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Impacts of water quality variation and rainfall runoff on Jinpen Reservoir, in Northwest China

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Abstract

The seasonal variation characteristics of the water quality of the Jinpen Reservoir and the impacts of rainfall runoff on the reservoir were investigated. Water quality monitoring results indicated that, during the stable stratification period, the maximum concentrations of total nitrogen, total phosphorus, ammonia nitrogen, total organic carbon, iron ion, and manganese ion in the water at the reservoir bottom on September 6 reached 2.5 mg/L, 0.12 mg/L, 0.58 mg/L, 3.2 mg/L, 0.97 mg/L, and 0.32 mg/L, respectively. Only heavy storm runoff can affect the main reservoir and cause the water quality to seriously deteriorate. During heavy storms, the stratification of the reservoir was destroyed, and the reservoir water quality consequently deteriorated due to the high-turbidity particulate phosphorus and organic matter in runoff. The turbidity and concentrations of total phosphorus and total organic carbon in the main reservoir increased to 265 NTU, 0.224 mg/L, and 3.9 mg/L, respectively. Potential methods of dealing with the water problems in the Jinpen Reservoir are proposed. Both in stratification and in storm periods, the use of measures such as adjusting intake height, storing clean water, and releasing turbid flow can be helpful to safeguarding the quality of water supplied to the water treatment plants.

Keywords: Water quality; Seasonal variation; Rainfall; Impact of storm runoff; Intake height adjustment

1. Introduction

Numerous reservoirs have been built for drinking water supply, power generation, agricultural irrigation, and flood control (Casamitjana et al., 2003; Liu et al., 2011). In recent years, most of them, particularly deep-water reservoirs, have faced eutrophication and seasonal water shortage (Yu and Wang, 2011). In deep-water reservoirs, seasonal stratification prevents the transport of dissolved oxygen from surface water to bottom water, which results in an anaerobic environment (McGinnis and Little, 2002; Beutel et al., 2007). Under long-duration anaerobic conditions, pollutants are released from sediment into the overlying water. When the reservoir water from different depths mixes due to the decrease of surface water temperature, pollutants in the reservoir may lead to water quality deterioration (McGinnis and Little, 2002; Beutel et al., 2007; Wang et al., 2012a).

With climate change all over the world, many studies on the influence of rainfall and runoff on reservoirs and rivers have been reported (Wang et al., 2012b; Wu et al., 2012; Liu et al., 2014). Rainfall events cause disturbances to water bodies by changing the hydrological conditions and influencing the thermal structure of reservoirs (Huang et al., 2014). Moreover, large amounts of particulate pollutants carried by runoff are brought into reservoirs. This causes serious exogenous pollution, which can conversely promote the overproduction of algae (Wang et al., 2001; Vaze and Chiew, 2004; Zhang et al., 2006).

During the storm period, reservoir water can be seriously polluted, increasing the cost of water treatment. Therefore, the

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investigation of water quality change regularities and the effects of runoff on reservoirs are highly significant to reservoir management. The aim of this study was to investigate the seasonal variations of the Jinpen Reservoir water quality and the impacts of different rainfall events on the water quality of the reservoir.

2. Materials and methods

2.1. Sampling sites

The Jinpen Reservoir (at latitudes from 34°13′N to 34°42′N and longitudes from 107°43′E to 108°24′E) is located in north of the Qinling Mountains and it is 90 km away from Xi'an City. The reservoir is the main water source of Xi'an City. It is a canyon-shaped deep-water reservoir (Ma et al., 2015), and its main reservoir length is 3.5 km. The total capacity of the reservoir is 2.0×10^8 m^3 and the effective capacity is 1.8×10^8 m^3. The main function of the Jinpen Reservoir is urban water supply. Agricultural irrigation, power generation, and flood control are its accessory functions.

The Heihe River, which originates from the Qinling Mountains, is the main water supply for the Jinpen Reservoir (Fig. 1). This river is 91.2 km long with a catchment area of 1 418 km^2, and the catchment is largely undeveloped, consisting primarily of mountains covered with forest. The arrangement of water monitoring sites is as follows: S1 is located in the upstream area; S2, S3, and S4 are located in the transition area; S5 is located in the deep-water area of the main reservoir; and S6 is located near the intake tower for the drinking water plants. In recent years, water quality problems have increased dramatically due to release of pollutants from sediment and storm runoff, leading to serious water quality problems in Xi'an City.

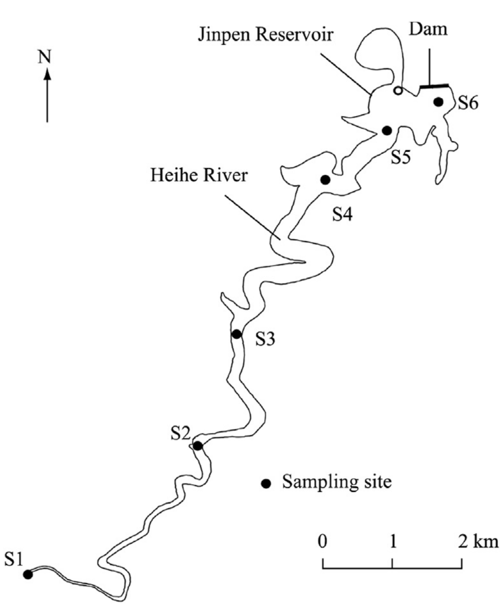

Fig. 1. Water sampling sites in Jinpen Reservoir and Heihe River.

2.2. Field observation

Under normal water quality monitoring conditions, water samples were collected weekly in the Jinpen Reservoir from November 1, 2013 to October 31, 2014. The dissolved oxygen (DO) concentration, water temperature, turbidity, and pH value were monitored in situ at sites S5 and S6 using a Hydrolab DS5 multi-probe sonde (Hach, USA) at 1-m water depth intervals. Water samples from sites S5 and S6 were taken every 5 m from the surface to the bottom using pre-cleaned high-density polyethylene bottles with preservative already added. All samples were immediately cooled and stored at 4°C before analysis.

During rainfall, the sampling interval was changed to once a day. The DO concentration, water temperature, turbidity, and pH value were determined vertically in situ from S1 to S6 at 1-m water depth intervals. Water samples were also collected vertically at these sites every 5 m from the surface to the bottom.

For the water samples, the concentrations of total nitrogen (TN), ammonia nitrogen (NH_4^+-N), total phosphorus (TP), total organic carbon (TOC), permanganate index (COD_{Mn}), iron ion (Fe^{3+}), and manganese ion (Mn^{7+}), as well as the algal density and algal species, were measured. Concentrations of TN and NH_4^+-N were determined with a SEAL AA3 HR AutoAnalyzer (SEAL, Germany). TP concentration was measured with ultraviolet-visible spectrophotometry after potassium persulfate digestion at 121°C for 30 min. TOC concentration was determined with a TOC-L total organic carbon analyzer (Shimadzu, Japan). COD_{Mn} concentration was determined with potassium permanganate oxidation and then titrated with sodium oxalate. Concentrations of metal ions were measured through inductively coupled plasma mass spectrometry (ICP-MS) after filtration through 0.22 μm filter membranes. Algal density and algal species were identified with the method of microscopic examination.

3. Results and discussion

3.1. Water quality variations of Jinpen Reservoir

Table 1 shows the mean values of concentrations of TN, TP, NH_4^+-N, TOC, Fe^{3+}, and Mn^{7+} in surface (0–0.5 m), middle (30–35 m), and bottom (60–70 m) water at four measurement times in one month in the main reservoir. The stratified period was from April to November, and the remaining time of the year was the mixing period (Huang et al., 2010, 2014).

During the research period, TN concentrations varied from 1.3 mg/L to 2.5 mg/L. Relatively low concentrations of TN commonly appeared in the mixing period. High concentrations of TOC in hot seasons (from June to September) were caused by the overproduction of algae in the surface water. At the same time, the DO in the bottom water was consumed. The TN concentration of the bottom water showed a tendency to increase, and it reached a maximum value of 2.5 mg/L before the storm period (usually in the middle of September). The TP concentration of the bottom water reached 0.12 mg/L