Water Science and Engineering 2015, 8(4): 301−308

HOSTED BY ELSEVIER

Available online at www.sciencedirect.com

Water Science and Engineering

journal homepage: http://www.waterjournal.cn

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

Zi-zhen Zhou, Ting-lin Huang*, Wei-xing Ma, Yang Li, Kang Zeng

School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, PR China

Received 14 May 2015; accepted 25 September 2015
Available online 17 December 2015

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

This work was supported by the National Science and Technology Pillar Program (Grant No. 2012BAC04B02) and the National Natural Science Foundation of China (Grant No. 51478378).
* Corresponding author.
E-mail address: huangtinglin@xauat.edu.cn (Ting-lin Huang).
Peer review under responsibility of Hohai University.

http://dx.doi.org/10.1016/j.wse.2015.12.003

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.

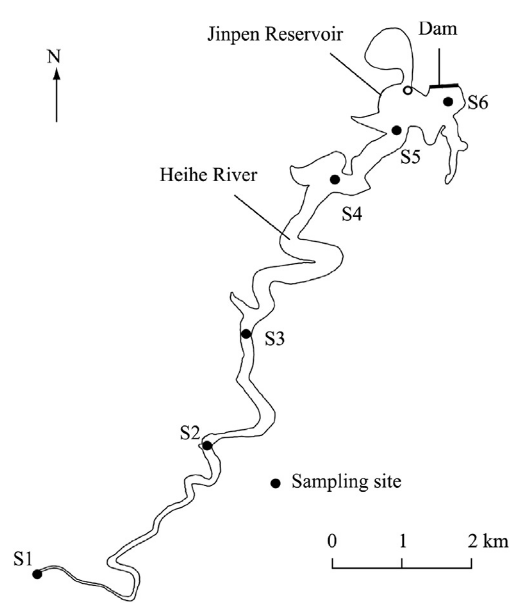

Fig. 1. Water sampling sites in Jinpen Reservoir and Heihe River.

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

Table 1
Concentrations of TN, TP, NH_4^+-N, TOC, Fe^{3+}, and Mn^{7+} in surface, middle, and bottom water of Jinpen Reservoir

Month	TN concentration (mg/L)			TP concentration (mg/L)			NH_4^+-N concentration (mg/L)		
	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
2013-11	1.3	1.4	1.2	0.02	0.02	0.03	0.14	0.15	0.25
2013-12	1.5	1.5	1.6	0.02	0.02	0.04	0.10	0.14	0.22
2014-01	1.4	1.5	1.6	0.02	0.02	0.03	0.12	0.20	0.24
2014-02	1.5	1.4	1.5	0.02	0.02	0.02	0.15	0.15	0.18
2014-03	1.4	1.3	1.4	0.03	0.02	0.03	0.15	0.15	0.21
2014-04	1.8	1.4	1.6	0.02	0.03	0.04	0.15	0.16	0.24
2014-05	2.0	1.7	1.8	0.02	0.02	0.05	0.12	0.14	0.38
2014-06	1.9	1.7	1.9	0.03	0.03	0.08	0.18	0.16	0.42
2014-07	1.9	1.8	2.0	0.04	0.05	0.09	0.15	0.15	0.39
2014-08	1.8	1.9	2.1	0.04	0.06	0.10	0.18	0.16	0.48
2014-09	1.8	1.8	2.5	0.03	0.05	0.12	0.18	0.15	0.52
2014-10	1.3	1.4	1.7	0.02	0.10	0.16	0.28	0.44	0.65

Month	TOC concentration (mg/L)			Fe^{3+} concentration (mg/L)			Mn^{7+} concentration (mg/L)		
	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
2013-11	2.5	2.5	2.9	0.17	0.18	0.20	0.06	0.07	0.08
2013-12	2.2	2.3	2.4	0.15	0.21	0.18	0.05	0.06	0.07
2014-01	2.3	2.2	2.4	0.16	0.21	0.22	0.06	0.05	0.08
2014-02	2.5	2.4	2.4	0.15	0.18	0.25	0.05	0.06	0.10
2014-03	2.4	2.3	2.4	0.18	0.19	0.25	0.03	0.04	0.06
2014-04	2.4	2.6	2.6	0.14	0.18	0.28	0.03	0.04	0.07
2014-05	2.6	2.7	2.6	0.17	0.19	0.32	0.04	0.04	0.09
2014-06	3.2	2.7	2.5	0.16	0.21	0.42	0.01	0.04	0.12
2014-07	3.1	2.8	2.9	0.14	0.21	0.56	0.02	0.07	0.15
2014-08	3.5	2.9	3.3	0.16	0.32	0.88	0.02	0.07	0.20
2014-09	2.8	2.9	3.5	0.15	0.25	0.97	0.05	0.12	0.34
2014-10	1.8	2.5	3.8	0.32	0.21	0.37	0.04	0.08	0.12

in September. The NH_4^+-N and TOC concentrations of the bottom water reached 0.52 mg/L and 3.5 mg/L, respectively. The high concentrations of TN, TP, NH_4^+-N, and TOC were due to release of pollutants from sediment under anaerobic conditions (Beutel et al., 2007; Wang et al., 2012a; Yang et al., 2012).

During the storm period in September, the quality of the bottom water changed with the storm runoff flowing into the reservoir. As shown in Table 1, TN, Fe^{3+}, and Mn^{7+} concentrations decreased from 2.5 mg/L, 0.97 mg/L, and 0.34 mg/L to 1.7 mg/L, 0.37 mg/L, and 0.12 mg/L, respectively. However, the concentrations of TP, NH_4^+-N, and TOC increased to 0.16 mg/L, 0.65 mg/L, and 3.8 mg/L, respectively.

Fig. 2 shows the microscopic examination results of algae, which are the mean values at four measurement times in one month in the main reservoir. Algal density started to increase from April, with the increase of water temperature and illumination intensity. A maximum algal density, 2.5×10^6 cells/L, occurred in September, and green algae accounted for 75%. After the storm period, the algal density experienced a sharp decrease. From November to April of the next year, the algal density decreased to 0.5×10^6 cells/L, and diatoms were the dominant species. The proportion of diatoms started to decrease from 68% in December to 15% in September of the next year. Meanwhile, the proportion of green algae started to increase from December and reached a maximum of 75% in September of the following year.

3.2. Effects of different rainfall events on water quality

Field work was conducted on five different rainfall events of 22 mm, 17 mm, 19 mm, 107 mm, and 42 mm. Different rainfall amounts and inflows corresponded to different undercurrent thickness (Table 2). The normal inflow to the reservoir was below 10 m^3/s. The largest rainfall of the monitoring year occurred on September 9, when the inflow reached 579 m^3/s, and the maximum undercurrent thickness reached 40 m. With high inflow continuously flowing into the

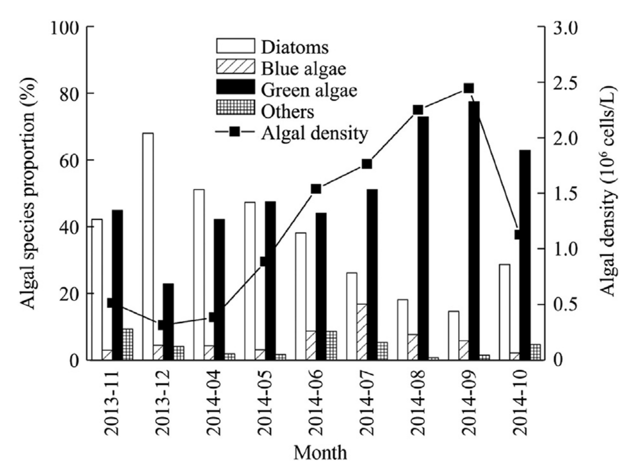

Fig. 2. Algal density and species proportions of Jinpen Reservoir.

Table 2
Five different rainfall events and corresponding inflows to Jinpen Reservoir and undercurrent thickness.

Date	Rainfall (mm)	Inflow (m^3/s)	Maximum undercurrent thickness (m)
2014-05-01	0	6	0
2014-05-11	22	72	22
2014-07-11	17	59	19
2014-08-07	19	63	20
2014-09-06	0	6	0
2014-09-09	107	579	40
2014-09-12	42	280	45
2014-09-17	0	72	50
2014-09-27	0	10	0

reservoir, the undercurrent thickness further expanded to 50 m on September 17.

The results of measurement of concentrations of pollutants at different monitoring sites are shown in Fig. 3. Under normal runoff conditions, the turbidity was quite small. With rainfall of about 20 mm, the turbidity of the upstream water at S1 increased to about 160 NTU. However, under storm runoff conditions, the turbidity rapidly increased to 359 NTU at S1. Throughout the process of runoff flowing into the reservoir, the water turbidity gradually decreased. During the three small rainfall events on May 11, July 11, and August 7, the maximum TOC, TP, and NH_4^+-N concentrations at S1 in the upstream water were 5.1 mg/L, 0.072 mg/L, and 0.72 mg/L, respectively. With the inflow to the reservoir, the concentrations of pollutants decreased gradually. At S5 in the main reservoir, the maximum TOC, TP, and NH_4^+-N concentrations decreased to 4.2 mg/L, 0.036 mg/L, and 0.56 mg/L, respectively. These concentrations of pollutants and the turbidity at S5 were at the normal levels. The main reservoir near the intake tower was nearly unaffected.

Under storm runoff conditions, the inflow to the reservoir reached 579 m^3/s on September 9, and, at the same time, the turbidity in the upstream water increased to 359 NTU. The upstream inflow water quality also deteriorated. The concentrations of TOC, TP, and NH_4^+-N upstream increased to 7.2 mg/L, 0.2 mg/L, and 1.2 mg/L, respectively. The storm runoff significantly influenced the intake tower area, where the corresponding turbidity at S6 was 139 NTU, and the concentrations of TOC, TP, and NH_4^+-N increased to 4.5 mg/L, 0.076 mg/L, and 0.62 mg/L, respectively.

The source water of the Jinpen Reservoir is the rain flowing through mountains, jungles, and farmland. During the storm, large amounts of pollutants carried by the storm runoff flowed into the river and eventually into the reservoir. The reservoir water quality is greatly influenced by the storm runoff.

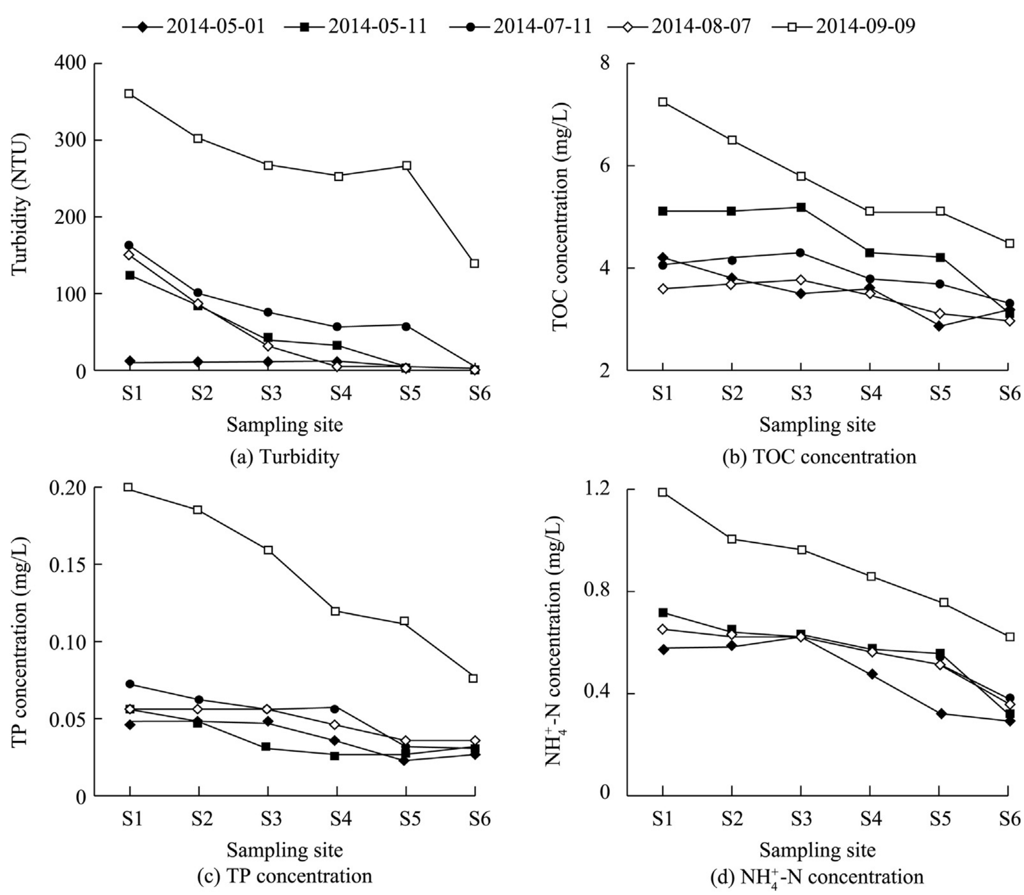

Fig. 3. Pollutant concentrations at different sites under different runoff conditions.

3.3. Effects of storm runoff on water quality

3.3.1. Effects of storm runoff on stratification

Before the storm on September 6, the Jinpen Reservoir was still in a stable stratification state. As shown in Fig. 4, the temperature difference between the surface and bottom water was about 12°C. Vertical turbidity was maintained at 4−6 NTU. The bottom water was in an anaerobic state.

In general, the temperature of inflowing water was higher than that of the bottom water and lower than that of the surface water of the main reservoir, so the inflowing water formed an undercurrent. If the amount of the undercurrent was small, it would mix with the water in the river before flowing into the reservoir. On September 9, the rainfall was 107 mm, and the inflow was 579 m^3/s. The undercurrent that flowed into the main reservoir was 40 m thick (Table 2). The vertical water column in the reservoir started to mix with the undercurrent, because the undercurrent speed was slowed down. As shown in Fig. 4, the vertical water temperature difference was rapidly compressed. In the process of mixing, the water temperature difference continued to decrease. On September 27, the temperature difference was reduced to 4°C, and the water column was in a state of mixing. Thus, the stratified structure of the main reservoir was damaged.

3.3.2. Effects of storm runoff on DO concentration, turbidity, and pH value

After the storm, the DO concentration of the bottom water (at a depth of 70 m) in the main reservoir quickly increased to 9.2 mg/L on September 9. This was because of the high concentration of DO in the undercurrent; it reached nearly 10 mg/L on September 17. Due to the high concentration of TOC (Fig. 3), the DO concentration of the bottom water decayed rapidly. DO was quickly consumed by the easily decomposed organic matter from mountains and jungles. On September 27, the DO concentration of the bottom water decayed to 6.6 mg/L.

After the storm, the subsurface flow with a high turbidity of 264 NTU started to mix with the reservoir water, and the average turbidity of the water column increased from 5 NTU on September 6 to 131 NTU on September 9. On September 17, the mixing process of the undercurrent and the reservoir water was nearly completed, and the average turbidity of the water column increased to 65 NTU. However, on September 27, the average turbidity of the water column decreased to 30 NTU.

After the storm, the pH value of the bottom water experienced an increase from 7.29 on September 6 to 8.62 on September 17, and then decreased to 8.46 on September 27, showing the same trend as the DO concentration and turbidity.

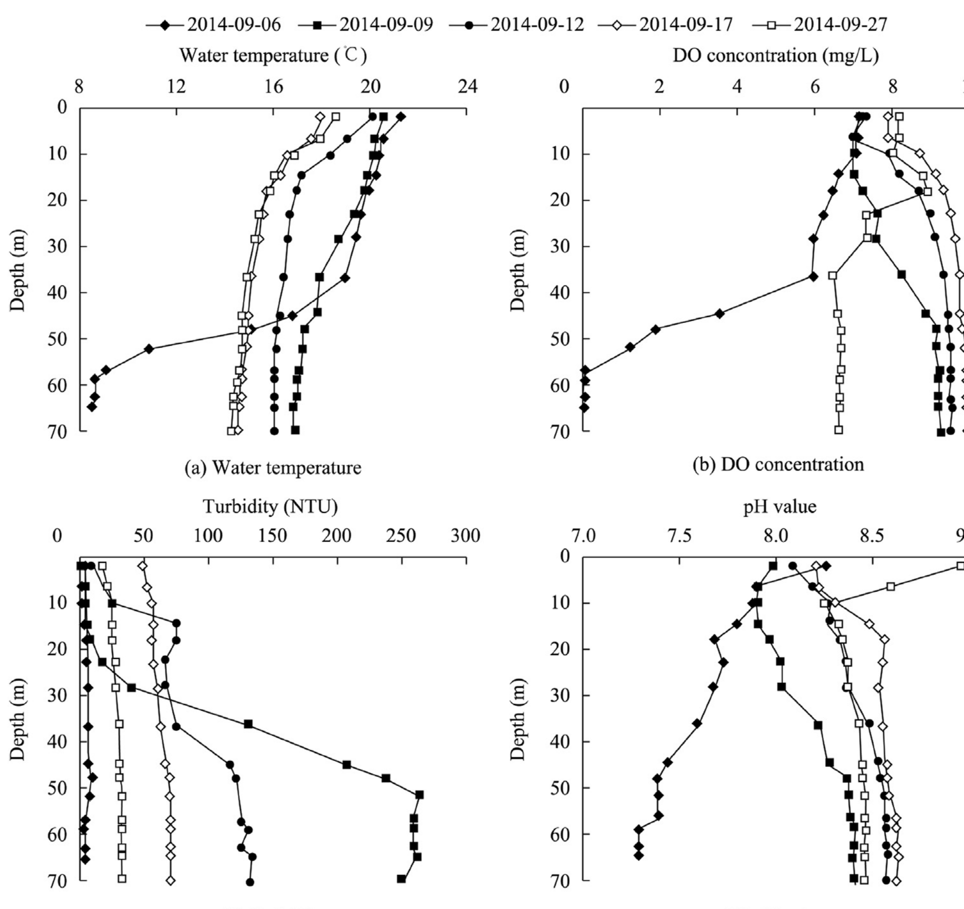

Fig. 4. Vertical variations of water temperature, turbidity, DO concentration, and pH value in main reservoir.

3.3.3. Effects of storm runoff on nutrient salts, organic matter, and metals

In the main reservoir (S5), pollutant concentrations at different depths were examined before the storm on September 6 and during the storm on September 9 (Table 3).

During the storm, the TP and NH_4^+-N concentrations increased significantly. The average concentrations of TP and NH_4^+-N increased from 0.053 mg/L and 0.28 mg/L to 0.107 mg/L and 0.48 mg/L, respectively. More seriously, the TP concentration of the bottom water reached 0.224 mg/L. The high turbidity and granular materials brought by the storm runoff were the main causes of the increased concentration of TP. Human feces and animal excrement were the main causes of the increased concentration of NH_4^+-N (Chen et al., 2005; Liang et al., 2008).

The average concentrations of TOC at sampling depths below 40 m increased to 3.75 mg/L. The dissolved organic carbon (DOC) concentration of the bottom water on September 9 was also measured, and the value 3.85 mg/L was almost the same as that of TOC (3.90 mg/L). It was obvious that soluble small-molecule organic matter accounted for most of the TOC. This fact provided an explanation for the rapid consumption of DO in the bottom water after the storm.

The concentrations of Fe^{3+} and Mn^{7+} in the bottom water decreased from 0.97 mg/L and 0.32 mg/L on September 6 to 0.38 mg/L and 0.18 mg/L on September 9, respectively. Since there was no artificial metal pollution source in the upstream region of the Jinpen Reservoir, the metal concentrations of the storm runoff were quite low. Undercurrent with low metal concentrations mixed with the water with high metal concentrations, causing the decrease of the concentrations of Fe^{3+} and Mn^{7+}. The metal ions that were released from the sediment were in a reduction state. These ions were further oxidized by the undercurrent with a high DO concentration. Thus, sedimentation of oxides was also a reason for the decrease.

3.3.4. Effects of storm runoff on algae

Before and during the two light rains on July 11 and August 7 and the storm on September 9, the algal density was analyzed through the method of microscopic examination, and the results are shown in Fig. 5. After the rains on July 11 and August 7, the algal density decreased from 1.9×10^6 cells/L and 2.0×10^6 cells/L to 1.4×10^6 cells/L and 1.6×10^6 cells/L, respectively. A slight increase of diatoms and a small decrease of green algae were observed. The colder inflow from the upstream and the weak illumination intensity might be the main reasons.

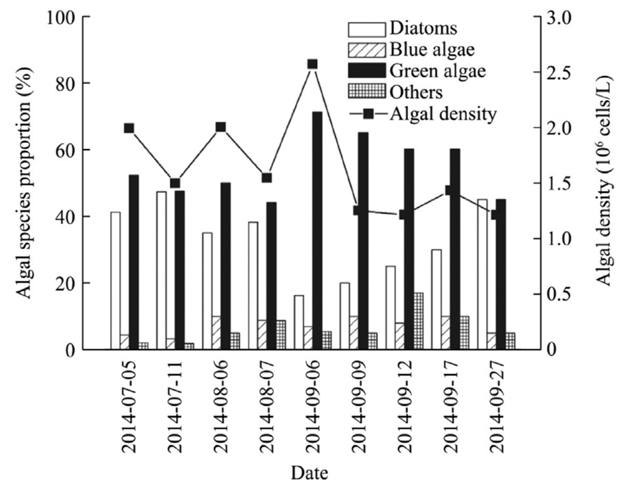

Fig. 5. Algal density and algal species proportions before and after rainfalls.

However, the decreased amplitude of algal density during the storm reached 51.3%, which was greater than that during the light rainfalls. As demonstrated in Table 4, after the storm, the quality of surface water was improved. The concentrations of nutrient salts and organic matter were quite low. This might explain why algal blooms in the surface water were not observed in the next ten days. After the storm, the proportion of green algae was still above 50%, accounting for the majority of the algae.

4. Solutions to water problems

4.1. Seasonal water quality problems

In the stratification months, especially from June to September, the overproduction of algae in the surface water increases the cost of the water treatment plants. The bottom water is severely polluted by the pollutants released from the sediment and the sink of suspended organic particles. The intake height adjustment is used as a method to avoid

Table 3
Pollutant concentrations at different depths before and during storm in main reservoir.

Sampling depth (m)	TP concentration (mg/L)		TN concentration (mg/L)		TOC concentration (mg/L)		COD_{Mn} concentration (mg/L)		NH_4^+-N concentration (mg/L)		Fe^{3+} concentration (mg/L)		Mn^{7+} concentration (mg/L)	
	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During
0.5	0.032	0.022	1.5	1.3	3.2	1.5	3.8	3.2	0.16	0.32	0.22	0.16	0.03	0.05
20	0.032	0.024	1.3	1.3	2.9	1.6	3.1	3.3	0.15	0.32	0.18	0.15	0.03	0.04
40	0.028	0.112	1.5	1.3	3.1	3.5	3.2	4.5	0.16	0.44	0.22	0.18	0.02	0.02
60	0.054	0.155	1.8	1.4	2.9	3.6	3.2	4.3	0.36	0.58	0.38	0.19	0.28	0.12
70	0.118	0.224	2.5	1.8	3.2	3.9	4.2	4.9	0.58	0.72	0.97	0.38	0.32	0.18

Table 4
Quality of surface water after storm on September 9.

Item	DO concentration (mg/L)	Turbidity (NTU)	TN concentration (mg/L)	TP concentration (mg/L)	NH_4^+-N concentration (mg/L)	TOC concentration (mg/L)	Fe^{3+} concentration (mg/L)	Mn^{7+} concentration (mg/L)
Value	10.2	0.1	0.32	0.008	0.02	0.342	0.01	0.01

supplying the surface water and bottom water. Another method is to destroy the water stratification and thus inhibit the release of pollutants from sediment. A water-lifting aerator is an effective technology, solving the seasonal water quality problems for deep-water reservoir. During the water-lifting aerator operation, a strong disturbance of water will destroy the stratification and the DO concentration in the bottom water will increase, thus inhibiting release of pollutants from sediment. Furthermore, algae production will be controlled, as algae are pushed into the water below (Miu and Yin, 2007; Cong et al., 2009, 2011).

4.2. Storm runoff problems

During the storm period, the turbidity of the outflow reached levels as high as 130 NTU, which significantly exceeded the turbidity limitation provided in *Environmental Quality Standards for Surface Water* (GB3838−2002) of China. On the other hand, the source water with high turbidity greatly increased the cost of water treatment. The water quality of the effluent of the water treatment plant was also unstable and worse under the storm runoff conditions than under the normal runoff conditions.

Storing clean water, releasing turbid flow, and dredging are considered effective methods of solving storm runoff problems (Wang and Hu, 2009). The strategy of storing clean water has been effectively applied to the Sanmenxia Reservoir (Wang et al., 2005). Releasing turbid flow has become the main strategy of controlling sedimentation in the Xiaolangdi Reservoir. The strategy of dredging has been used in the Hengshan Reservoir and Zhuwo Reservoir (Wang and Hu, 2009). Nonetheless, the fundamental method of preventing soil erosion in upstream areas and the surrounding environment is improving vegetation coverage, changing farming practices, changing land use patterns, and cultivating plants with well-developed roots (Wilkinson, 1999; Reubens et al., 2007; Li et al., 2011; Nunes et al., 2011).

5. Conclusions

Long-duration anaerobic conditions in the bottom water caused by stratification can lead to seasonal variation of water quality in the Jinpen Reservoir. During the stratification period, the bottom water is polluted by the pollutants released from the sediment. However, as a canyon-type reservoir, the Jinpen Reservoir is sensitive to storm runoff. Under normal runoff conditions, the water quality of the inflow is better than that of the main reservoir. However, during storm periods, the stratification is destroyed and the water quality is severely polluted by the storm runoff. Particulate nitrogen, phosphorus, and soluble organic molecules are brought into the reservoir by the inflow, leading to higher concentrations of TN, TP, and TOC under storm runoff conditions than under normal runoff conditions. Understanding the variation of water quality and the impact of rainfall runoff on reservoir water quality can provide theoretical guidance for water managers to ensure outflow water quality during the flooding season. Thus, for reservoir managers, it is extremely important to control the water quality at all times during the storm.

References

Beutel, M., Hannoun, I., Pasek, J., Bowman, K.K., 2007. Evaluation of hypolimnetic oxygen demand in a large eutrophic raw water reservoir, San Vicente Reservoir, Calif. J. Environ. Eng. 133(2), 130−138. http://dx.doi.org/10.1061/ASCE0733-93722007133:2130.

Casamitjana, X., Serra, T., Colomer, J., Baserba, C., Pérez-Losada, J., 2003. Effects of the water withdrawal in the stratification patterns of a reservoir. Hydrobiologia 504(1−3), 21−28. http://dx.doi.org/10.1023/B:HYDR.0000008504.61773.77.

Chen, L.D., Peng, H.J., Fu, B.J., Qiu, J., Zhang, S.R., 2005. Seasonal variation of nitrogen-concentration in the surface water and its relationship with land use in a catchment of northern China. J. Environ. Sci. 17(2), 224−231 (in Chinese).

Cong, H.B., Huang, T.L., Chai, B.B., Zhao, J.W., 2009. A new mixing-oxygenating technology for water quality improvement of urban water source and its implication in a reservoir. Renew. Energy 34(9), 2054−2060. http://dx.doi.org/10.1016/j.renene.2009.02.007.

Cong, H.B., Huang, T.L., Chai, B.B., 2011. Research on applying a water-lifting aerator to inhibit the growth of algae in a source-water reservoir. Int. J. Environ. Pollut. 45(1), 166−175. http://dx.doi.org/10.1504/IJEP.2011.039093.

Huang, T.L., Zhang, W.S., Chai, B.B., 2010. Study on the characteristics and control of endogenous pollution in source water reservoir with great depth. Environ. Pollut. Control 32(3), 1−4 (in Chinese).

Huang, T.L., Li, X., Rijnaarts, H., Grotenhuis, T., Ma, W., Sun, X., Xu, J., 2014. Effects of storm runoff on the thermal regime and water quality of a deep, stratified reservoir in a temperate monsoon zone, in Northwest China. Sci. Total Environ. 485−486, 820−827. http://dx.doi.org/10.1016/j.scitotenv.2014.01.008.

Li, X.H., Zhang, Z.Y., Yang, J., Zhang, G.H., Wang, B., 2011. Effects of Bahia grass cover and mulch on runoff and sediment yield of sloping red soil in southern China. Pedosphere 21(2), 238−243. http://dx.doi.org/10.1016/S1002-0160(11)60123-9.

Liang, T., Wang, S., Cao, H., Zhang, C., Li, H., Song, W., Chong, Z., 2008. Estimation of ammonia nitrogen load from nonpoint sources in the Xitiao River catchment, China. J. Environ. Sci. 20(10), 1195−1201. http://dx.doi.org/10.1016/S1001-0742(08)62209-3.

Liu, R., Wang, J., Shi, J., Chen, Y., Sun, C., Zhang, P., Shen, Z., 2014. Runoff characteristics and nutrient loss mechanism from plain farmland under simulated rainfall conditions. Sci. Total Environ. 468−469, 1069−1077. http://dx.doi.org/10.1016/j.scitotenv.2013.09.035.

Liu, W., Jiang, D., Cheng, T., 2011. Effects of flood on thermal structure of a stratified reservoir. Procedia Environ. Sci. 10(Part B), 1811−1817. http://dx.doi.org/10.1016/j.proenv.2011.09.283.

Ma, W.X., Huang, T.L., Li, X., Zhou, Z.Z., Li, Y., Zeng, K., 2015. The effects of storm runoff on water quality and the coping strategy of a deep canyon-shaped source water reservoir in China. Int. J. Environ. Res. Public Health 12(7), 7839−7855. http://dx.doi.org/10.3390/ijerph120707839.

McGinnis, D.F., Little, J.C., 2002. Predicting diffused-bubble oxygen transfer rate using the discrete-bubble model. Water Res. 36(18), 4627−4635. http://dx.doi.org/10.1016/S0043-1354(02)00175-6.

Miu, J.G., Yin, P.J., 2007. Study on water improvement function, capacity of lifting water and oxygenation of a water-lifting aerator. Chin. J. Environ. Eng. 1(1), 7−13 (in Chinese).

Nunes, A.N., De Almeida, A.C., Coelho, C.O., 2011. Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Appl. Geogr. 31(2), 687−699. http://dx.doi.org/10.1016/j.apgeog.2010.12.006.

Reubens, B., Poesen, J., Danjon, F., Geudens, G., Muys, B., 2007. The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: A review. Trees 21(4), 385−402. http://dx.doi.org/10.1007/s00468-007-0132-4.

Vaze, J., Chiew, F.H., 2004. Nutrient loads associated with different sediment sizes in urban stormwater and surface pollutants. J. Environ. Eng. 130(4), 391−396. http://dx.doi.org/10.1061/(ASCE)0733-9372(2004)130:4(391).

Wang, G., Wu, B., Wang, Z.Y., 2005. Sedimentation problems and management strategies of Sanmenxia Reservoir, Yellow River, China. Water Resour. Res. 41(9), W09417. http://dx.doi.org/10.1029/2004WR003919.

Wang, S., Qian, X., Han, B.P., Luo, L.C., Hamilton, D.P., 2012a. Effects of local climate and hydrological conditions on the thermal regime of a reservoir at Tropic of Cancer, in southern China. Water Res. 46(8), 2591−2604. http://dx.doi.org/10.1016/j.watres.2012.02.014.

Wang, S., Qian, X., Wang, Q., Xiong, W., 2012b. Modeling turbidity intrusion processes in flooding season of a canyon-shaped reservoir, South China. Procedia Environ. Sci. 13, 1327−1337. http://dx.doi.org/10.1016/j.proenv.2012.01.125.

Wang, X., Li, T., Xu, Q., He, W., 2001. Study of the distribution of non-point source pollution in the watershed of the Miyun Reservoir, Beijing, China. Water Sci. Technol. 44(7), 35−40.

Wang, Z.Y., Hu, C., 2009. Strategies for managing reservoir sedimentation. Int. J. Sediment Res. 24(4), 369−384. http://dx.doi.org/10.1016/S1001-6279(10)60011-X.

Wilkinson, A., 1999. Poplars and willows for soil erosion control in New Zealand. Biomass Bioenergy 16(4), 263−274. http://dx.doi.org/10.1016/S0961-9534(99)00007-0.

Wu, L., Long, T.Y., Liu, X., Guo, J.S., 2012. Impacts of climate and land-use changes on the migration of non-point source nitrogen and phosphorus during rainfall-runoff in the Jialing River Watershed, China. J. Hydrol. 475, 26−41. http://dx.doi.org/10.1016/j.jhydrol.2012.08.022.

Yang, M., Li, L., Li, J., 2012. Prediction of water temperature in stratified reservoir and effects on downstream irrigation area: A case study of Xiahushan reservoir. Phys. Chem. Earth Parts A/B/C 53−54, 38−42. http://dx.doi.org/10.1016/j.pce.2011.08.019.

Yu, Z.Z., Wang, L.L., 2011. Factors influencing thermal structure in a tributary bay of Three Gorges Reservoir. J. Hydrodyn. Ser. B 23(4), 407−415. http://dx.doi.org/10.1016/S1001-6058(10)60130-8.

Zhang, Q., Xu, C.Y., Becker, S., Jiang, T., 2006. Sediment and runoff changes in the Yangtze River basin during past 50 years. J. Hydrol. 331(3), 511−523. http://dx.doi.org/10.1016/j.jhydrol.2006.05.036.