Thematic issue: water environment of the Three Gorges Reservoir

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The Three Gorges Project is a key project for China to develop and control the Yangtze River, and it is currently one of the largest hydro-engineering projects in the world. The Three Gorges Dam (TGD) is located in the Yichang City of Hubei Province and controls a catchment area of 1 million km² which accounts for 56% of the Yangtze River basin area. After the completion of the TGD, the interception and impoundment formed an “artificial lake” in the Yangtze River Valley, known as the Three Gorges Reservoir (TGR). The TGR lies in midlatitude region (28°32'N–31°44'N, 105°44'N–111°39'N) with a river length of 667 km and a total water surface area of 1084 km² (Fig. 1). Under the normal storage water level of 175 m a.s.l. and the flood control water level of 145 m a.s.l., the TGR has a total storage capacity of 39.3 billion m³ and a flood control capacity of 22.15 billion m³. The TGR is situated in a subtropical humid monsoon climate with an annual mean temperature of 16.6 °C and an annual mean rainfall of 1124.5 mm. The rainfall in the TGR area is most intensive from April to October, counting for roughly 80% of annual total rainfall.

The TGR experienced three-step experimental impoundment in June 2003, October 2006 and November 2008, during which the storage water level reached 145, 156 and 175 m, respectively. After that, the TGR is managed according to an annual operation mode as: (i) each year

from February to June, the reservoir water level gradually is reduced from 175 m to the flood control level of 145 m; (ii) from July to August, the reservoir water runs at a low level of 145 m; (iii) from September to October, the reservoir water level is gradually impounded from 145 to 175 m; (iv) from November to January of the following year, the reservoir water is maintained at a high level of 175 m (Fig. 2). The TGR impoundment has brought tremendous economic and social benefits by flood control, power generation, shipping, tourism, water supply, irrigation and so on (Cao 2012; Qiu et al. 2003). At present, the Three Gorges Power Plant annually generates about 100 billion kWh, saving 20–25 billion RMB per year calculated by standard coal price (Wang 2007; Zhou 2006).

However, as a consequence of dam construction and operation, the natural flow regime of the Yangtze River is disturbed and a number of negative environmental impacts and uncertainties on the upstream and downstream areas cannot be avoided (Müller et al. 2008; Qiu 2012; Tan et al. 2010). The TGR is an important freshwater resource reservoir in China, which is also an ecological sensitive area with significance (Du et al. 2009). Since the establishment of TGD in 1990s, the Chinese government and related departments have set up a number of scientific research projects studying the environmental characteristics and environmental impacts of TGR, including the national key scientific projects and technological projects. From the ninth 5-year plan time period to the thirteen 5-year plan time period, the project covered the sustainable development and ecological rehabilitation model of the environmental changes in the upstream area of the Yangtze River, the ecological security protection and ecological economy system reconstruction in the TGR, the application of the ecological restoration and comprehensive treatment technology in the water-level fluctuation zone of the TGR and the application of water pollution prevention and algae bloom control technology in the TGR, etc. In addition, some international cooperation projects have also been launched, for example the Sino-German cooperation project YANGTZE, which focused on the research of water environment characteristics and tributaries eutrophication

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Fig. 1 Location of the Three Gorges Reservoir in China

mechanism in the TGR. Based on these scientific research projects, some common negative environmental impacts brought by the TGR impoundment have been well discussed:

Water eutrophication and algae bloom occurrence in the TGR tributaries After the impounding of the TGR, the TGR mainstream is still considered mesotrophic, whereas the TGR tributaries changed from mesotrophic to eutrophic or hypereutrophic (Cai and Hu 2006; Cai and Sun 2012). Furthermore, algae blooms in the TGR tributaries have been

reported to occur in spring, summer and autumn each year since 2003 (CNEMC 2013). It is generally known that water eutrophication caused by excessive nutrient inputs is one of the main factors contributing to algae bloom formation (Schindler and Fee 1974). However, studies indicated that the changes in hydrodynamics and meteorological conditions due to the TGR impoundment were the driven factors of algae bloom formation (Yang 2014). Sensitive areas especially are where tributaries meet the main stream of

Fig. 2 Water level changes in the TGR under the scheduling operation annually (Han et al. 2016)

Yangtze due to specific flow patterns caused by the extreme high flow rate of the Yangtze river ($> 10,000 \text{ m}^3$) and the relatively low ones of the tributaries ($< 1000 \text{ m}^3$) (Holbach et al. 2013, 2014). Previous studies showed that the TGR impoundment deepened water level, slowed water velocity, prolonged water retention time and reduced water self-purification capacity in the TGR, particularly in the backwater area of the TGR tributaries (Xiao et al. 2009). The changed hydrodynamics were easy to form thermal stratification in the TGR tributaries, which lead to the occurrences of algae blooms under appropriate meteorological conditions (Holbach et al. 2013, 2014; Liu et al. 2012; Yang 2014).

Land use change and soil erosion in the TGR basin
The TGR basin is one of the most serious soil erosion areas in China, and the average of soil erosion amount and soil erosion modulus reached $19,364.71 \times 10^4 \text{ t/a}$ and $2741.48 \text{ t/(km}^2 \text{ a)}$, respectively (Long et al. 2012). It was reported that the TGD construction caused land utilization changes in the TGR area, characterized by size, scenic features, land use pattern and land use degree, etc. (Cao et al. 2007). From 1977 to 2005, statistic data indicated that about 2 km^2 arable land in the TGR basin was applied for other purposes annually, and arable lands with slope grade less than 25° in the TGR basin decreased dramatically, but those with slope grade more than 25° almost remained the same (Zhang et al. 2009). Due to reservoir water management, the water-level fluctuation zone with an area of 349 km^2 was formed in the river bank of the TGR mainstream (Zhang 2013). The periodic alternation of wetting and drying in the water-level fluctuation zone affected the migration and transformation of nutrients in soils (Yuan et al. 2007). Previous study indicated that water eutrophication in the reservoir mostly occurred around the water-level fluctuation zone during the impounding period of the

TGR, which was related to slow water velocity, sufficient sunlight, as well as the release of nitrogen and phosphorus from the soil to the water (Shi 2014). Thus, the nutrient inputs from water-level fluctuation zone by soil erosion were possible nutrient sources of the TGR and can influence nutrient distribution in water of the TGR.

Ecological security in the TGR The TGR impoundment has caused fundamental changes on the habitat environment of the aquatic organism in the TGR and thus influenced the species communities and the biomass of aquatic organisms in the TGR. Dai et al. found an acute increase in algae species in the TGR tributaries after the impounding of the TGR, as well as a significant increase in nutrient concentrations (Dai et al. 2010). Shen et al. indicated that the biodiversity of aquatic organisms in the TGR became more fragile after the TGR impoundment than before (Shen 2010). During the past three decades, previous studies indicated that the eco-environmental quality in the Daning River, a tributary of the TGR, was gradually falling into the middle or poor levels (Ma et al. 2008).

Geological disaster in the TGR The TGR area is among the typical areas where geological disasters would easily happen. Since the initial operation of the TGR in 2003, the occurrences of geological disasters including collapses and landslides have significantly increased due to the periodic fluctuation of water level in the TGR. Liu et al. recorded that there were 5706 geological disaster points in the TGR region, including 3830 landslide points, 1107 unstable slopes, 549 collapse points, 90 mudslide points, 85 ground subsidence points and 45 ground fissure points (Liu et al. 2004).

From the perspective of ecology, it has only been over one decade since the initial impoundment of the TGR; thus, the reservoir ecosystem is still in constant adjustment and gradual stabilization. To recognize the latest situation of ecological environment in the TGR, to explore the eco-environmental effects and to promote the ecological environment of the TGR, “Environmental Earth Science” edited this thematic issue on “Environmental Research of the Three Gorges Reservoir,” which contains 16 articles mainly focusing on nutrient imports of the upstream rivers of the TGR (Han et al. 2016; Ren et al. 2016; Zheng et al. 2016), eutrophication problem in the tributary bay (Cui et al. 2016; Zhang et al. 2016a) and water quality changes in the reservoir area (Huang et al. 2016; Kranzioch-Seipel et al. 2016; Zhao et al. 2016). There are also articles studying the land use change (Teng et al. 2016; Wang et al. 2016) and geological disasters in the TGR region (Chen et al. 2016; Dumperth et al. 2016; Guo et al. 2016; Zhang et al. 2016b). Furthermore, the optimal TGR operation mode is analyzed from the perspective of ecological water level of the downstream of the TGR (Dai et al. 2016).

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