THE WATER CHEMICAL CHARACTERISTICS OF QINGLONGDONG KARST SPRING, KUNMING CHINA

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Abstract
Karst water plays a very important role in providing a municipal water supply in Kunming City, Yunnan Province, China. It contributes approximately 50% of the drinking water for the city. Given the rapid growth in urbanization and of the economy of Kunming City in the last decades, most karst springs have been suffering from human impact, in both quality and quantity. Qinglongdong Spring (QLDS) is located in Dabanqiao village, Northwestern Kunming, 23 km away from Kunming downtown and is an important component of the water supply system of Kunming City. It was previously abandoned in 2003 and 2004 due to high levels of organic contamination.

In order to better understand factors impacting the spring water quality and quantity, a Greenspan CTDP300 multi-parameter data logger (water level, pH, EC, and T), and a rain gauge were installed. Water samples were manually collected and analyzed between May and August 2003 to 2009. The test results revealed that the Qinglongdong Spring study area not only has a well-developed groundwater drainage system, but also the vadose zone is very thin. Given this hydrogeological situation, QLDS has a rapid response to rainfall events, and therefore, the pollutants are transported inside the aquifer rapidly as well. Manual sampling indicates an increasing trend of nitrate content in the spring from 2006 to 2009. It is possible that this area may be influenced by sewage, which is being disposed of illegally, but this would need further investigation.

Introduction
Kunming is the capital city of Yunnan Province, China, with a population of over 6 million. Geographically, it is located within the Yangtze River and Pearl River watershed. Dianchi Lake is located downstream of Kunming city, and is one of the largest surface water bodies in Yunnan province. It once was one of the main water sources for municipal water supply. Unfortunately, it has been heavily polluted since the late 1980s, which exacerbated the water shortage of Kunming. Kunming is located within a karst faulted basin, which is a unique landform. Hundreds of karst springs exist in this basin. These karst springs are now the other main water sources for municipal purposes for the city and most are used by the municipal water supply systems. Karst water contributes around 50% of the drinking water in Kunming.

Kast aquifers are fragile and are very sensitive to human activities and environmental change (Ravbar, 2007). The influence of industry and agriculture on karst aquifers is a global problem, which has attracted worldwide attention (Drew et al., 1999). With rapid urbanization and a growing economy in the last decades, many human activities are straining the karst groundwater resources of Kunming City. The groundwater has been overexploited because of the increasing demand for water. This large-scale land use change in karst areas inevitably results in negatively affecting the quality and quantity of the groundwater. Hundreds of springs in the Kunming faulted karst basin have dried out and produced less water. Some important water source springs have been contaminated, including Haiyuan Spring and Kunming Heilongtan Springs. The latter has been abandoned as a drinking water source.

Nevertheless, there are few studies that have been done to investigate those springs. In 2007, construction on Kunming City’s new international airport was started. This site is adjacent to the outlet of Qinglongdong Spring (QLDS), which is an important drinking water source spring. Most of the recharge area of the spring...
was occupied by the new airport (Figure 1). In order to understand the impact of the new airport construction on the spring water, with respect to quality and quantity, a comprehensive research was carried out in 2007. This paper presents some of the results of this study.

**Study Area and Methods**

The study area is located in the northeastern portion of Kunming, about 20 km from the Kunming downtown area. The climate in this area is a latitude plateau monsoon climate, with mean annual air temperature of 14.5°C and the mean annual precipitation of 1035 mm. There are two seasons in this region, the rainy season and the dry season. The rainy season occurs from May to October. The rainfall during the rainy season contributes 90% of the annual precipitation. The following dry season is from November to April of the next year. This pattern of precipitation has a very substantial impact on the behavior of groundwater.

The recharge area of these springs is dominated by Paleozoic carbonate rocks of Cambrian to Permian age (Figure 1). Lithologically, the Lower Permian carbonate is composed mainly of limestone, dolomitic limestone and dolomite, and the percentage of dolomite increases from Carboniferous to Devonian. There are some thin inter-layers of mudstone or sandstone within the Devonian and Cambrian carbonate formations. Karst features can be seen on the Lower Permian and Carboniferous carbonate rocks, where there are many dolines, depressions and sinkholes. The poorly permeable Cambrian, Carboniferous, and Permian clastic layers between the carbonate sequences constitute the hydrogeological barriers. Quaternary alluvial sediments are deposited along the surface water courses. These used to be farmlands planting orchards, vegetable or corn fields, or paddy fields planting rice before the construction of the new airport.

Qinglongdong Spring is located at the contact zone between the karst aquifer and the alluvial sediment. A sub-vertical fault cuts through from the northwest to the southeast. 100 meters away from the fault to the northwest, there is another spring named Huanglongdong Spring, which is also used as a municipal water supply. Between these two springs, there is a thin belt of impermeable Permian clastic sediments extending in a northerly direction. This impermeable belt acts as a hydrological barrier separating the catchments of the two springs. There are several sinking streams distributes in the western part of study area. However, the direction of their underground flow has not been reliably proven yet. There is a sinkhole, named Qiaotou Sinkhole, at about 1 km north of the springs.

The annually mean discharge of QLDS is 473 liters per second (l/s). The minimal discharge is about 5 l/s and the maximum can be up to 3 cubic meters per second (m³/s) or more.

The QLDS had been utilized as a water source for years. Water is mainly pumped by the Baoxianghe water plant, and partly pumped by neighboring villages and factories for the purposes of drinking and industrial use. Along with the rapid urbanization, the nearby town, named Dabanqiao, has become a suburb of Kunming city. In the 1980s, and especially after the 1990s, some factories and other enterprises such as a cement factory, and an oil depot were built in the karst area, as well as highways extending in all directions (e.g., a beltway, new airport highway), the railway network, and countless quarries. Several farms used for food crops have shifted to vegetable cultivation, which increased the use of fertilizers and pesticides. As a consequence, QLDS once had been abandoned due to the pollution of aromatic hydrocarbons substances during 2003 and 2004. However, it has been used again since 2005, because of limited water supplies for municipal supply.

A Greenspan CDTP300 data logger with probes for the continuous measurement of water level, temperature (T), electrical conductivity (EC) and pH at 15 min intervals was installed at the QLDS in February 2007 and data...
was collected until September 2007. A rain gauge was installed on the roof of the pumping station building, which is 50 m away from the spring. The spring discharge was measured with an OTT C20 Current Meter in July 2008 and May 2009. For other sampling times, the discharge was estimated empirically.

The spring water was sampled between 2006 and 2009 in the period from May to August for physical and chemical analyses. T and EC were measured in situ with WTW MultiLine P4 in 2006 and 2009, and WTW 330i conductivity meter in 2007 and 2008. The contents of nitrates, o-phosphates, and ammonium were analyzed by using the corresponding Visicolor-ECO colorimetric tests field laboratories. Total hardness (Ca+Mg) and calcium content (Ca) were determined using the standard titrimetric method (Greenberg, 1992).

Results and Discussion

The monitoring results of Greenspan CDTP300 data logger are presented in Figure 2. The small serrate fluctuation of the spring water level was caused by water pumping from Dabanqiao horticultural farm. They pumped water from a karst window, 20 m upstream of our monitoring site.

The responses of water level, temperature, EC and pH of QLDS to rainfall event were different. The general trend is that the temperature, EC and pH of the springs will rise briefly and then drop in half an hour after heavy rain. The response of water level to precipitation is special. The water level started to rise in half an hour after rainfall, but then fell soon thereafter. At the beginning of rainy season, the soil water deficit is serious after a long dry period. Therefore, following the first heavy rainfall has no obvious effect on the spring water flow or has longer lag time. The rapid response of QLDS to precipitation shows that its vadose zone has limited capacity as a water buffer. Alternatively, there exists a well-developed groundwater drainage system. A dye tracing in this area showed that a fast groundwater flow system exists in study area (Knez et al., 2012). Of course, this may relate to the thin vadose zone of QLDS, with average thickness of 30–40 meters. However, for some rainfall events, the event of 22 mm precipitation on 29 April 2007 for instance, the response of the spring water level showed a delay of one day.

For the whole time period of data logger monitoring, water level of the spring is more sensitive to rainfall, especially for heavy rainfall events. It should be noted that it is difficult to explain two broad peaks formed in the time from 29 April to 28 May and from 15 August to 15 September. Each of them lasted for around 30 days. We proposed that another water source had joined in. The trend of temperature was relatively stable, only departing from this trend after heavy rainfall events. In contrast, the EC value was continuously increasing until the heaviest rainfall event occurred. For pH, we observed a slowly increasing trend during the period of no rain, and slowly decreasing after the first heavy rainfall event.

Some anomalous hydrologic events can be observed in Figure 2. At the first glance, it seems like anomalous data that might be caused by instrument error, but after examining more closely on a scale of days, it can be observed that each event which appears in Figure 2 is represented by a group of data, and the parameters (water level, T, EC, and pH) changed synchronously for between 5 and 10 hours (Figure 3). Most of the events began in the early morning before sun rise. One of events might be caused by small quantity of sewage disposal near the outlet of the spring. This pulse may have arisen...
from the wastewater discharge. But this conclusion needs be verified by further tracer testing.

The results of chemical parameters are shown in Figure 4. The content of nitrates increased from 10 mg/l (May 2007), to 15 mg/l (July 2008), and 22 mg/l (June 2009) to 70 mg/l (August 2009).

Another important pollution source of QLDS is an oil storage depot named Hunlongtan, in the northeastern part of the study area. It was built in 1995 and began operations in 1996. The oil storage capacity was about 34000 m$^3$, stored in dozens of tanks of sizes 60–5000 m$^3$. Every three to four years the tanks needed to be washed, or when the type of oil change for a tank. In general, oil storage varieties and quantities are adjusted according to the market each year. Some oil storage tanks needed be washed every year. There was no oil and water separation pool built until 2000, and the waste water drained directly into the karst depressions. Later the oil and water separation pool was actually built at the bottom of a karst doline. Unfortunately, there is a visible
dissolution fissure which is 20 to 30 cm in width. During a continuous heavy rain, the oil might overflow from the top of the pool, and then rapidly recharged into the karstic groundwater, where it could be held in storage in the karst aquifer for a long period of time (Kogovsek, 2004). Most of the time the samples from the spring showed visible oil spray. Therefore, oil leakage pollution is still of great concern for Qinglongtan Spring, which must be dealt with.

**Conclusions**

After nearly one year’s continuous measurement of water level, temperature (T), electrical conductivity (EC), and pH of Qinglongdong Spring showed that the study area has a well developed groundwater drainage system and/or the vadose zone is very thin. Under such a hydrogeological situation, the response of QLDS to rainfall events is fast, and the pollutant transport into the aquifer is rapid. Meanwhile, the analysis of specific time periods in the data revealed that there might exist some additional pollution sources and pathways, but further work is required to understand these occurrences.

The investigation of nitrate content from 2006 to 2009 showed that the concentration of nitrate in the spring increased from 2007 to 2009, which might be influenced by a new airport construction project over the source area to the spring.

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