiexi general merchandise mall (P6) that showed 309.2% growth. If the turbidity of recharging water has a higher value than that of the pumping water, it indicates that some pollutants may invade the GWHPs system.

### Petroleum-related pollutants (PRP)

The average contraction of petroleum-related pollutants in recharging water decreased to 55.6% when compared to that of the pumping water. The small range of contraction of PRP during groundwater pumping and recharging was acceptable, because of the different organic anti-freeze compounds (ethylene glycol, propylene glycol and betaine), lubricant and refrigerating fluid used in these pumps (Klotzbücher et al., 2007). However, if the contraction of PRP in the recharging water is much higher than that of the pumping water, there may be something wrong with the GWHPs equipments, which will thus result to PRP leakage.

### Total coliforms

All the concentrations of total coliforms in pumping and recharging waters were less than 3 MPN/L (except the GWHPs project in Shenyang Institute of Engine Design, Aviation Industry Corporation Group (P2) with 13 MPN/L in pumping water), and less than 3 MPN/L in recharging water. The high concentrations of total coliforms in pumping water showed the deterioration of water quality in the sampling projects. The decrease of the concentrations of total coliforms may result from the decrease of water temperature during the GWHPs running.

**Table 3.** The monitoring and analysis results of pumping and recharging waters of GWHPs.

| Monitoring parameter | Sampling project | | | | | | | | | | | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | P2 | | P3 | | P4 | | P5 | | P6 | | | |
| | PW | RW | PW | RW | PW | RW | PW | RW | PW | RW | PW | RW | PW | RW |
| Temperature (°C) | 14.0 | 10.7 | 14.1 | 9.5 | 10.4 | 5.1 | 14.5 | 13.3 | 12.6 | 7.6 | 15.0 | 7.0 | 13.4 | 8.9 |
| Turbidity (NTu) | 0.48 | 0.41 | 0.54 | 2.21 | 0.72 | 0.42 | 1.04 | 1.24 | 0.39 | 0.57 | 1.04 | 2.90 | 0.70 | 1.29 |
| pH | 6.74 | 6.73 | 6.71 | 6.59 | 6.56 | 6.68 | 7.10 | 6.93 | 6.71 | 6.66 | 6.72 | 6.66 | 6.76 | 6.71 |
| TDS (mg/L) | 532 | 424 | 512 | 454 | 564 | 528 | 460 | 444 | 388 | 352 | 504 | 478 | 493 | 447 |
| TMG (mg/L) | 558 | 458 | 506 | 466 | 498 | 478 | 428 | 406 | 384 | 322 | 494 | 462 | 478 | 432 |
| SO4 (mg/L) | 143 | 145 | 132 | 134 | 158 | 160 | 125 | 127 | 126 | 128 | 123 | 125 | 134 | 136 |
| Cl (mg/L) | 55.3 | 56.3 | 60.7 | 61.5 | 67.8 | 69.0 | 64.7 | 56.9 | 60.5 | 61.6 | 69.5 | 71.1 | 63.1 | 62.7 |
| TH (mg/L) | 314 | 314 | 300 | 300 | 336 | 336 | 328 | 324 | 256 | 248 | 316 | 316 | 308 | 306 |
| NN (mg/L) | <0.003 | <0.003 | 0.005 | 0.005 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| F (mg/L) | 0.15 | 0.15 | 0.12 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.20 | 0.25 | 0.15 | 0.16 |
| PRP (mg/ L) | 0.59 | 0.06 | 0.03 | 0.06 | 0.09 | 0.06 | 0.06 | 0.07 | 0.06 | 0.08 | 0.04 | 0.19 | 0.14 | 0.09 |
| Fe (mg/L) | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | 0.03 | 0.03 | 0.68 | <0.03 | <0.03 | 0.16 | 0.13 | 0.042 |
| Mn (mg/L) | 0.02 | 0.02 | 0.08 | 0.06 | 0.03 | 0.03 | <0.02 | <0.02 | <0.02 | <0.02 | 0.24 | 0.25 | 0.06 | 0.06 |
| Cu (mg/L) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.04 | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 |
| Zn (mg/L) | 0.022 | 0.034 | <0.004 | <0.004 | 0.022 | <0.004 | 0.004 | 0.004 | 0.091 | <0.004 | 0.011 | 0.048 | 0.025 | 0.015 |
| TC (MPN/L) | <3 | <3 | 13 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| TBC (MPN/ml) | 0 | 1 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

P1 is GWHPs project in the Institute of Metal Research, Chinese Academy of Sciences; P2 is GWHPs project in Shenyang Institute of Engine Design, Aviation Industry Corporation Group; P3 is GWHPs project in Chengjian Dongyi residential area; P4 is GWHPs in Five Rings Sport Shop; P5 is GWHPs project in Shenyang Jianzhu University; P6 is GWHPs project in Tiexi General Merchandise Mall. PW is pumping water and RW is recharging water.

## Total bacterial count (TBC)

The GWHPs project of Chengjian Dongyi residential area (P3) and the GWHPs project of Shenyang Jianzhu University showed 0 MPN/L in both pumping and recharging waters. The GWHPs project in Shenyang Institute of Engine Design, Aviation Industry Corporation Group (P2) showed 1 MPN/L in both pumping and recharging waters. The GWHPs in Five Rings Sport Shop (P4) showed 2 MPN/L in pumping water and 0 MPN/L in recharging water. The GWHPs project of Tiexi general merchandise mall (P6) showed 1 MPN/L in pumping water and 0 MPN/L in recharging water. The GWHPs project in the Institute of Metal Research, Chinese Academy of Sciences is the only sampling site that showed total bacterial count increase in recharging water. However, the average total bacterial count is 0 MPN/L in pumping water and 1 MPN/L in recharging water. So, the total bacterial count decreases during the GWHPs system running.

## Conclusion

From the 17 groundwater quality parameters monitoring and analysis, it was concluded that although there were some changes in temperature, pH and the concentrations of TDS, TMG, Cl, TH, Zn, petroleum-related pollutants (PRP), Fe, turbidity, $SO_4$, total bacterial count and fluoride, the groundwater quality was higher than Chinese groundwater quality standard category III. The groundwater heat pumps showed little impacts on urban shallow ground water quality in the heating season. The monitoring and analysis results could give scientific suggestions to technology improvement engineering and running management of GWHPs. However, multi-years, long-term and positioning studies should be continued in the following work.

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