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Assessing and predicting water quality of outflow under water level fluctuation of the Three Gorges Reservoir, China

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ABSTRACT

The Three Gorges Reservoir (TGR) has made a significant contribution to social and economic development and has vast effects on the aquatic environment. However, reservoirs can also produce a negative impact on the environment. The Three Gorges Dam (TGD) started operation since 2003. TGR operates at a low water level for 145 m during flood season while the water level rises to 175 m during the non-flood season. Water level is an essential hydrological parameter impacting water quality. Continuous and periodical water level change makes the changes of water quality in reservoirs more complicated. This study examined water quality changes in the main channel outflow of the Yangtze River after (TGD) completion and analyzed its relationship with water level fluctuation (WLF). Results showed that water quality indicators (DO, COD_{Mn}, and NH_3–N) had cyclical changes for hydrological scheduling control, and water quality indicators at different water levels had significant differences, which reflected the response of water quality to reservoir scheduling. According to water quality index, TGR water quality was best at high water level and stayed worst at low water level. Predicting outcomes of the Auto-Regressive Integrated Moving Average model showed water quality would still keep a good level in the future. A comprehensive understanding of temporal variability in water quality and evaluation result will be helpful in investigating water quality at a high precision time for water management.

Keywords: Three Gorges Reservoir; Outlet water quality; Water level scheduling; Impact assessment; Auto-Regressive Integrated Moving Average model

1. Introduction

Hydraulic projects have been built along major rivers in many countries, where environment and social status towards to be better [1]. Dams locate at river basins play an important role in ecological, social, and economic development, such as managing water storage, optimizing hydropower function, transportation, agriculture, environment, and leisure [2]. Three Gorges Dam (TGD) has made a significant contribution to national economic and social development, including flood control, water supply, electrical power production, etc. which has triggered international concerns by its consumption of environmental resources [3].

After TGD's building up, the monitoring, and evaluation of water quality play a vital role in management of water and environmental resources. For instance, some findings suggested that dams at low-latitude have

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possibility to discharge cooler, anoxic deep water, which could downgrade downstream ecosystem utilizing changing their regimes or giving rise to hypoxic stress, and low-latitude dams can alter water quality by tropical and subtropical rivers [4]. Persistent thermal stratification and consequent oxygen depletion might get mass production in deeper reservoirs, which to some degree, relied on the depth of water released from the dams and water retention time in the reservoir [5]. Reservoir in south Brazil reported that the downstream impacts of dam included a negative effect on fish assemblages, which had a potential decrease in the diversity of mechanisms for energy flow [6]. Valle and Kaplan [5] concluded that at the post-dam period, both upstream and downstream had higher water levels in the dry season, and the time of duration of wet-season drawdown was procrastinated and lengthened, which changed flood pulse [7]. During closed spillway, there was a growing acidity and a declining oxygen content as approached the dam while at the opened spillway, DO has declined fiercely toward the downstream [8]. Results from the River Continuum reported that the trapping of sediment at the impounded zone of the reservoir and its accumulation in the rear of the dam had limited the sediment that reached areas of downstream [9].

Negative environmental and socioeconomic impacts of the Three Gorges Reservoir (TGR) have attracted considerate attention. An increasing number of researches about TGR in recent years have focused on nitrogen contamination, organic pollutants, water quality, impact of reservoir regulation on downstream lakes [10], water and sediment discharge of the Yangtze River [11], geomorphic impacts of the TGD, sediment content, and other hydrological and biological properties. Tang et al. [13] found that excessive phosphorus loading was a severe problem during the post-TGR period, and turbid water with high suspended loads released during the flood season in cycles, and about 20% of sediment inflow would be discharged entering the TGR, and the size of deposited sediment volume increased at a rate of 0.117 billion tonnes per year in the TGR [12]. Researches on the main channel of the Yangtze River of the TGR usually pay attention on average annual changing trends, or change in a few years. It is necessary to estimate water quality continuously and extensively. Furthermore, a lot of water environment and water quality problems pertain to water level fluctuation (WLF) zone, WLF by TGD regulation which could adversely or profitably influence water quality. Because of the importance of TGR, the identifications of impacts triggered by WLF has become a primary task for water quality safety and hydrographic environment stability. Nevertheless, the relationship between WLF and TGR water quality has received little research attention [14,15].

TGR operates at a low level for 145 m during flood season while the water level rises to 175 m during the dry season. For flood control, TGR always discharge a certain amount of water and falls to low water level, in order to deal with the flood season for downstream safety. TGR stores water to a high-water level for shipping, power generation, and future water supply. This operation is obviously seasonal [16]. Meanwhile, this periodic dam operation makes a dynamic influence to hydrological factors [17]. Flood can increase the pollution load inputting to reservoirs, and can also lead a huge number of sediment pollution into the reservoir [18].

The WLF zone can help filter nutrients, non-point source pollutants, and other contaminant, and it is also an essential factor in promoting water quality in a reservoir [19]. The turbidity of Poyang Lake rose at the low water level [20]. Research reported that the concentration of organic contaminant, electrical conductivity were on the increase at high water level in the Tapacura reservoir [21]. The internal sediment pollution would increase because lower water levels could contribute to the release of sediment pollutants, but the input of pollutants decreased during low water level [22].

TGD operational regulations engender periodic WLFs of 30 m, which alter water storage periodically. Pollutant release could be a frequent occurrence during WLF zone. TGR's periodic operation also changes water residence times, oxygen consumption, and the circulation of substance. These factors have a great influence on water quality. TGR serves as critical living and production materials for cities and countryside along the Yangtze River. Due to its eco-environmental and societal impacts, it is significative to study the relationship between WLF and TGR water quality.

In this study, the objectives include: (1) investigate the differences of each water quality parameters (DO, COD_{Mn}, and NH_3–N) and water quality index (WQI) at different WLF periods from 2011 to 2018; (2) analyze the relationship between water level and three water quality parameters in the long-term observation; (3) assess and predict the general temporal trend of the water quality by Auto-Regressive Integrated Moving Average model (ARIMA) prediction model to determine the future water quality status. Ultimately, this study will conduce to parse water quality change processes and improve water conservation and management strategies for the TGR.

2. Materials and methods

2.1. Study area

The Yangtze River is the largest river in China and the third-largest river in the world. The TGR is in the area of subtropical monsoon climate, where floods, drought, and meteorological disasters are common phenomenon. The TGR locates at the upstream of the Yangtze River, stretching along the Yangtze River. The outflow of the Yangtze River mainstream in the TGR is located at Nanjinguan District, Yichang City of Hubei Province (Fig. 1).

For flood control, power generation and shipping, the TGR operates at a low level for 145 m during flood season while the water level rises to 175 m during the dry season. In this study, the operating water level of the TGR divides into four periods in a year (Fig. 2). Period I: discharging period (late December to early June), when the water level decreases from 175 to 145 m. Period II: low level operation period (June to early September), when the water level maintains approximately at 145 m. Period III: impounding period (September to late October), when the water level increases from 145 to 175 m. Period IV: high-level operation period (November to December), when the water level keeps around 175 m.

Fig. 1. Location of TGR in the Yangtze River, China.

2.2. Data sources

The data used in this study were obtained from the China National Environmental Monitoring Centre (CNEMC) (http://datacenter.mee.gov.cn/websjzx/queryIndex.vm). In order to evaluate the water quality of the TGR after the TGD into a formal operation, weekly water parameters data from 2011 to 2018 of the outflow (Nanjinguan District, Yichang City of Hubei Province) of the Yangtze River mainstream in the TGR were collected from the CNEMC. For this study, DO, COD_{Mn}, and NH_3–N were used to evaluate water quality situations and future trends.

The water level weekly data (from 2011 to 2018) of the outflow of the Yangtze River mainstream in the TGR

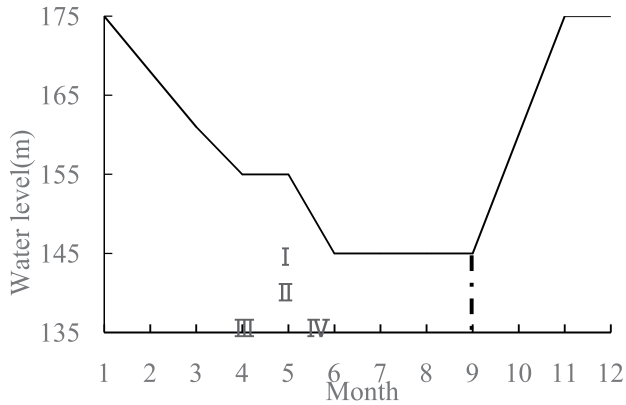

Fig. 2. Water level fluctuation pattern of Three Gorges Reservoir hydrological regimen: (I) discharging period, (II) low level operation period, (III) impounding period, and (IV) high level operation period.

were provided by the China Changjiang Maritime Safety Administration (https://cj.msa.gov.cn/xxgk/xxgkml/aqxx/gksq/index_18.shtml).

2.3. WQI computation

WQI is utilized in groundwater quality assessment specifically, which is a reliable mean for understanding the overall water quality among a variety of water parameters present in the water. According to the report from WHO, WQI can expound the combinatorial effect of each parameter as well as all qualitative parameters. Each water qualitative parameter occurs in different ranges and has behavior by concentration-impact relationship. According to WQI method, different water parameters are transformed to the same scale in order to present large quantities of water quality data into a single number. Through WQI method, water quality can be evaluated qualitatively and quantitatively, without interference due to individual abnormal water quality indicators. According to the National Standard of Environmental Quality (GB3838-2002), based on a single factor water quality identification index, an objective evaluation can be obtained through the WQI method. The following steps are involved in WQI calculation: (a) calculation of each single factor water quality identification index (p_i), (b) calculation of WQI which is the average of all the p_i.

2.3.1. Single factor water quality identification index

The single factor water quality identification index (p_i) represents the corresponding level for the concentration of every water parameter in the National Environmental Quality Standards for Surface Water (GB3838-2002). p_i is computed using the following equation:

$$p_i = x_1 \cdot x_2 \tag{1}$$

where x_1 represents the level of one water quality parameter concentration within the standard, and x_2 represents relative weight in the concentrations scale of the certain water quality level (Table 1).

Table 1
Standard range of concentration (mg L^{-1}) for every water quality parameter based on Environmental Quality Standards for Surface Water (GB3838-2002)

Water quality parameter	I	II	III	IV	V
DO (mg L^{-1})	7.5	6.0	5.0	3.0	2.0
COD_{Mn} (mg L^{-1})	2.0	4.0	6.0	10.0	15.0
NH_3–N (mg L^{-1})	0.15	0.5	1.0	1.5	2.0

For most water quality parameters (except for DO), p_i is calculated by following expression:

$$x_1 \cdot x_2 = k + \frac{c_i - c_{i,k(\text{lower limit})}}{c_{i,k(\text{upper limit})} - c_{i,k(\text{lower limit})}} \tag{2}$$

For DO, p_i is calculated by following expression:

$$x_1 \cdot x_2 = k + 1 - \frac{c_i - c_{i,k(\text{lower limit})}}{c_{i,k(\text{upper limit})} - c_{i,k(\text{lower limit})}} \tag{3}$$

where k = 1, 2, 3, 4, 5, respectively, represents level I, II, III, IV, and V for the certain water quality parameter concentration. $c_{i,k(\text{upper limit})}$ and $c_{i,k(\text{lower limit})}$, respectively, represent upper and lower concentration of level k for certain water quality parameter i.

2.3.2. Water quality index

WQI is average value of all p_i. WQI is computed using the following equation:

$$\text{WQI} = \frac{1}{n}\sum_{i=1}^{n} p_i \tag{4}$$

where n is the number of p_i which participants in the WQI calculation.

For WQI, with smaller values representing higher water quality (Table 2).

2.4. ARIMA model – time serial predicting model

An ARIMA model is a prediction model by timing sequence, which is the most common method for time series analysis. The full name of ARIMA (p, d, q) is Auto-Regressive Integrated Moving Average model, abbreviated as ARIMA, in which AR(p) is a self-regression term, I(d) is the number of integrations made when the time series is optimized to be stationary, MA(q) is the moving average.

The time series data is treated as a random sequence through this mathematical model, which can be used to predict future trends of time sequence based on past and present data, even with missing data. ARIMA model has been a good application of prediction for climate change, economic management, water level change trend, and water quality

Table 2
Evaluation standard for WQI

Judgment criteria	Water quality level
$1.0 \le WQI \le 2.0$	I
$2.0 \le WQI \le 3.0$	II
$3.0 \le WQI \le 4.0$	III
$4.0 \le WQI \le 5.0$	IV
$5.0 \le WQI \le 6.0$	V

change trend. The ARIMA model can be described as the following equation:

$$X_t = \sum_{j=1}^{p} \phi_j X_{t-j} - \sum_{k=1}^{q} \theta_k \varepsilon_{t-k} + \varepsilon_t \quad (5)$$

where X_t is the sequence of observed time series, $\phi_1,\phi_2,\ldots \phi_p$ are AR coefficients, $\theta_1,\theta_2,\ldots,\theta_q$ are MA coefficients, $\varepsilon_1, \varepsilon_{t-k},\ldots,\varepsilon_t$ are error terms, p is the order of the autoregressive model, q is the order of the moving-average model.

To develop an ARIMA model, the first step is to determine whether the time series data is stationary or not, and makes the time series data more stable through applying the differencing approach. The next step is to determine the model parameter estimation and diagnosis, p and q should be estimated through autocorrelation and partial autocorrelation and the Akaike information criterion (AIC).

This study of water quality parameters forecasting was by the software of SPSS to built up an ARIMA model.

3. Results

3.1. Temporal trends in water quality parameters

Fig. 3 provides the temporal variations of the water quality parameters from 2010 to 2018. Fig. 4 shows boxplot graphs of the concentration of each water parameters, and Table 3 shows average water quality parameters variable of different periods from 2011 to 2018. DO exhibited apparent periodicity and fluctuation every year, which had a high-low-high changing fluctuation pattern during a year. The average DO concentration peaked at high-level operation period and was lower at low-level operation period. The sequence of the concentration of DO at four periods was high-level operation period (period IV), discharging period (period I), impounding period (period III), low-level operation period (period II). The average concentration of DO at different periods all met level I (GB3838-2002). There was a significant difference of DO between period I, IV, and period II, III ($p < 0.05$; Tables 3 and 4).

Average concentrations of COD_{Mn} and NH_3–N showed similar temporal patterns that were higher at low level operation period and lower at high level operation period, both had no significant annual fluctuation during a year. The sequence of the concentrations of COD_{Mn} and NH_3–N at four periods was period II, III, I, and IV. The concentrations of COD_{Mn} at different periods all met the level I standard (GB3838-2002). The average concentration of NH_3–N at period I, II, III met the level I standard (GB3838-2002), while at period IV it nearly met level II standard (GB3838-2002). There was a significant difference of COD_{Mn} among period I, II, and IV ($p < 0.05$). There was a significant difference of NH_3–N between period II and period IV ($p < 0.05$).

3.2. WLF effects to water quality

Temporal variation of WLF and runoff in the TGR are demonstrated in Fig. 5. WLF could trigger water environment changes, releasing nutrients from soils, deposit sediment, and plants under water surface. The water level is maintained at the lowest at 145 m at summer to control flooding, and the water level is raised to 175 m in winter for generating electricity and shipping. As a result, WLF brings about a 30 m amplitude of the TGR. Fig. 7 shows the temporal variation in water level from 2011 to 2018.

Coefficients of Pearson's correlation analysis between water level, runoff, and water quality parameters are demonstrated in Table 5. DO is positive related to water level and run off, at a significance level of 0.01. COD_{Mn} and NH_3–N are negatively related to water level and run off, while NH_3–N is negatively related to water level at a significance level of 0.05.

3.3. Water quality assessment using the WQI method

As an integrative indicator, WQI is used to evaluate water quality condition based on multiple water quality parameters. WQI of the TGR outlet was calculated to assess the effects of the WLF by the TGD on the Yangtze River. Temporal variation of weekly WQI from 2011 to 2018 is illustrated in Fig. 6. Boxplot graphs of WQI at different periods are shown in Fig. 7. The average WQI at different periods is shown in Table 6. Average WQI was maximum at period II (low level operation period) while it was minimum during period IV (high level operation period). ANOVA analysis represented in Table 7 demonstrates that there was no significant difference among WQI at different periods. The average WQI at different periods all met level II (WQI standard). The sequence of the average of WQI at four periods was period II, III, I, and IV. Overall, the water quality at high water level was better than the water quality at low water level.

3.4. Predictive value of water quality parameters by ARIMA model

From Fig. 8, it can see that black lines are the measured data, and blue lines are raw data fitting value calculated by the ARIMA model based on measured data. The difference between raw measured data and fitting value is not significant, which indicated the ARIMA model was effective.

Based on calculation results by SPSS, comparison for all possible models was done, the most fitted ARIMA models were chosen for water quality parameters. ARIMA (1,1,1) for DO, ARIMA (2,1,2) for COD_{Mn}, ARIMA (1,1,1) for NH_3–N.

In accordance with Forecasting norm for hydrology intelligence (GB/T 22482-2008), the allowable error between raw data and fitting data could be 20%. According to Table 8, the average prediction accuracy for each water

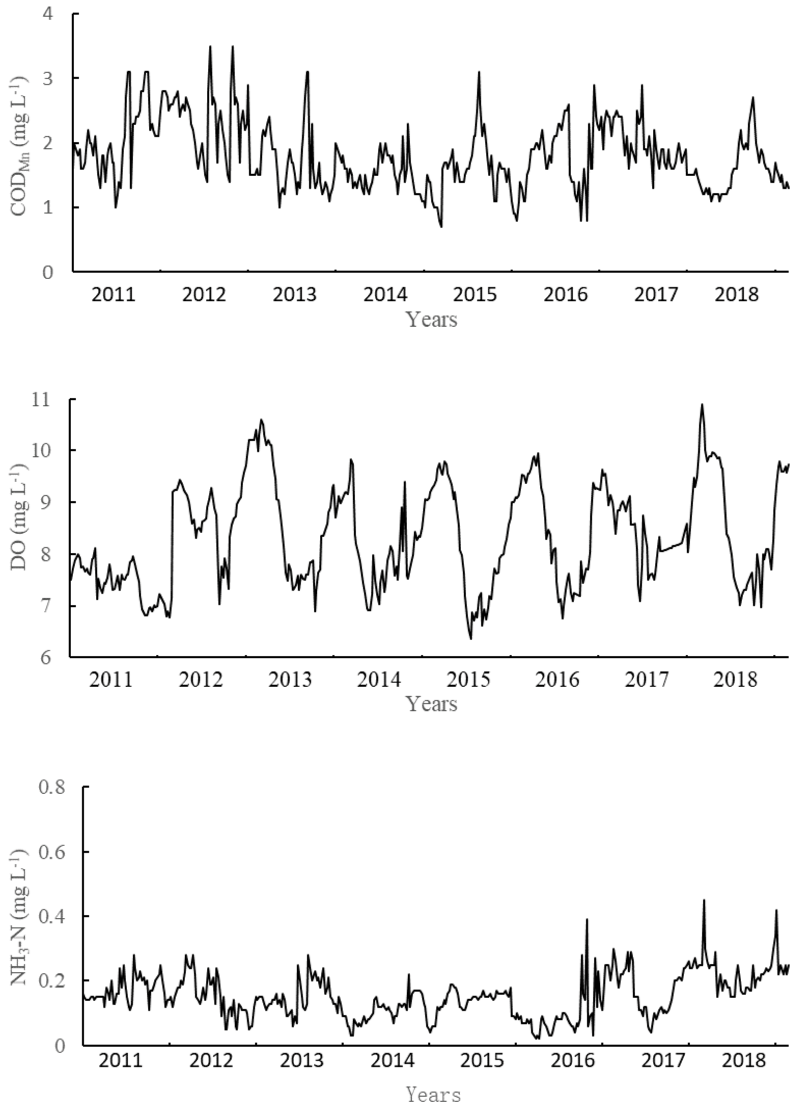

Fig. 3. Concentration of DO, COD_{Mn}, and NH_3–N time series of the TGD from 2011 to 2018.

quality parameter ARIMA model are 97.28%, 87.25%, and 80.74%, and the accuracy grade for each model are all over suboptimal level. In conclusion, the prediction models were convincing.

Water parameters data from the CNEMC was only documented to 2018. Future trend was predicted base on historical data from 2011 to 2018. According to the ARIMA models from Table 8, the concentration of each water quality parameter in 2019 was simulated.

The average predicted the concentration of each water quality parameter at different periods are illustrated in Table 9. It can be seen that, at different periods of 2019, the concentration of DO and COD_{Mn} will meet level I standard (GB3838-2002), and NH_3–N will meet level II standard (GB3838-2002). The average concentration of DO will be lowest at low water level and will peak at high water level. The average concentration of COD_{Mn} and NH_3–N will have max value at low water level and decrease to a minimum value at high water level.

Table 3
Comparison of average water quality parameters variable for TGR at different periods from 2011 to 2018

Period	DO (mg L^{-1})	COD_{Mn} (mg L^{-1})	NH_3–N (mg L^{-1})
I	8.60	1.83	0.14
II	7.63	1.92	0.15
III	7.80	1.81	0.14
IV	8.68	1.71	0.13

Based on the forecasted results for water quality parameters of 2019, WQI at different periods of 2019 were calculated. According to Table 10, average prediction WQI will be maximum at period II, which means the water quality will be worst at a low water level. Average prediction WQI in the discharging period and high level operation period will

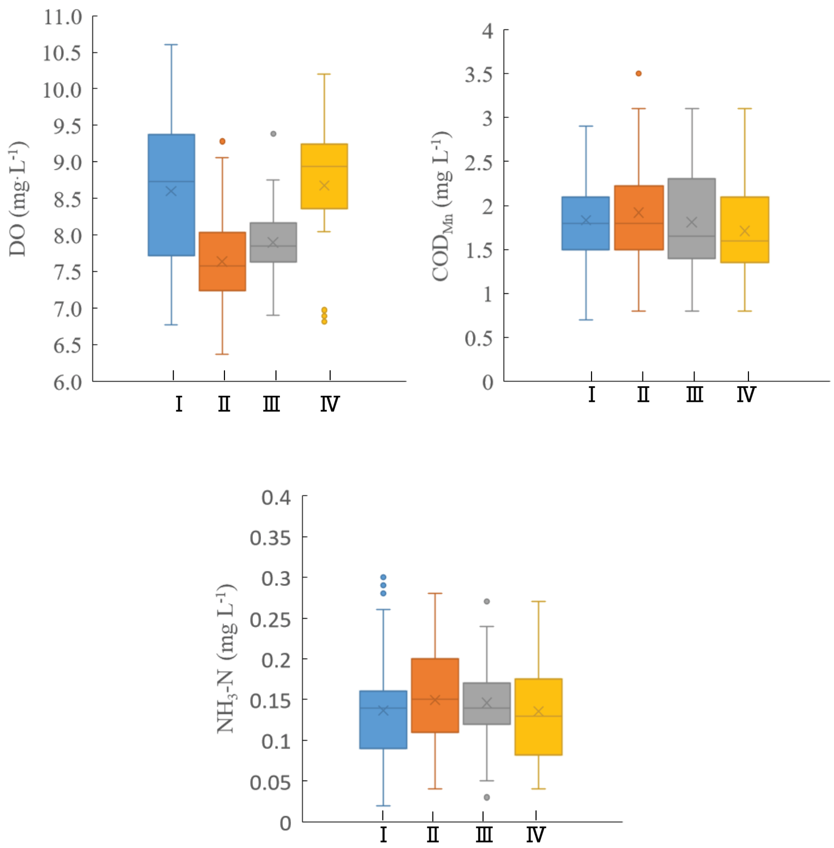

Fig. 4. Boxplot graphs of the concentration of DO, COD_{Mn}, and NH_3–N at different periods of time from 2011 to 2018. (I) Discharging period (175–145 m), (II) low-level operation period (145 m), (III) impounding period (145–175 m), and (IV) high-level operation period (175 m).

be similar, which means the water quality in these periods will be best.

4. Discussion

4.1. Temporal pattern of water quality parameters

Periodic trend in NH_3–N and COD_{Mn} indicate that maxima appear at low water level and minima at high water level, while the opposite condition for DO, which agrees with results from Rao and Latha [23] and Abbasnia et al. [24].

DO consumption rate was lower when the water flux was low during the dry season with high water level, and higher with high velocity. High flow volume at low water level period could cut down DO concentration due to interflow carrying a lot of suspended solids and organic matters, which increased the oxygen consumption rate [25]. In addition, high flow volume and rainstorm at low water level period helped soluble chemical substances released

Table 4
ANOVO matrix for water quality parameters at different periods from 2011 to 2018

DO					COD_{Mn}					NH_3–N				
	I	II	III	IV		I	II	III	IV		I	II	III	IV
I	–	1.03[a]	0.75[a]	–0.09	I	–	–0.15[a]	–0.02	–0.10[a]	I	–	–0.01	0	0.01
II	–1.03[a]	–	0.28	–1.12[a]	II	0.15[a]	–	0.13	0.24[a]	II	0.01	–	0.01	0.02[a]
III	–0.75[a]	0.28	–	–0.84[a]	III	0.02	–0.13	–	0.11	III	0	–0.01	–	0.01
IV	–0.09	1.12[a]	0.84[a]	–	IV	–0.10[a]	–0.24[a]	–0.11	–	IV	–0.01	–0.02*	–0.01	–

[a]Correlation is significant at the 0.05 level (2-tailed)

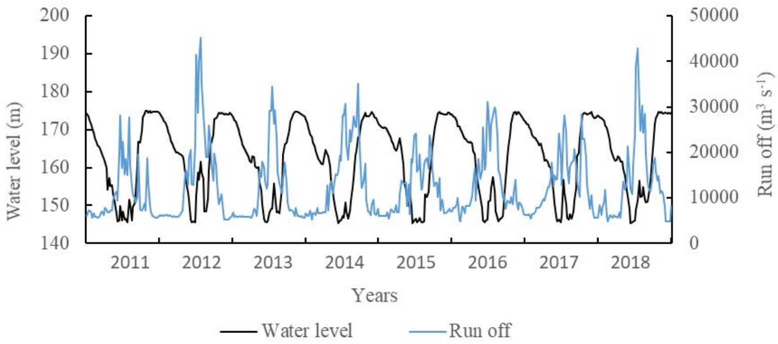

Fig. 5. Water level fluctuation in the TGR from 2011 to 2018.

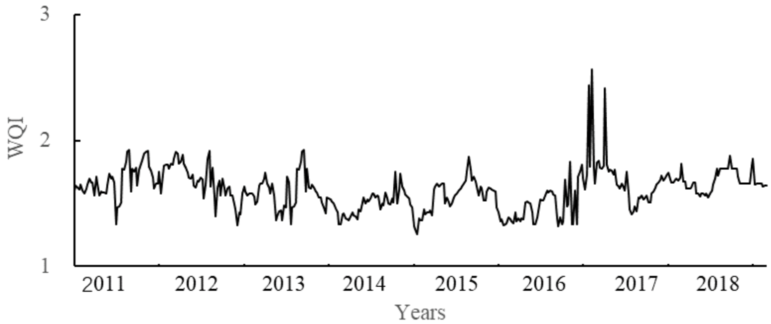

Fig. 6. WQI time series of the TGD from 2011 to 2018.

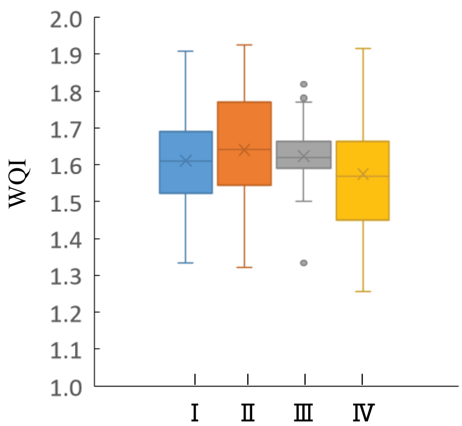

Fig. 7. Boxplot graph of WQI at different periods from 2011 to 2018: (I) discharging period (175–145 m), (II) low-level operation period (145 m), (III) impounding period (145–175 m), and (IV) high-level operation period (175 m).

from the sediments and deteriorated water quality, the lack of DO at the bottom is a principal endogenous pollution source in the reservoir [26].

DO is a crucial indicator of water quality. The preservation of DO in the water body is one significant factor for water resource management [27]. Higher DO contends can exert a stronger self-purification ability for water, which could accelerate the oxidation reaction of contaminant and enhance them precipitate with sediment [28]. Moreover, when the DO content was high at high water level period, the sediment in water body was at the oxidation state, which would create a suitable living environment for aerobic bacteria [29].

DO consumption rate is an indicator for the activity levels of the microbial community, and water temperature can also affect the content of DO [30]. During the flood season with low water level, the algae cell concentration peaks and consumed more oxygen due to higher temperature in summer, which also triggered algae blooms [31,32].

The periodic allocations by the TGD alter water flux and water level of the TGR. COD_{Mn} and NH_3–H are negative indexes for water quality condition [33]. Pollutants such as COD_{Mn} and NH_3–H are associated with industrial activities and sanitary sewage, derived from some soluble inorganic nitrogen and inorganic salts by some agricultural practices and mining activities [34,35].

When entering high water level period, the TGR extends to lake face, the decreased in water flow speed caused sediment settlement by impoundment. Pollutants are settled readily as water flux speed decreased and retention time was prolonged at winter with high water level [36]. The contaminant included nitrogen and heavy metal interacted with suspended sediment and accumulated in the bed [37]. Pollutants are deposited in sediment, some are oxidized or degraded, others are absorbed by organism [38,39]. The anti-seasonal operation pattern and the increase in reservoir capacity of TGR can increase the dilution capacity. The COD_{Mn} will be difference by water level and the flow velocity change in different periods [40,41]. Due to the abundant water quantity at high water level, the COD_{Mn}

Table 5
Pearson's correlation matrix for water level, runoff, and water quality parameters of outlet in the TGR from 2010 to 2018

	Water level	Run off	DO	COD_{Mn}	NH_3–N
Water level	1				
Run off	–0.555[b]	1			
DO	0.460[b]	–0.382[b]	1		
COD_{Mn}	–0.028	–0.098	–0.150[b]	1	
NH_3–N	–0.105[a]	–0.071	0.057	0.172[b]	1

[a]Correlation is significant at the 0.05 level (2–tailed)
[b]Correlation is significant at the 0.01 level (2–tailed)

Table 6
Comparison of average WQI variable for TGR at different periods of time from 2011 to 2018

Period	I	II	III	IV
WQI	1.61	1.65	1.61	1.57

Table 7
ANOVO matrix for WQI at different periods from 2011 to 2018

Period	I	II	III	IV
I	–	–0.036	–0.001	0.039
II	0.036	–	0.041	0.081
III	0.001	–0.041	–	0.038
IV	–0.039	–0.081	–0.038	–

Table 9
ARIMA model forecasted results of 2019

Water quality parameters (mg L^{-1})	Period of time			
	I	II	III	IV
DO	8.59	7.53	7.62	8.68
COD_{Mn}	1.80	1.96	1.80	1.75
NH_3–N	0.14	0.15	0.15	0.14

Table 10
Forecasted WQIs of 2019 at different periods of time

Period of time	I	II	III	IV
WQI	1.62	1.65	1.63	1.62

concentration was lower by the stronger self-purification ability of water body.

During the period of low water level, with water flowing rapidly, TGR shrinks into river face. Low water period at flood season with a high concentration of nitrogen, when non-point source pollution has significant impact on water quality [42]. Water quality will be contaminated by organic matter pollution leakage, which can result in an increasing permanganate index of water body.

4.2. Temporal pattern of WQI

TGD has played an important role in socioeconomic development and life Services in the TGRA, such as electricity generation and navigation, etc. However, the large dam has also generated some environmental issues [43]. There are two opposing opinions on the impact of dam construction toward the water quality. On one side, the dam decreases the flow velocity, sediment transport, and block hydrological continuity. The opposing opinion is that the dam raises the water level and storage capacity in the reservoir area, and can push off hydraulic residence time, thus improving the self-purification capacity of the water resource.

The results show that the water quality at a high-water level period was best, while the water quality at a low water level period was worst. During the low-water level period, the pollutions could not diffuse easily with lower reservoir water content, and the DO content had a negative relationship with the high temperature. In the high-water level period, contaminants could be diluted and settled by higher reservoir water content. No significant differences were found among different periods. WQI at different periods reached level I of comprehensive water quality classification, and there was no obvious

Table 8
ARIMA model accuracy of fitting determination

Water quality parameters	ARIMA model	Average prediction accuracy	Model accuracy grade
DO	ARIMA (1,1,1)	97.28%	Optimal level
COD_{Mn}	ARIMA (2,1,2)	87.25%	Suboptimal level
NH_3–N	ARIMA (1,1,1)	80.74%	Suboptimal level

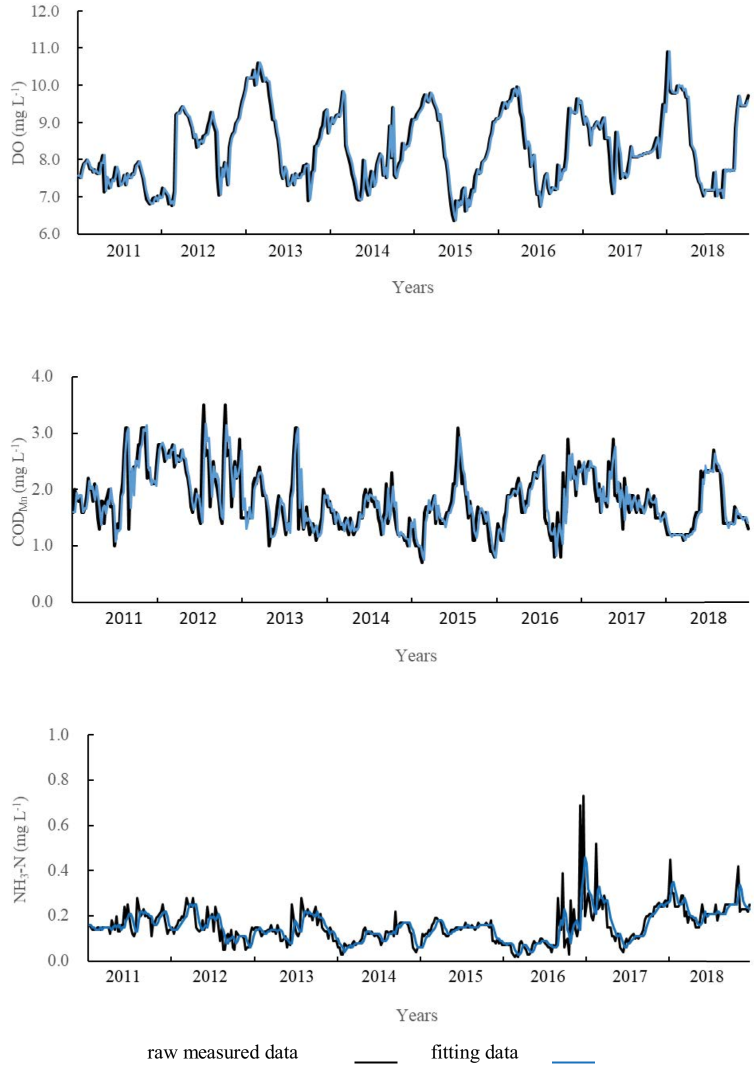

Fig. 8. Comparison of raw measured data and fitting data.

deterioration in water quality at different periods. One explanation for lack of striking deterioration in water quality is that large-scale impoundment increased retention time of water, which can raise the dilution of pullulations and the absorption of silt. The decreasing trend of water flow velocity towards the TGD led a fine-grained particle being deposited in downstream of the sediment [44,45]. In addition, water resource management and protection have been implemented in TGRA, such as reducing non-point pollution and banning farming in WLF zone.

Agricultural non-point pollution and domestic sewage along the TGR should be severely controlled, although some water resource managements had been implemented. In addition, the particulate inputs should be concerned along the Yangtze River [46].

4.3. ARIMA model prediction results for water quality

The concentration of each water quality parameter of 2019 was predicted by the ARIMA model. The prediction accuracy of each ARIMA model was up to standard. The results show that in the future, the concentration of each water quality parameters at different water level would meet the level I standard based on the National Standard of Environmental Quality (GB3838-2002). According to the forecasting results, the WQI at different periods in 2019 would still meet level I standard of the evaluation standard for WQI, and the water quality at high water level period will be best, while the water quality at low water level period will be worst, which will maintain the same variation trend like past. By ARIMA prediction results, the water quality pattern changes in the future are quite similar to the previous variation trend, which demonstrates the water quality condition will still be influenced by WLF, and reveals a difference at outflow in TGR between flood season and non-flood season.

5. Conclusion

The present study analyzed the water quality of outlet water in the TGR after the TGD completed. Water quality parameters, such as DO, COD_{Mn}, and NH_3–N at different water levels were evaluated. WQI and ARIMA model were applied to assess and predict the water quality. The anti-season operation of the reservoir's water levels created the largest WLF zone in the world, which varied from 145 to 175 m above mean sea level. Internal pollution release in the WLF zone are originated from agricultural activity, shipping, and sewage disposal. The WLF becomes a significant factor for water quality parameters, which can influence the water velocity and impoundage for the water body.

Results of water quality parameters evolution showed that contend of DO was highest when water level was high, and lowest when water level was low. The concentration of DO had a positive relationship with water level, and a negative relationship with run flow. The content of COD_{Mn} and NH_3–N were lowest at high water level and highest at low water level period. The concentration of NH_3–N had a negative relationship with water level. Results of WQI assessment demonstrated that the water quality remained clean at different periods, and the water quality was best at high water level. The predicting outcomes of ARIMA model showed that, in the future, each water quality parameters contend will meet level I or II of National Standard of Environmental Quality (GB3838-2002), and the water quality condition will still remain clean.

Overall, this study provides crucial insights between hydrologic and water quality for TGR. Research results are useful for explicating an overview of water resource and water quality of TGR. Further studies should be carried out to spatial difference of water quality, spatial distribution of point and no-point source of pollution, and dominant factors which affect water quality. Mass of water quality data and long-term observation on a time scale and spatial scale are also needed to make a further evaluation for TGR water quality.

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