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Detecting the leakage source of a reservoir using isotopes

Peng Yi[a,b,1], Jing Yang[a,b,1], Yongdong Wang[c], Vincent de Paul Mugwanezal[b], Li Chen[a,d,*], Ala Aldahan[e]

[a] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China
[b] College of Hydrology and Water Resources, Hohai University, Nanjing 210098, China
[c] Hydrology and Water Resources Survey Bureau of Jiangsu Province, Yangzhou Branch, Yangzhou 225002, China
[d] Division of Hydrologic Sciences, Desert Research Institute, Nevada, USA
[e] Department of Geology, United Arab Emirates University, Al Ain 15551, United Arab Emirates

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ABSTRACT

A good monitoring method is vital for understanding the sources of a water reservoir leakage and planning for effective restoring. Here we present a combination of several tracers (^{222}Rn, oxygen and hydrogen isotopes, anions and temperature) for identification of water leakage sources in the Pushihe pumped storage power station which is in the Liaoning province, China. The results show an average ^{222}Rn activity of 6843 Bq/m^3 in the leakage water, 3034 Bq/m^3 in the reservoir water, and 41,759 Bq/m^3 in the groundwater. Considering that ^{222}Rn activity in surface water is typically less than 5000 Bq/m^3, the low level average ^{222}Rn activity in the leakage water suggests the reservoir water as the main source of water. Results of the oxygen and hydrogen isotopes show comparable ranges and values in the reservoir and the leakage water samples. However, important contribution of the groundwater (up to 36%) was present in some samples from the bottom and upper parts of the underground powerhouse, while the leakage water from some other parts indicate the reservoir water as the dominant source. The isotopic finding suggests that the reservoir water is the main source of the leakage water which is confirmed by the analysis of anions (nitrate, sulfate, and chloride) in the water samples. The combination of these tracer methods for studying dam water leakage improves the accuracy of identifying the source of leaks and provide a scientific reference for engineering solutions to ensure the dam safety.

1. Introduction

Detecting sources of water in a dam leakage is crucial for amendments and restoration of the dam and accompanied power plant function maintenance. Leakage is a major safety issue which may threaten dam stability and results in dam break through various mechanisms such as erosion, fracturing and collapse (Berhane et al., 2013; Chen et al., 2016). Some commonly used methods for assessment of water leakage rely on the hydrological characteristics of the dam through monitoring flow over time, which cannot identify the source of the leakage water (Lee, 1977; Tan et al., 2009). The best way to close a leak successfully is to find the leakage pathway across the "impermeable" barrier and plug it (Kofoed et al., 2006).

Although techniques such as resistivity tomographic have been used to identify sources and pathways of dam leakage, the identification was in many cases hampered by permeability conditions (Zhao et al., 2011). Geochemical tracer approach, including natural and artificial water tracers, was also used in some cases for detecting source of leakage in dams (Bedmar and Araguas, 2002; Rozycki et al., 2006; Di and Wang, 2010). Application of artificial tracers for the identification of leakage source involves different tests such as boreholes, interconnection experiments between reservoir or boreholes and the emerging water (Lewis and Teel, 1994; Zhao et al., 2011; Zhechao et al., 2014) that may entail risk for the dam construction. The borehole method is damaging because it involves borehole drilling in the dam. For the interconnection tests, the tracer injection ways and quantities may result in large uncertainty of the data.

Use of natural tracers has been practiced for identification of source water in dam leakage and can be considered as DNA of the water body through accurately providing information concerning the origin of the water at the leak points (Plata and Iragüen, 1992). The commonly used natural tracers for this purpose are the temperature and conductivity of water, chemical composition and stable isotopes (Käss, 1998). The natural stable isotopes of oxygen and hydrogen have been used widely

* Corresponding author. State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China.
E-mail address: lchen@dri.edu (L. Chen).
[1] These two authors contributed equally to this work and should be considered co-first authors.

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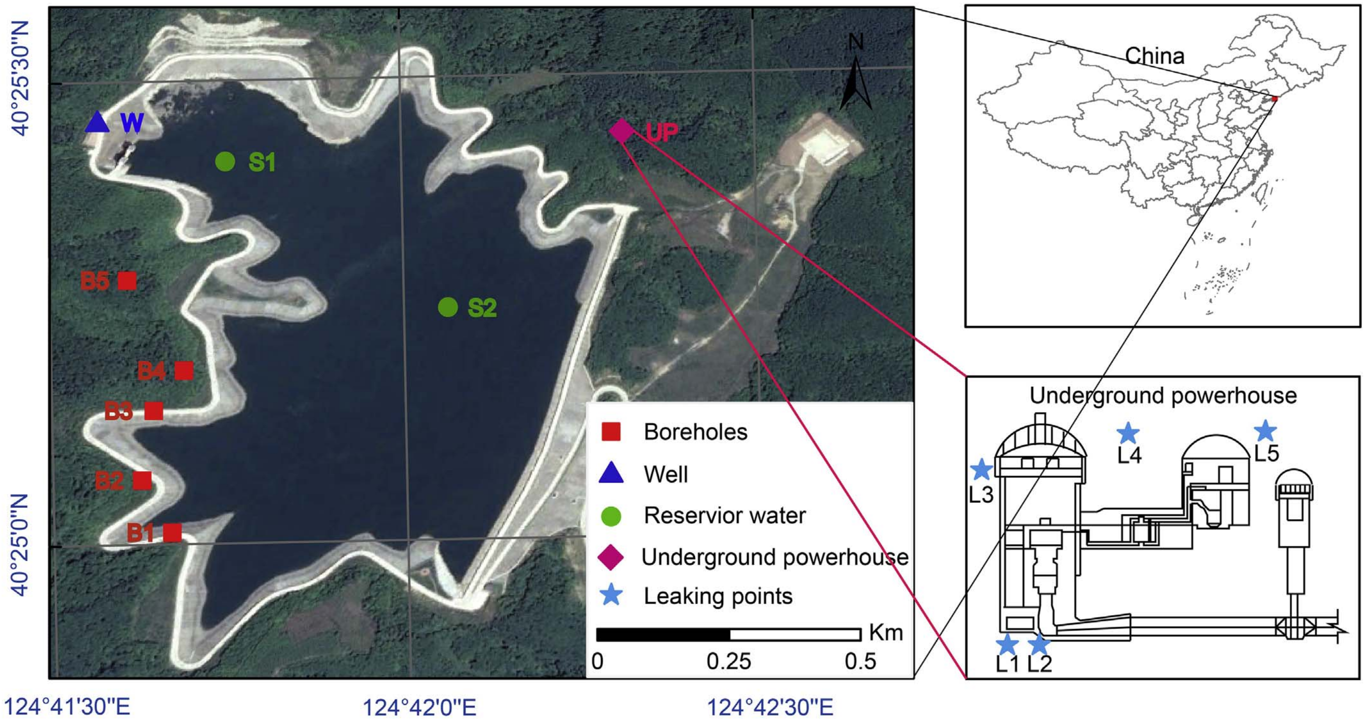

Fig. 1. Location of the Pushihe pumped storage power station and the distribution of sampling points. Boreholes (red box), well (blue triangle), reservoir water (green circle), underground powerhouse (pink diamond) and leaking points (blue star). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

to investigate the leaks from dams and reservoirs owing to their precision and accuracy (Ghomshei and Allen, 2000). Herczeg and Leaney (2010) and Petitta et al. (2010) have used ^{18}O and ^{2}H for identification of the interaction of the water bodies, and Ghomshei and Allen (2000) showed the potential of using these isotopes in the studies of dam leakage. The most important advantage of the isotopic methods is that the recharge sources of the dam leakage water can be determined and the relative contributions of different components to the total signal provides reliable references for solving dam safety problems (Gat, 1996; Gates et al., 2008). In addition to the isotopic approach, the chemical composition of the water such as nitrate (NO_3), sulfate (SO_4) and chloride (Cl) can be used as an auxiliary character to identify the water sources (Mook, 2002).

Although ^{222}Rn has been widely used to evaluate the exchange between groundwater and surface water (Ellins et al., 1990; Wu et al., 2004; Dulaiova et al., 2005; Cook et al., 2003; Kluge et al., 2007; Gleeson et al., 2009; Dimova et al., 2013; Chanyotha et al., 2014), it was barely used for the evaluation of water leakage source in dams. Since ^{222}Rn has a short half-life (3.82 days), it has great potential in the study of rapid mixing processes that occur on time scales of hours to several days (Zheng et al., 2016). The obvious differences of ^{222}Rn activity from different sources can be found and the origin of the leaks can be identified accordingly. However, the rapid escape of ^{222}Rn into the atmosphere can introduce errors in assessing the contribution of rainfall in the leakage water. The accuracy of the leakage assessment results can thus be improved by combining data from stable oxygen and hydrogen isotopes with ^{222}Rn.

In the investigation presented here, a novel approach of applying activity of ^{222}Rn together with stable oxygen and hydrogen isotopes and the chemical composition of the water is used for assessing water sources in a dam leakage. The performance of this combined tracers approach is demonstrated and evaluated through a case study of the underground power house of Pushihe reservoir in the Liaoning province of China. To identify the source of leakage in the underground powerhouse of the Pushihe reservoir, the isotopic composition of the leakage water was analyzed along with water samples from the potential sources (reservoir water and groundwater). Comparison of the water chemical composition will provide means of delineating leakage sources and pathways. This approach can offer a scientific reference in tackling the problem of seepage and drainage by the engineering technology and thereby improves the safety and operational benefit of the pumped storage power station.

2. Sampling and analytical techniques

The Pushihe pumped storage power station is located in the Liaoning province (40°25′15.47″N124°41′0.92″E), China. The Pushihe basin has an area of 1212 km^2, river length of 121.8 km, and river average gradient of 2.44‰. The dam was constructed between 2006 and 2009 and was approved by the state as the first large scale pumped storage power station in the northeast region, with a total capacity of 1200 MW. The upper reservoir station is located within the village of Dongyanghe, and can withhold up to 12,560,000 m^3 of water, of which 10,290,000 m^3 can be used for power production. The lower reservoir station is located in the village of Xiaogushan and it can withhold up to 29,050,000 m^3 of water, of which 16,210,000 m^3 can be pumped to the upper reservoir (Li et al., 2008).

The upper reservoir of the Pushihe pumped storage power station is located in the spring of the mountain, and the retaining building is a reinforced concrete face rock-foil dam. Li et al. (2008) estimated that the total leakage rate is about 5833 m^3/d if no anti-seepage measures are undertaken. The leakage rate is largest at the dam foundation, which accounts for 78.5% of the total leakage rate, while less than 200 m^3/d seeps out around the banks of the reservoir. The reservoir operation monitoring data show that the total seepage is up to 10 L/s. To identify the source of leakage in the underground powerhouse of the Pushihe reservoir, the isotopic composition of the leakage water was analyzed along with water samples from the potential sources (reservoir water and groundwater). For this purpose, water samples were collected during the period August 26, 2014 to June 15, 2015, from the