Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2018.22206

125 (2018) 187–192
September

Algal community structure and water quality assessment in the draw down area of Hanfeng Lake during the storage and dry periods of the Three Gorges Reservoir, China

Fengling Gan[a], Binghui He[a,*], Bing Yang[a], Debao Wang[b]

[a]*College of Resources and Environment, Southwest University, Beibei District, Chongqing 400715, China, email: 435626022@qq.com (F. Gan), hebinghui@swu.edu.cn (B. He), 1934363370@qq.com (B. Yang)*
[b]*Water Power Survey and Design, Chengdu, Sichuan 610073, China, email:506827729@qq.com (D. Wang)*

Received 2 February 2018; Accepted 17 March 2018

ABSTRACT

The water level of the Three Gorges Reservoir (TGR), the largest man-made canyon-shaped reservoir in China, reaching 172.8 m in December 2008 drew attention from all over the world. Hanfeng Lake is considered a critical zone of water management in the TGR. Thus, to understand the water environment and changes to the algal community structure of Hanfeng Lake at the 172. 8 m water level, the physical parameters, chemical parameters, number of phytoplankton species, biological density, and biomass of the ecological index in the lake were observed 12 times over one year during the storage period (January–February and September–December) and the dry period (April–August) in 2015. The results indicated that the trend of variation in concentration of each environmental factor has consistent influence trend in Hanfeng Lake. The distribution diversity of Hanfeng Lake in the storage period was generally higher than that in the dry period, while the distribution was more uniform and the species richness was lower in the storage period. Based on our investigation of water quality in Hanfeng Lake in 2015, the Hanfeng Lake belong β-pollution to α-pollution.

Keywords: Three Gorges Reservoir; Hanfeng Lake; Storage period; Dry period; Algal community assessment; Water quality assessment

1. Introduction

As one of the largest hydro power engineering schemes in the world, the Three Gorges Reservoir (TGR) has attracted scientific attention both in China and all over the world. The construction of the reservoir presents varying degrees of irreversible and significant social and environmental impacts [1–2]. Unfortunately, completion of the TGR has exerted a tremendous impact on the mainstream, watershed tributaries, and downstream regions of the Yangtze River. Water quality in the area has deteriorated to the point where design expectations have been exceeded [3–5]. Today, water quality is the focus of research on the TGR region, where Lake Eutrophication has led to economic disruption and lasting damage to the aquatic ecosystem because of dissolved and adsorbed pollutants [6–8]. With the gradual operation of the TGR, increasing degradation of water quality has been observed. Nitrogen (N) and phosphorus (P) concentrations have increased from the soil erosion and sediment deposition created by artificial activity [9]. Several studies have indicated that the nutrient loading in the TGR for the large qualities sediment deposition during its operation [10]. Nutrient loading, particularly that of total phosphorus (TP), can lead to eutrophication. For the wetland agriculture adjacent with resource of pollution tends to favour the growth of invasive and aggressive.

*Corresponding author.

Presented at the 4th Annual Science and Technology Conference (Tesseract'17) at the School of Petroleum Technology, Pandit Deen Dayal Petroleum University, 10–12 November 2017, Gandhinagar, India

The Hanfeng pre-reservoir was designed to reduce the impact of the 45 km^2 Fluctuating Zone and is formed by the HanFeng pre-dam of the TGR. To reduce the impact of the Fluctuating Zone, the TGR pre-dam is rare in the world which is specially designed and the largest artificial lake body in domestic [11]. Thus, understanding the effect of spatial and temporal distributions in the TGR is necessary to evaluate the water quality of Hanfeng Lake. HanFeng pre-reservoir hydrology and water quality time change of commissioning is divided into two periods by combined Hydrological and Morphological Variation of the time feature with water quality indicators time clustering analysis: the storage period (January–February and September–December) and the dry period (April–August). In this work, we evaluated the pre-reservoir in controlling influence of water environment of the Hanfeng Lake in controlling pollution and identified the major influencing factors source of pollutants in the area to provide a reference for environmental governance of the lake.

2. Materials and methods

2.1. Study area

Hangfeng Lake is an important branch of the Yangtze River in the TGR Region, China. It is a newly-constructed artificial lake built after the Three Gorges Dam and the largest urban artificial lake in the West Midlands area of China. It is 177.5 km long, has an area of 5172.5 km^2, and flows into the Yangtze River through four major channels: East River, Taoxi River, Zhuxi River, and Toudao River. Hanfeng Lake is 4.5 km away from Kaxian County, which has a subtropical monsoon humid climate, an annual average rainfall of 1385 mm, and annual average temperature is 18.5°C. Kaixian Country is one of the largest water-fluctuating zones in the TGR, and the Hanfeng Lake area represents over 12.3% of water-fluctuating zones in the region [12].

2.2. Field sampling

In the present study, four stations (Fig. 1) were set up in Hanfeng Lake to enable synchronous sampling during the dry and storage periods of 2015. A time-series of temperature, dissolved oxygen (DO), pH, electrical conductivity (BC), mean transparency (SD), suspended substances (SS), total nitrogen (TN), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), total phosphorus (TP), dissolved phosphorus (DP), and phosphate (PO_4-P) samples were taken from the surface layer (0.5 m under water surface), middle layer, and bottom layer (0.5 m above water bottom) of the lake 12 times over a period of one year (the time interval of sampling was one month). And if the water depth was less than 5.0 m which had 0.5 m distance to surface waters. Water samples were collected using a 2.5 L sample collector, immediately filtered, and passed through 0.45 μm pore-size cellulose filters to monitor water quality.

2.3. Analysis methods

Sample processing was performed as follows: (1) Water temperature, DO, pH, and BC were directly determined by a portable multi-parameter water quality instrument (Model: MINISONDE5X). (2) Lake SD was estimated using a Secchi disk. (3) TN, NH_4-N, NO_2-N, NO_3-N, TP, DP, and PO_4-P were determined by the standard methods given in Ballot (2010) [13]. (3) Phytoplankton identification was performed following the standard methods and work of Kiplagat (1998) [14].

3. Results

3.1. Environmental parameters of Hanfeng Lake

3.1.1. Physical property of water

The basic physico-chemical properties of water at each sampling site are shown in Fig. 2. The mean water

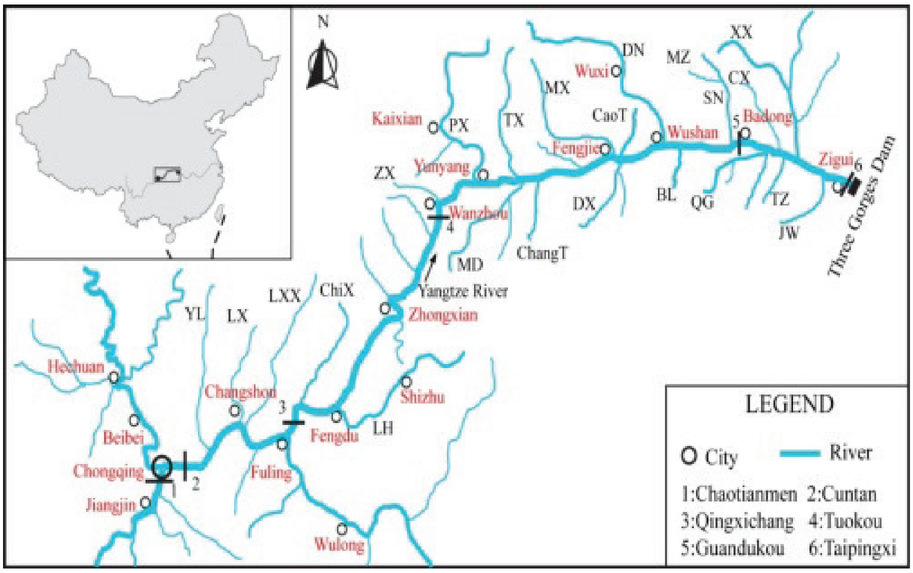

Fig. 1. Location map of Hanfeng Lake.

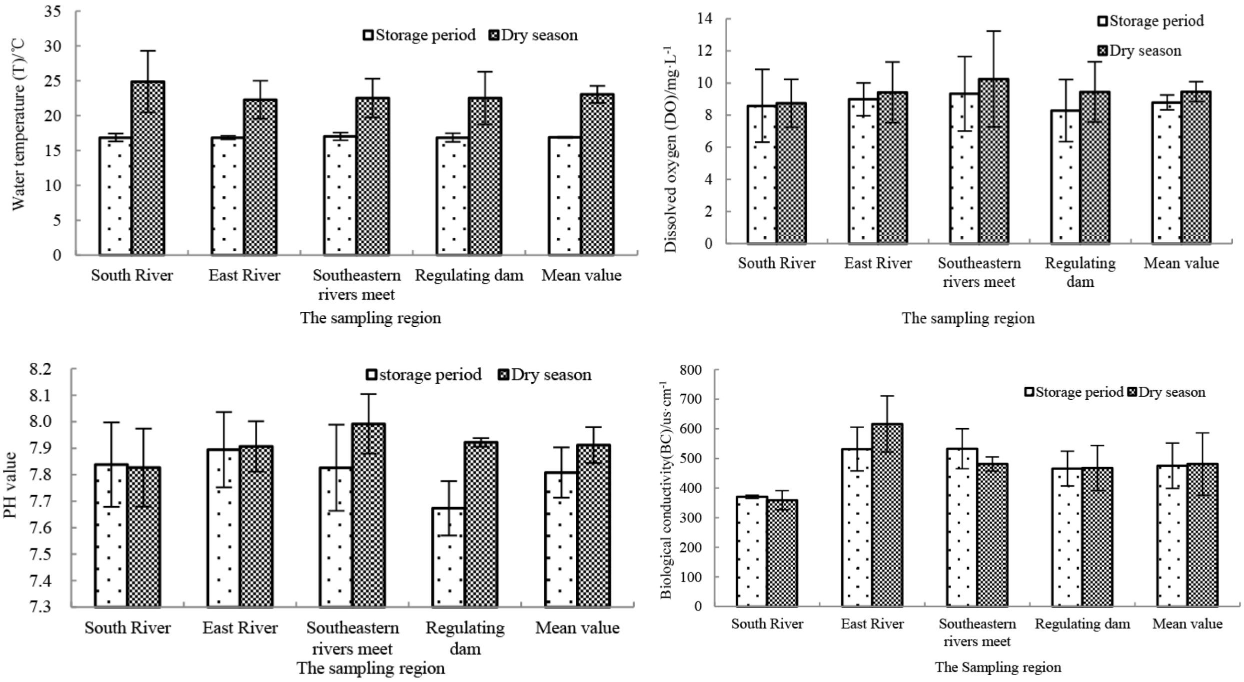

Fig. 2. The change of physical and chemical properties of Hanfeng Lake during the storage period and dry period.

temperature of Hanfeng Lake was 19.98°C, and the water temperature in the dry period was higher than that in the storage period. Water temperature decreased from the southeastern rivers to the regulating dam. The mean pH of Hanfeng Lake was 7.86, and pH values obtained in the storage period were lower than those recorded in the dry period. pH values also decreased from the southeastern rivers to the regulating dam. According to surface-water environmental standards, the water quality of Hanfeng Lake belongs to the first category. The mean DO concentration of Hanfeng Lake was 9.13 mg·L^{-1}, and DO concentrations in the storage period were lower than those in the dry period. DO concentrations also decreased from the southeastern rivers to the regulating dam. According to surface-water environmental standards, the water quality of Hanfeng Lake belongs to the first category. The BC of Hanfeng Lake was 478.07 us·cm^{-1}, and BCs in the storage period were lower than those in the dry period. BCs also decreased from the southeastern rivers to the regulating dam by 8.68%, and those of the South River were lower than those of the East River.

3.1.2. Suspended solid and transparency

The variations in SS and SD in Hanfeng Lake are shown in Fig. 3. The mean SS in Hanfeng Lake was 24.06 mg·L^{-1}, and the SS in the storage period was lower than that in the dry period. SS also decreased from the southeastern rivers to the regulating dam. This finding shows that SS increased from the upper reaches of the lake to its lower reaches. The SD of Hanfeng Lake was 0.7 m, and SD in the storage period was higher than that in the dry period. SD also increased from the southeastern rivers to the regulating dam.

3.1.3. Nitrogen forms

The variations of N forms in Hanfeng Lake are shown in Fig. 4. The mean TN concentration of Hanfeng Lake was 1.30 mg· L^{-1}, and TN values in the storage period were lower than those in the dry period. TN values also increased from the southeastern rivers to the regulating dam. The mean NO_3-N concentration in Hanfeng Lake was 1.28 mg·L^{-1}, and NO_3-N values in the storage period were higher than those in the dry period. NO_3-N concentrations also increased from the southeastern rivers to the regulating dam. The mean NH_4-N concentration in Hanfeng Lake was 0.28 mg·L^{-1}, and NH_4-N concentrations in the storage period were lower than those in the dry period. NH_4-N concentrations also decreased from the southeastern rivers to the regulating dam. The mean NO_2-N concentration in Hanfeng Lake was 0.025 mg·L^{-1}, and NO_2-N concentrations in the storage period were higher than those in the dry period. In addition, NO_2-N concentrations increased from the southeastern rivers to the regulating dam.

3.1.4. Phosphorus forms

The variations of water P forms in Hanfeng Lake are shown in Fig. 5. The mean TP concentration of Hanfeng Lake was 0.12 mg·L^{-1}, and TPs in the storage period were higher than those in the dry period. TPs also decreased from the southeastern rivers to the regulating dam. This result demonstrates that TPs decreased from the upper reaches of the lake to its lower reaches. The mean DP in Hanfeng Lake was 0.088 mg·L^{-1}., and DP values in the storage period were higher than those in the dry period DP values also increased from the southeastern rivers to the regulating dam. This finding reveals that DPs decreased from the upper reaches

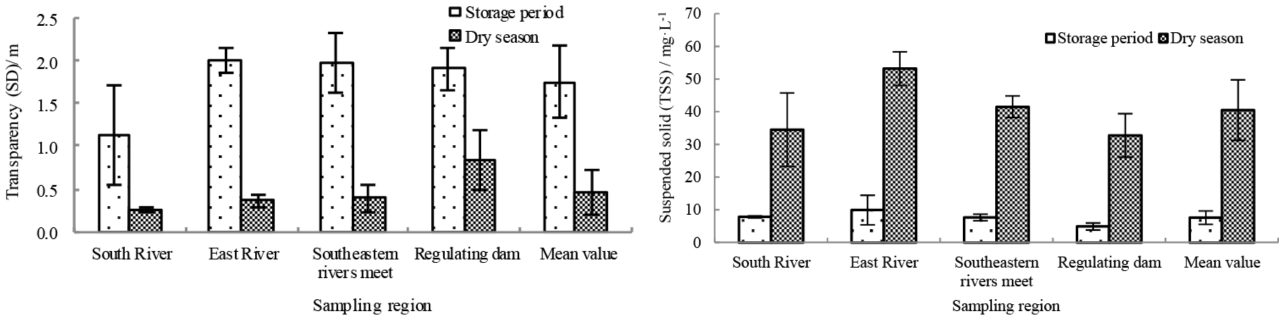

Fig. 3. The variation of water SD and TSS in Hanfeng Lake during the storage period and dry period.

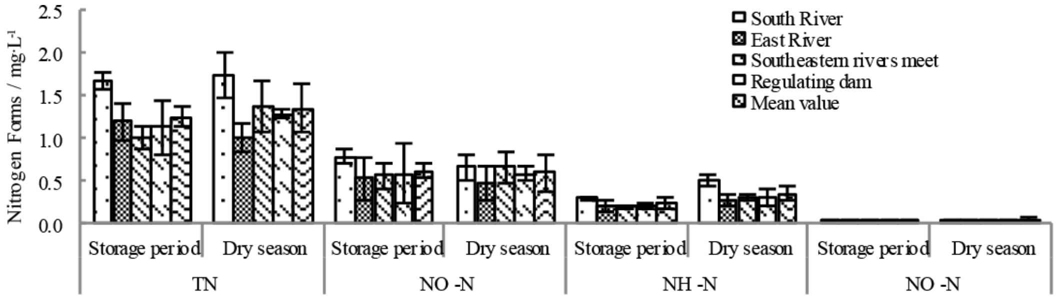

Fig. 4. The variation of water water nitrogen in Hanfeng Lake during the storage period and dry period.

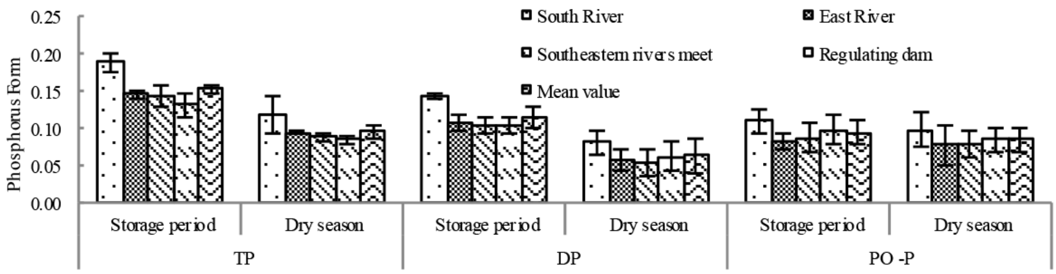

Fig. 5. The variation of water water phosphorus in Hanfeng Lake during the storage period and dry period.

of the lake to its lower reaches. The mean PO_4-P in Hanfeng Lake was 0.088 mg·L^{-1}, and PO_4-P concentrations in the storage period were higher than those in the dry period. PO_4-P concentrations also decreased from the southeastern rivers to the regulating dam.

3.2. *Analysis and evaluation of phytoplankton diversity*

The dominant species of phytoplankton in Hanfeng Lake included Cyanophyta and Chlorophyta (about 80 species) during the storage period, Bacillariophyta and Chlorophyta (about 122 species) during the dry period, and Cyanophyta and Chlorophyte (about 65 species) during the storage period. The population density of phytoplankton dominance were Cryptophyta, Pyrroptata and Bacillariophyta during the Storage period → Bacillariophyta, Cyanophyta and Chlorophyta during the Dry period → Cyanophyta, Pyrroptata and Cryptophyta during the Storage period. Meanwhile, the population biomass of phytoplankton was Pyrroptata during the Storage period → Bacillariophyta and Cryptophyta during the Dry period → Pyrroptata during the Storage period.

The phytoplankton diversity indices in Hanfeng Lake are shown in Fig. 6. The most significant change in the phytoplankton Shannon-Wiener diversity index (H') was observed in February, when the water level began to drop, and the lowest H' value was found in October, when the backwater returned to rise after the Three Gorges Reservoir impounded. H' values in the storage period were higher than those in the dry period. Hence, water quality was β-medium pollution. The Pielou-Evenness index (J) values observed in the storage period were higher than those recorded in the dry period. The water quality was α-medium pollution in the dry period and β-medium pollution in the storage period. The Margalef richness index (D) was significantly negatively correlated with the H' and J values. D values in the dry period were higher than those in the storage period. The water quality was clean-type in Dry period and β-medium pollution in Storage period.

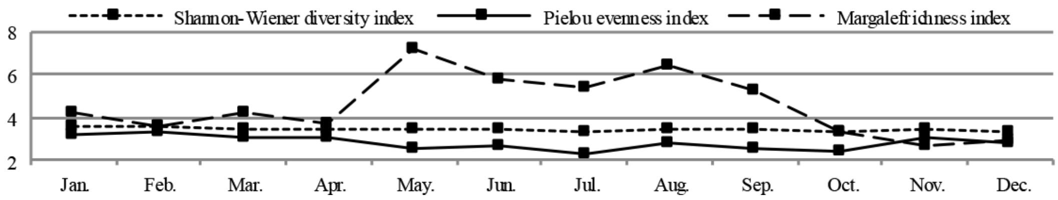

Fig. 6. The diagram of phytoplankton diversity indices in HanFeng Lake.

4. Discussion

4.1. Analysis of environment factors

The soil type in the Yangtze River basin was mainly purple sandy shale with serious soil erosion for the fast soil-forming process and light-textured. In addition, the velocity in the dry period was relatively larger by strong rain wash so that the SS in the dry period was higher than that in the storage period and the SD in the former was lower than that in the latter. Water levels significantly increased in the storage period, causing the vegetation of the bank to become submerged, the release of nitrogen-phosphorus nutrients in water body by the microbial action and the release volume increased with the increase of PH value [15]. Based on the conditions of eutrophication occur in lake and reservoir: TN>0.2 mg·L^{-1}, TP>0.02 mg·L^{-1} [16]. The TN concentration in the lake was 8.6 times the threshold lies and and the TP concentration was 8.7 times the threshold. These results demonstrate that TN and TP concentrations in Hanfeng Lake reached the threshold lies. of eutrophication. This illustrates the source of the nitrogen and phosphorus have close link with fertiliser usage [17]. P is believed to be a limiting factor of algal growth if the TN/TP > 16:1, and N is considered a limiting factor of algal growth if the TN/TP < 16:1 [18]. The TN/TP ratio in Hanfeng Lake can be considered to the nitrogen was the key element for the nutritional status process of Hanfeng Lake. Increases in N concentration in the lake could lead to severe eutrophication.

In the storage period, elevation of water levels caused a large number of main streams to flow backward as a density flow. The soluble nutrients enter main stream with the water body, to enhance the nutrient content. However, the pH values observed in the storage period were relatively close to those found in the dry period. In the storage period of Hanfeng Lake, the most dominant species were mid-eutrophication species indicators. Among the reasons, the submerged zone of Hanfeng Lake was flat, so both drop of water and current velocity were small during the Storage period. In addition, the self-clarification ability of the lake decreases with increasing retention time, so pollution is difficult to dilute in the water body which was precipitated into the water-level fluctuation zone. Many other factors, such as traditional chemical fertilisers, domestic sewage, agricultural fertilisers, and industrial wastewater, could also increase the degree of eutrophication in the water-level fluctuation zone.

4.2. Algae biodiversity indices

Biological diversity is used to represent the relationship between the quantity and species of mixed-biological communities and an important parameter for appraising water quality. The higher the H′ value, the more complex and stable the community structure and the better the water quality. D is strongly dependent on species number and can reflect the phytoplankton distribution and plant community characteristics of a water column. J represents the extent of evenness of species distribution. The closer individual numbers are, the more homogeneous the number distribution of individuals in each algae, otherwise the lower.

Stable communities tend to present high levels of species diversity and evenness. J values exceeded 0.3 in the storage period of Hanfeng Lake, which means the community structure of algae in the lake is fairly complicated during this period. The pollution species indicators are some particular categories under the different levels of pollution. Domestic and overseas references have revealed that water quality could be evaluated using phytoplankton pollution indicators with a combination of real. A survey reported several phytoplankton pollution indicators in Hanfeng Lake, such as Melosirs varians C.A.AG (meso-eutrophic), Chlorella vulgaris Beij (light-eutrophic), Cryptomonas ovata Her (light-eutrophic), and Ceratium hirundinella (Mull) Schr (light-eutrophic). Based on this analysis, Hanfeng Lake cold be considered to be a light-eutrophic water body during the storage period because we detected C. hirundinella(Mull) Schr, C. vulgaris Beij, and C. ovata Her. The phytoplankton pollution indicators observed in the dry period were M. varians, C. vulgaris Beij and C. ovata her; thus, the water quality in this period could be considered medium-light eutrophic.

In general, the water quality in the storage period was significantly different from that in the dry period. The dominant species in the storage period was Pyrrophyta, which is sensitive to certain environmental factors such as permanganate index, TN, and NH_4^+-N. In the dry period, the dominant species was Bacillariophyta, which is sensitive to environmental factors such as TP and DP. Chlorophyta and Cyanophyta are influenced by TN, DN, and T. Thus, Hanfeng Lake could be considered light-eutrophic, which transition from river to lake.

5. Conclusion

The results of environmental factor analysis in this study indicated that the trend of variation in concentration of each environmental factor has consistent influence trend in Hanfeng Lake. The variation of concentration ranges moved from upstream to downstream, and that in the storage period was higher than that in the dry period. TN and

TP concentrations respectively reached up to 8.6 and 8.7 times the critical values, which beyond a limited value of algae that induced or aggravated the risk of water eutrophication. The N:P ratio in Hanfeng Lake was comparatively high, and the growth of algae was restrained by TN.

The distribution diversity of Hanfeng Lake in the storage period was generally higher than that in the dry period, and, while the distribution was more uniform, species richness was lower (0.85). The species diversity, degree of distribution uniformity, and species richness in the regulating dam were the highest among those recorded in all areas of interest. Based on our investigation of water quality in Hanfeng Lake in 2015, the Hanfeng Lake belong β-pollution to α-pollution.

Acknowledgements

This work was supported by the National Key Basic Special Foundation Project of China (JJ2015-016) and the National Science Foundation of China (KFJ-EW-STS-008). Special thanks are given to Mr. Bing Yang, Dr. Bing He and anonymous reviewers for improving the manuscript.

References

[1] M. Lu, S. Wu, C. Chen, J. Yi, Z. Wen, J. Chen, Y. Wang, X. Wang, P. Huang, A review of studies on water level fluctuating zone (WLFZ) of the Three Gorges Reservoir (TGR) based on bibliometric perspective, Acta Ecol. Sinica., 35(11) (2015) 3504–3518. (In Chinese)

[2] X. Yuan, Y. Zhang, H. Liu, S. Xiong, B. Li, W. Deng, The littoral zone in the Three Gorges Reservoir, China: challenges and opportunities. Environmental science and pollution research international, 20(10) (2013) 7092–7102.

[3] E. Szczepocka, B. Szulc, K. Szulc, B. Rakowska, Z.W. Joanna, Diatom indices in the biological assessment of the water quality based on the example of a small lowland river, Oceanol. Hydrobiol. Stud., 43(3) (2014) 65–273.

[4] Y. Huang, P. Zhang, D. Liu, Z. Yang, D. Ji, Nutrient spatial pattern of the upstream, mainstream and tributaries of the Three Gorges Reservoir in China, Environ. Monit. Assess., 186(10) (2014) 6833–6847.

[5] Y.-f. Wang, X.-l. Zhao, B.-h. He, Q. Huang Canonical correspondence analysis of Summer Phytoplankton Community and its environmental factors in Hanfeng Lake, Environ. Sci., 36(3) (2015) 922–927. (In Chinese)

[6] H. Zeng, L. Song, Z. Yu, H. Chen, Distribution of phytoplankton in the Three-Gorge Reservoir during rainy and dry seasons, Sci. Total Environ., 367(2) (2006) 999–1009.

[7] J. Zhang, B. Zheng, L. Liu, L. Wang, M. Huang, G. Wu, Seasonal variation of phytoplankton in the DaNing River and its relationships with environmental factors after impounding of the Three Gorges Reservoir: a four-year study, Procedia Environ. Sci., 2 (2010) 1479–1490.

[8] L. Zhang, J.-j. Wei, F. Li, C. Zhou, H.G. Douglas, Temporal and spatial variation of nutrients and Chlorophyll a, and their relationship in Pengxi River backwater area, Three Gorges Reservoir, Environ. Sci., 6(36) (2015) 2061–2069.

[9] X.L. Gao, J.M. Song, Phytoplankton distributions and their relationship with the environment in the Changjiang Estuary, China, Marine Pollut. Bull., 50(3) (2005) 327–335.

[10] Z.Y. Shen, L. Chen, Q. Hong, H. Xie, J.L. Qiu, R.M. Liu, Vertical variation of non point source pollutants in the Three Gorges Reservoir Region, Plos One, 8(8) (2013) 171–194.

[11] T. Zhang, J. Ni, D. Xie Severe situation of rural non point source pollution and efficient utilization of agricultural wastes in the Three Gorges Reservoir Area, Environ. Sci. Pollut. Res., 22(21) (2015) 16453–16462.

[12] Q. Huang, B.H. He, X.L. Zhao, Y. Wang, Temporal variation of trophic status in draw down area of Hanfeng Lake in the storage period of Three Gorges Reservoir in China, Environ. Sci., 36(3) (2015) 929–934.

[13] A. Ballot, J. Fastner, C. Wiedner, Paralytic shellfish poisoning toxin-producing cyanobacterium Aphanizomenon gracile in Northeast Germany, Appl. Environ. Microbiol., 76(4) (2010) 1173–1180.

[14] K. Kiplagat, K. Lothar, M.M. Francis, Temporal changes in phytoplankton structure and composition at the Turkwel Gorge Reservoir, Hydrobiologia, 368 (1998) 41–59.

[15] L. Yun, J. Willison, H. Martin, W. Pan, X. Xiong, Y. Ou, X. Huang, J. Wu, H. Zhou, Q. Xu, G. Chen, Y. Xi, J. Nie, Mulberry trees conserved soil and protected water quality in the riparian zone of the Three Gorges Reservoir, China. Environ. Sci. Pollut. Res., 23(6) (2016) 5288–5295.

[16] C. Ren, L. Wang, B. Zheng, A. Holbach, Total nitrogen sources of the Three Gorges reservoir -a spatio-temporal approach, Plos One, 10 (10) (2015) 1014–1458.

[17] E.D Ongley, Z. Xiaolan, Y. Tao, Current status of agricultural and rural non-point source pollution assessment in China, Environ. Pollut., 158 (5) (2010) 1159–1168.

[18] H. Xikang, X. Peng, G. Wei, L. Yonglong, Y. Na, Estimation of total nitrogen runoff rate and loading by agricultural fertilizers in the Yangtze River Delta area, Acta Scientiae Circumstantiae, 34 (6) (2013) 1585–1591.