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Application of Single Factor and Multi-Factor Pollution Indices Assessment for Human-Impacted River Basins: Water Quality Classification and Pollution Indicators

Gebrehiwet Reta*(**), Xiaohua Dong*(**)†, Zhonghua Li*, Huijuan Bo*(**), Dan Yu*(**), Hao Wan*(**) and Bob Su****(*)**
*China Three Gorges University, College of Hydraulic & Environmental Engineering, Yichang, 443002, China
**Hubei Provincial Collaborative Innovation Center for Water Security, Wuhan, 430070, China
***Comprehensive Law Enforcement Bureau for Protection of Water Resources in the Huangbaihe River Basin, Yichang, Hubei, 443005, China
****University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), 7500 AE Enschede, The Netherlands
†Corresponding author: Xiaohua Dong

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ABSTRACT

Anthropogenic activities are most likely to alter the natural composition of waters. Extensive phosphate mining in Huangbaihe River Basin (HRB), China, has resulted in the reduction of the self-purification capacity of freshwater reservoirs in the basin. Based on a three-year (2014-2016) water quality monitored data and the application of three pollution index assessment (PIA) methods: Single Factor Pollution Index (SFPI), Nemerow' Pollution Index (NPI), and Water Quality Index (WQI), the main objective of this study was to determine the water quality standards of surface water in the river basin. Research findings indicated that a holistic approach, a combination of a single factor and multi factor pollution indexes (MFPIs) method was able to distinguish pollutant characteristics and used to classify water quality of the river system. Comparison of the results showed that the SFPI classification is more conservative and highly influenced by the worst evaluated index. On the other hand, the MFPIs: the NPI and the WQI methods classified the water quality into a more reasonable grade because they integrate the effects of different impacting factors. The most impaired pollutants affected the water quality classification were total phosphorus (TP) and total nitrogen (TN). Application of the PIA result for the water quality management purpose in the basin showed that there is a direct causal relationship between the TP concentration and water quality of reservoir water; low water quality reservoirs were correlated with high TP. On the other hand, the reservoir water quality did not show any significant dependence on TN. A linear regression equation was proposed to determine WQI of reservoirs' water using measured TP. The equation may be used to characterize the pollution level of reservoir water for prioritizing water quality management measures in HRB.

INTRODUCTION

Water is the essential substance for survival of all forms of living beings on the earth. Freshwater from streams, rivers and lakes is a finite resource, essential for human existence (Adeosun et al. 2016). Freshwater, however, is increasingly under threat mainly due to anthropogenic influences such as population growth, unmanaged industrialization and accelerated urbanization etc., which are directly induced by human activities (Huo et al. 2014). As knowledge about the importance of water, especially freshwater for human beings and aquatic life is increasing, the need to understand water quality is also increasing (Kannel et al. 2007). Many ecologists and environmental scientists are striving to find management solutions to global environmental issues, including environmental pollution and contamination, ecosystem health, and climate change (Siddig et al. 2016). Different methods have been developed and applied to characterize water quality. Kowalkowski et al. (2006) used multivariate techniques to assess water quality of Brda river, Poland; Gürsoy (2016) applied remote sensing technology to classify water quality of Kizilirmak River's water, Turkey; and Zhu & Hao (2009) proposed fuzzy neural network to classify surface water quality in Suzhou, China. However, neither of these methods has a predefined evaluation criteria to control the analysis. Predefined evaluation criteria is helpful for the comparison of experimentally determined parameters with existing guidelines and may also be useful for checking legal compliance.

The best approach for water quality classification is using application of Pollution Index Assessment (PIA) methods (Mazurek et al. 2017). PIA method is an assessment method based on the physical and chemical properties of monitoring data and the application of index assessment method. The monitoring data, divided by the evaluation criteria, provides sub-indices that can be used as a water quality evaluation scale (Meng et al. 2015). PIA method can be divided into Single Factor Pollution Index (SFPI) and Multi-Factor Pollution Indices (MFPI) based on the number of evaluation projects selected by the monitoring data (Zhang et al. 2017). The SFPI method is one of the most recently applied pollution assessment methods used in different studies such as water pollution assessment (Yan et al. 2015) and heavy metal pollution assessment (Wang et al. 2013). SFPI analysis can help us to identify the dominant pollutant in a particular region (Singh et al. 2014). However, because contaminants are more likely to have a concurrent effect on the environment, the SFPI method alone may not be adequate for addressing the collective impact of pollutants on the environment (Duodu et al. 2017, Zhang et al. 2017). MFPI such as the Nemerow' Pollution index (NPI) (Nemerow 1991) and Water Quality Index (WQI) (Brown et al. 1970) methods can take into account the concomitant effects of different pollutants and are frequently used in pollution and contamination studies (Pesce & Wunderlin 2000, Sánchez et al. 2007). The NPI is used to assess the impacts of several pollutants on a particular water body and to analyse the extent of pollution of a single water quality parameter with reference to the standard values. WQI assessment allowed us to look into more comprehensive water quality indicators such as eutrophication indicators, demand indicators and industrial wastewater discharge indicators (Oliveira et al. 2007). The method has been applied for water quality classification of different regions in China such as Lake Poyang (Wu et al. 2017) and Yellow River, China (Hou et al. 2016) indicating the application of the WQI method for different surface water bodies. Pesce & Wunderlin (2000) applied water quality indices (WQI) to assess the water quality from multiple measured parameters and conclude that the use of WQI could be of particular interest for developing countries, because they provide cost-effective water quality assessment as well as the possibility of evaluating trends.

Based on a three-year (2014-2016) water quality monitoring results and the application of three PIA methods, the main objective of this study was to determine the water quality standards of surface water in Huangbaihe River Basin (HRB). The result of the analysis was related to the management practices by identifying the most sensitive indicators. The identified indicators will be used to identify polluted zones for prioritizing water quality management measures in the river basin.

MATERIALS AND METHODS

Study Area

HRB is one of the tributaries of Yangtze River, China, located between latitudes 31°00'18" N and 31°29'06" N and longitudes 111°03'54" E and 111°27'34" E (Fig. 1). HRB has been serving as first-class drinking water source protection zone with water supply amounting to 775,000 tons per day, serving a population of 2.269 million around Yichang City (Qu et al. 2016). The river has four cascaded reservoirs: Xuanmiaoguan, Tianfumiao, Xibeikou and Shangjiahe located at the upstream, middle stream and downstream of the river basin (Fig. 1). The total storage capacity of the cascaded reservoirs is: Xuanmiaoguan, 40.54×10^6 m^3, Tianfumiao, 64.2×10^6 m^3, Xibeikou, 210×10^6 m^3, and Shangjiahe, 16.46×10^6 m^3.

Phosphate mining in the region is on large scale, covering more than 260 km^2 (28%) of the study area including the four reservoirs (Wang et al. 2016) (Fig. 1). The mining activity includes exploitation, exploration and pre-beneficiation of phosphate ore. Mining effluent and reused process water, which was directly discharged into nearby streams and reservoirs, was the main water quality risk associated to the mining activities in the river basin (Bao et al. 2018, Wang et al. 2016).

Water Quality Sampling and Analytical Procedure

Water samples were collected from twelve stations (Fig. 1), once a month between 2014 and 2015. After 2015, some of the stations were put into an automatic real-time water quality monitoring system (Zhu et al. 2010), therefore, the frequency of water quality data collection was increased to three times a month between 2015 and 2016. Water sample preservation, transportation and analysis were according to the methods stipulated in the State Environmental Protection Administration, China (SEPA 2002) and the Environmental Quality Standards for Surface Water of China (China 2002). Analytical methods of the selected water quality parameters are given in Table 1.

Pollution Index Assessment Method

Single-factor pollution index: The single factor pollution index (SFPI) method is determined according to the principle of maximum membership grade. The category of the most affected assessment factor is used as the comprehensive water quality classification (Ji et al. 2016). The method is simple and convenient and can be used directly to understand the relationship between the water quality status and assessment standards (Ji et al. 2016, Yan et al. 2015).

$$P = (P_i)_{(MAX)} \qquad ...(1)$$

Where, P is classification of surface water body (at the location of water use, or station) according to (China 2002), P_i is classification of parameter i, $(P_i)_{\max}$ is the maximum

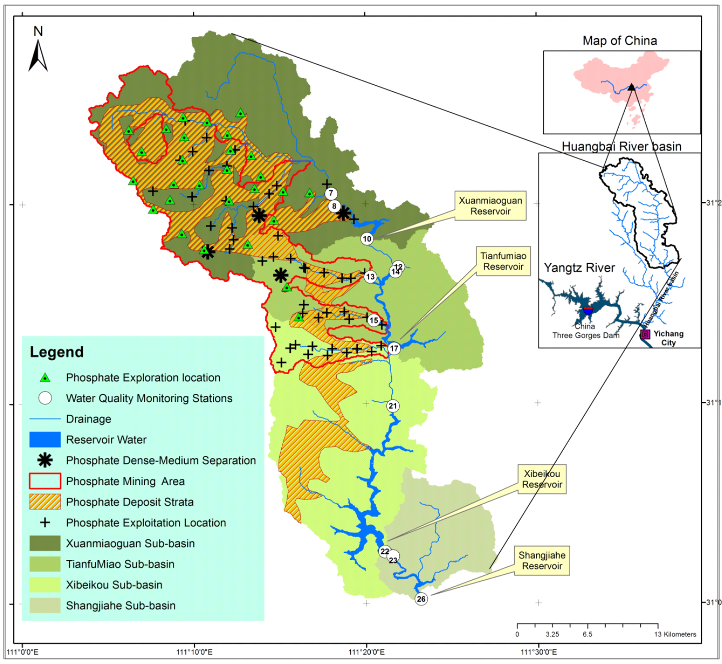

Fig. 1: Location map of monitoring stations and mining infrastructures: Stations 7 and 8 are stream water quality stations located in Xuanmiaoguan reservoir watershed, stations 12, 13, 14 and 15 are stream water quality stations located in Tianfumiao reservoir watershed, stations 21 is stream water quality station located in Xibeikou reservoir watershed, stations 23 is stream water quality station located in Shangjiahe reservoir watershed. Monitoring stations 10, 17, 22, and 26 are reservoir water quality stations located at the outlets of Xuanmiaoguan, Tianfumiao, Xibeikou, and Shangjiahe reservoir respectively.

classification for all the parameters (the most polluted parameter)

Nemerow' pollution index: NPI has been proposed by Nemerow (1971) on behalf of the US Environmental Protection Agency (EPA). NPI takes the effect of SFPI index into account and is frequently used in water quality assessments around the world (Ji et al. 2016, Liu et al. 2017). The mathematical formula of NPI has the form (Nemerow 1971):

$$NPI=\sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n}P_i\right)^2+\left[(Pi)_{MAX}\right]^2}{2}} \qquad ...(2)$$

Where, NPI is the Nemerow Pollution Index; n is the total number of water quality parameters; P_i is the relative pollution index of parameter i; and $(P_i)_{\text{MAX}}$ is the maximum classification for all the parameters.

$$P_i = \frac{C_i}{C_o} \qquad ...(3)$$

Where, C_i is the measured value of parameter i and C_o is the permissible level of i at location of water use, P_i is the relative pollution contributed by the water quality parameter i.

For cases where contaminant level decreases in value as pollution increases such as DO, the relative value is computed as follows.

$$P_{DO} = \frac{\left|C_{DOf} - C_i\right|}{C_{DOf} - C_o} \qquad ...(4)$$

Where, C_{Dof} is the maximum value that DO can attain (dissolved oxygen concentration level at saturation).

For the case where the contaminant has permissible level ranging from C_o min to C_o max, such as pH,

$$P_{PH} = \left(C_i - \frac{\left[\frac{(C_o)_{\min} - (C_o)_{\max}}{2}\right]}{(C_o)_{\max}} \right) \qquad ...(5)$$

Weighted arithmetic water quality index: The water quality index method was initially developed by Horton (1965) in the United States under the supervision of Environmental Protection Agency EPA. Recently, many modifications have been considered for WQI concept through various scientists (Tyagi et al. 2013). The weighted arithmetic water quality index method, hereafter, the water quality index (WQI), ranges from clean (0-25), slightly polluted (26-50), moderately polluted (51-75), heavily polluted (76-100), and seriously polluted (≥100) (Tyagi et al. 2013). The method has been widely used in different studies (Bora & Goswami 2017, Rao et al. 2010) and the calculation of WQI was made by Brown et al. (1972) using the following equation:

Table 1: Analytical methods and water quality parameters.

Parameters	Abbreviation	Units	Analytical methods	Detection limit
pH	pH	mg/L	Glass electrode	-
Dissolved Oxygen	DO	mg/L	Iodimetry (Modified Winkler method)	0.2
Permanganate Index	COD_{mn}	mg/L	Acidic potassium permanganate method	0.5
Biological Oxygen Demand	BOD_5	mg/L	Five days incubation test	2.0
Ammonium Nitrogen	NH_4^+	mg/L	Auto discrete analyzer	0.025
Total Phosphorus	TP	mg/L	Molybdenum blue method	0.01
Total Nitrogen	TN	mg/L	Ultraviolet spectrophotometer method	0.05
Fluoride	F	mg/L	Fluoride selective electrode method	0.02

Table 2: Standard surface water quality classification criteria.

Water quality grade	Clean	Slightly polluted	Moderately polluted	Heavily polluted	Seriously polluted	Reference
(GB 3838-2002)	Class I	Class II	Class III	Class IV	Class V	(China 2002)
NPI	< 0.7	0.7 ≤ NPI < 1.0	1.0 ≤ NPI < 2	2 ≤ NPI < 3.0	≥ 3.0	(Yan et al. 2015)
WQI	0-25	26-50	51-75	76-100	≥ 100	(Tyagi et al. 2013)

Table 3: Surface water quality standard in China (GB 3838-2002).

DO	pH	F	CODmn	BOD5	NH4+	TPS	TPR	TN	(GB 3838-2002)
≥ 7.5	6.0-9.0	≤ 1.0	≤ 2.0	≤ 3	≤ 0.15	≤ 0.02	≤ 0.01	≤ 0.2	Class I.
≥ 6.0	6.0-9.0	≤ 1.0	≤ 4.0	≤ 3	≤ 0.5	≤ 0.1	≤ 0.025	≤ 0.5	Class II.
≥ 5.0	6.0-9.0	≤ 1.0	≤ 6.0	≤ 4	≤ 1.0	≤ 0.2	≤ 0.05	≤ 1.0	Class III
≥ 3.0	6.0-9.0	≤ 1.5	≤ 10	≤ 6	≤ 1.5	≤ 0.3	≤ 0.1	≤ 1.5	Class IV
≥ 2.0	6.0-9.0	≤ 1.5	≤ 15	≤ 10	≤ 2.0	≤ 0.4	≤ 0.2	≤ 2.0	Class V

TPS = TP from streams, TPR = TP from reservoirs and lakes

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \qquad ...(6)$$

Where, q_n = Quality rating of the nth water quality parameter, W_n = Unit weight of the nth water quality parameter.

Quality Rating Calculation (q_n)

$$q_n = [(V_n - V_i)/(S_n - V_i)]X100 \qquad ...(7)$$

Where, V_n is the measured value of the nth water quality parameter at a given sample location; V_i is the ideal value of the n^{th} water quality parameter in pure water; S_n is the permissible level of the n^{th} water quality parameter (V_i = 7 for pH; V_i = 14.6 mg/L for DO; and V_i = 0 for all other parameter (Rao et al. 2010).

Calculation of unit weight (W_n)

The unit weight (W_n) is calculated using the expression

$$W_n = K/S_n \qquad ...(8)$$

Where, S_n is the standard permissible value of n^{th} water quality parameter; and K is the constant of proportionality calculated as:

$$K = \left[1 \Big/ \sum_{n=1}^{n} \frac{1}{S_n} \right] \qquad ...(9)$$

Assessment Criteria

The Environmental Quality Standard for Surface Water China (China 2002) referred to as (GB 3838-2002), applies to all usable surface waters within the territory of China. According to (GB 3838-2002) standards, surface water bodies are classified from Class I to Class V, analogous to clean to seriously polluted water source. Class I is mainly applicable to the water from sources, and the national natural reserves; Class II is mainly applicable to first class of protected areas for centralized sources of drinking water; Class III is mainly applicable to second class of protected areas for centralized sources of drinking water; Class IV is mainly applicable for industrial use; and Class V water bodies mainly applicable for agricultural use. Generally, water quality Class I-Class III is described as “good” and Class IV-Class V is described as “poor” and water quality worse than Class III is no longer suitable for drinking water. The environmental quality standards (Table 2) are taken as the assessment criteria in this research. The level Class III of (GB 3838-2002) is taken as the convenient permissible limit (see S_n, Equation 7) for the evaluation of surface water status in HRB (Yan et al. 2015). Data analysis was conducted using SPSS V20 (Norušis 1986).

RESULTS

The single factor pollution index (GB 3838-2002) result: The result of eight experimentally determined parameters pH, DO, COD_{mn}, BOD_5, NH_4^+, TP, TN and F were compared with water quality standards for surface waters in China (GB3838-2002), (Table 3), to determine the water quality classification for each water quality parameter. The station average concentration value was used for the water quality assessment. The worst individual evaluated pollutant, based on the (GB3838-2002) guidelines establish the water quality grade for the station (Table 4).

According to the (GB 3838-2002) and the monitoring results (Table 4) the water quality at the monitoring station can be classified as Class IV (33%) and Class V (67%), indicating the worst water quality grades in China surface water quality standard (China 2002). Out of the eight water quality parameters considered for this study, the most impeach parameter is TN.

Numerous pollution index results: The Numerous Pollution Index (NPI) was calculated for all parameters (Table 1) at the twelve monitoring stations (Fig. 1). The first step was to calculate the relative pollution index (pi) of each parameter according to Equation 3. The second step is to calculate NPI according to Equation 2. The Pi result indicated that all monitoring locations were under various degrees of pollution during the monitoring period (Table 5). The dominant water quality classification according to the NPI analysis was Class III (except station 22 which was Class II). The most impaired parameter triggering NPI was again TN.

Water quality index analysis result: The Water Quality Index (WQI) was calculated for all parameters (Table 1) at the twelve monitoring stations (Fig. 1). The first step in the WQI calculation was to estimate the 'unit weight' assigned to each parameter considered in the calculation (Table 6). By assigning unit-weights, different units and dimensions used by each parameter is transformed to a common scale. From the unit weight assignment (Table 6), it can be observed that the maximum weight, i.e., 0.571 is assigned to TP, which marks that the key significant parameter in the water quality index assessment was TP.

The WQI analysis result is presented in Table 7. According to this result, water quality standared at the monitoring station can be classified as Class II (25%), Class III (50%), and Class IV (25%). The contribution of the individual pollutant was calculated based on the relative pollution of individual parameters and the total pollution from all parameters (Table 7). Result indicated that TP influenced classification of 67% of monitoring stations (Stations: 8, 10, 13, 14, 15, 17 22 and 26), and TN influenced classification of 33% of monitoring stations (Stations: 7, 12, 21 and 23) (Table 7) emphasized the role of TP to the water quality variation in HRB.

DISCUSSION

Water quality classification of Huangbaihe river basin: The Environmental quality standard for surface water (GB 3838-2002) (Table 3), is the basis to provide indexes need to be controlled and the limits for water quality in China (China 2002). The SFPI is the basic criteria for the evaluation of (GB 3838-2002) in China (Zhang 2017).

The SFPI classification result (Table 4) indicated that the water in the river basin is generally "poor", 33% of monitoring stations were classified as Class IV (heavily polluted) and 67% of monitoring stations were classified as Class V (seriously polluted) implies the water quality requires treatment before use for drinking water supply. Out

Table 4: Single factor pollution index classification result.

Stations	pH	DO	COD_{mn}	BOD_5	NH_4^+	TP	TN	F	(GB 3838-2002) Classification
7	8.459,I	9.136,I	0.978,I	2.86,I	0.094,I	0.068,II	1.76,V	0.386,I	Class V
8	8.509,I	8.849,I	2.08,II	3.232,III	0.223,II	0.084,II	1.531,V	0.34,I	Class V
10	8.543,I	9.015,I	1.466,I	2.736,I	0.097,I	0.037,III	1.31,IV	0.374,I	Class IV
12	8.423,I	9.153,I	1.233,I	2.853,I	0.117,I	0.046,II	1.676,V	0.37,I	Class V
13	8.44,I	9.087,I	1.087,I	2.94,I	0.107,I	0.082,II	1.17,IV	0.506,I	Class IV
14	8.465,I	8.957,I	1.557,I	2.69,I	0.151,II	0.068,II	1.297,IV	0.378,I	Class IV
15	8.523,I	9.05,I	1.159,I	3.3,III	0.125,I	0.108,III	1.566,V	0.329,I	Class V
17	8.518,I	8.928,I	1.755,I	2.945,I	0.114,I	0.04,III	1.701,V	0.35,I	Class V
21	8.555,I	9.025,I	1.525,I	2.802,I	0.115,I	0.036,II	1.484,IV	0.29,I	Class IV
22	8.459,I	8.926,I	1.498,I	2.928,I	0.082,I	0.03,III	1.569,V	0.27,I	Class V
23	8.346,I	9.14,I	1.487,I	2.847,I	0.106,I	0.034,II	1.513,V	0.301,I	Class V
26	8.339,I	8.937,I	1.78,I	2.879,I	0.097,I	0.029,III	1.755,V	0.279,I	Class V

In the column pH: The value "8.459,I" represented; 8.459 is the station average and I is the classification result, Class I

Table 5: Nemerow pollution index classification result.

St	Relative pollution index (P_i)							NPI
	pH	COD_{mn}	BOD_5	NH_4^+	TP	TN	F	
7	0.114,I	0.25,I	0.563,II	0.069,I	0.225,I	1.81,III	0.303,I	1.329, III
8	0.111,I	0.549,II	0.854,II	0.389,I	0.601,II	1.65,III	0.366,I	1.255, III
10	0.127,I	0.285,I	0.716,II	0.109,I	0.836,II	1.455,III	0.346,I	1.103, III
12	0.082,I	0.317,I	0.775,II	0.195,I	0.366,I	1.932,III	0.212,I	1.425, III
13	0.112,I	0.150,I	0.75,II	0.16,I	0.911,II	1.703,III	0.389,I	1.280, III
14	0.115,I	0.276,I	0.689,II	0.217,I	0.341,I	1.611,III	0.392,I	1.202, III
15	0.105,I	0.250,I	0.808,II	0.136,I	0.683,II	2.078,IV	0.241,I	1.535, III
17	0.125,I	0.331,I	0.748,II	0.090,I	0.706,II	1.617,III	0.313,I	1.211, III
21	0.129,I	0.327,I	0.732,II	0.136,I	0.202,I	1.378,III	0.231,I	1.029, III
22	0.098,I	0.217,I	0.663,II	0.061,I	0.700,II	1.163,III	0.245,I	0.884, II
23	0.096,I	0.512,II	0.808,II	0.052,I	0.245,I	2.27,IV	0.362,I	1.665, III
26	0.095,I	0.366,I	0.695,II	0.126,I	0.373,I	1.75,III	0.399,I	1.299, III

Table 6: Water quality index: Unit weight calculation result.

Parameters	(GB3838-2002) Standard permissible value (Sn)	Ideal value of the parameter in pure water (Vi)	Unit weight (Wn)	% Parameter Contribution
pH	7.500	7.000	0.015	1.524
DO	5.000	14.6 00	0.023	2.286
COD_{mn}	6.000	0.000	0.019	1.905
BOD_5	4.000	0.000	0.029	2.857
NH_4^+	1.000	0.000	0.114	11.429
TP	0.200	0.000	0.571	57.143
TN	1.000	0.000	0.114	11.429
F	1.000	0.000	0.114	11.429
$\sum W_n = 1.000$				

of the eight parameters considered TN, TP and BOD_5 were influencing the water quality classification but TN was the worst evaluated parameter determining the total water quality classification in the river basin. Evaluation of the different results (Table 4) showed that the SFPI classification is more conservative and highly influenced by the worst evaluated index while the effect of the other factors is concealed. In many cases, application of SFPI for water quality assessment may be helpful for the comparison of the experimentally determined parameters with existing guidelines and may also be useful for checking legal compliance. However, because the method only considers the single most significant factor, it is limited in its ability to characterize the total conditions of surface water quality. SFPI has been applied to different big rivers in China such as Haihe River Basin in 2006 (Liu et al. 2010) and Wen-Rui Tang River in eastern China (Ji et al. 2016), however, there were also criticisms that the method is aiming at overprotection of water use function (Yin & Xu 2008).

For an area like the HRB where large parts of the watershed is affected by extensive human activities such as the phosphate mining (Fig. 1) (Bao et al. 2018; Wang et al. 2016), a number of elements are expected to co-exist and their negative impacts often result from the combined effects between them (Brady et al. 2015). The SFPI do not adequately reflect the synergistic effect of multiple-pollution factor (Duodu et al. 2017). As multi factor pollution indicators (MFPIs), the NPI and WQI were used to assess the impacts of several pollutants on a particular water body and to analyse the extent of pollution of a single water quality parameter with reference to the standard values. The NPI method compromised between the worst evaluated pollutants (the effects of the SFPI) and the average evaluated pollutants in a weighted environmental quality index (Ji et al. 2016), therefore, each station index reflects both the highest relative evaluated value and the average of all relative values. The NPI results (Table 5) indicated that the river water is generally Class III (moderately polluted). The most impaired pollutants triggering water quality grade was TN. The NPI and SFPI were applied to analyse the water quality

Table 7: Water quality index analysis result.

Station	Contribution of parameters for the total pollution								WQI
	pH	DO	COD_{mn}	BOD_5	NH_4^+	TP	TN	F	
7	4.480	1.599	0.476	1.607	0.793	12.857	20.686	3.464	45.962,II
8	4.389	1.656	1.045	2.439	4.449	34.349	18.852	4.184	71.362,III
10	1.774	0.525	0.200	0.754	0.460	70.434	6.127	1.456	81.729,IV
12	3.657	1.636	0.603	2.214	2.223	20.917	22.082	2.417	55.750,III
13	4.419	1.627	0.286	2.143	1.831	52.077	19.467	4.442	86.293,IV
14	4.510	1.548	0.526	1.968	2.481	19.457	18.414	4.475	53.379,III
15	4.236	1.631	0.476	2.309	1.549	39.049	23.749	2.758	75.757,IV
17	1.752	0.489	0.232	0.787	0.379	59.469	6.808	1.317	71.234,III
21	4.876	1.435	0.622	2.092	1.558	11.529	15.744	2.639	40.496,II
22	1.493	0.434	0.152	0.697	0.255	58.947	4.897	1.031	67.906,III
23	4.023	1.501	0.975	2.309	0.590	13.983	25.943	4.137	53.461,III
26	1.471	0.559	0.257	0.732	0.529	31.394	7.368	1.682	43.992,II

Table 8: Summary water quality classification result of Huangbaihe river basin.

Stations	Pollution Index Assessment			Highest grade	Lowest grade
	SFPI: (GB 3838-2002)	NPI	WQI		
7	Class V	Class III	Class II	Class II	Class V
8	Class V	Class III	Class III	Class III	Class V
10	Class IV	Class III	Class IV	Class III	Class IV
12	Class V	Class III	Class III	Class III	Class V
13	Class IV	Class III	Class IV	Class III	Class IV
14	Class IV	Class III	Class III	Class III	Class IV
15	Class V	Class III	Class IV	Class III	Class V
17	Class V	Class III	Class III	Class III	Class V
21	Class IV	Class III	Class II	Class II	Class IV
22	Class V	Class II	Class III	Class II	Class V
23	Class V	Class III	Class III	Class III	Class V
26	Class V	Class III	Class II	Class II	Class V

of Taihu Lake, China (Xu et al. 2014) and found that the NPI method was more suitable for reflecting the comprehensive situation of water quality. However, neither of them were ready to give an overall view of the spatial and temporal trends in the overall water quality nor do they allow all stakeholders to receive information on the overall water quality (Debels et al. 2005; Tomas et al. 2017).

The WQI provides overall summaries of water quality and potential trends on a simple and scientific basis (House 1990; Kaurish & Younos 2007). The WQI classification results indicated that 75% of water in river is classified as "good" and can be applied for drinking water supply purpose. The most impaired pollutants with the highest contribution to the WQI classification at the monitoring stations were: TP influenced the classification of 67% of monitoring stations and TN influenced the classification of 33% of monitoring stations (Table 7), marks that the key significant parameter to the water quality classification was TP. The spatial trend of water quality in the four sub basin of HRB (Fig. 1) is analysed in (Fig. 2). According to the result, the water quality status in HRB has a downstream increasing trend corresponded with a decreasing trend of TP in the river and reservoirs water (Fig. 2).

Water quality classification results of HRB based on the three PIA methods is summarized in Table 8. The summarized results indicated that water in the river basin can be classified from highest grade Class II to lowest grade Class V. Comparison of water quality standards in HRB with similar river basins in different parts of China, the statistical analysis result by Xia et al. (2011), showed that 66% water quality in China is within (Class I- Class III), 18% within (Class IV-Class V) and 16% are still under the worst water quality (below Class V). A national survey of seven major rivers in China in 2012 demonstrated that water quality measurements in 12.3% of 577 monitored sections were below Class V (Huo et al. 2014). The same survey of 177 major lakes in China, carried out in 2010, revealed the same result that 3% of lakes were oligotrophic, 45% mesotrophic, and 52% of lakes eutrophic; the three major lakes including Lake Tai, Lake Chao and Lake Dianchi are the most pol-

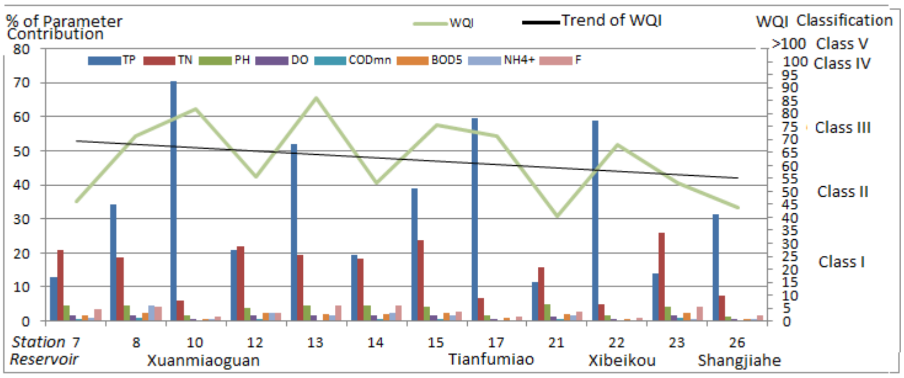

Fig. 2: Spatial trend of water quality in Huangbaihe River Basin.

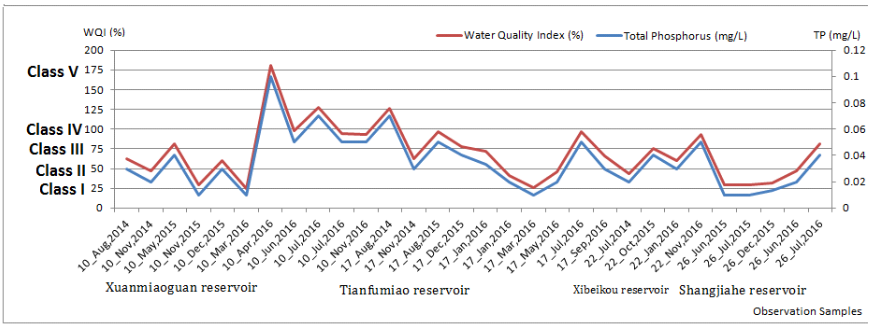

Fig. 3: Spatial variation of the water quality index (WQI) and total phosphorus (TP) at the four reservoirs; Xuanmiaoguan (station 10), Tianfumiao (station17), Xibeikou (station 22), and Shangjiahe (station 26).

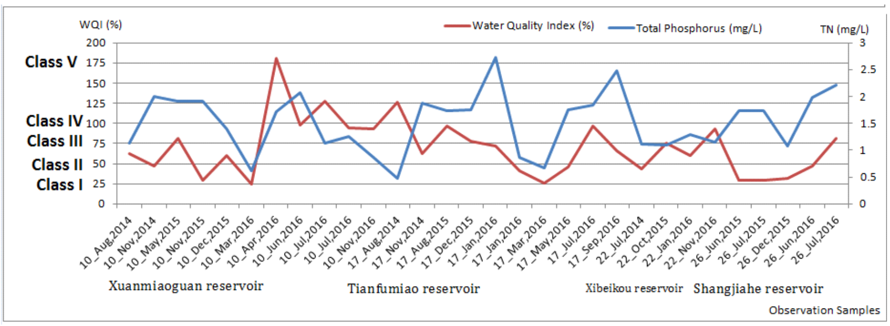

Fig. 4: Spatial variation of the water quality index (WQI) and total nitrogen (TN) at the four reservoirs; Xuanmiaoguan (station 10), Tianfumiao (station17), Xibeikou (station 22), and Shangjiahe (station 26).

luted with water quality below Class V (Jiang 2009). This indicated that our present findings are in agreement considering the general water quality standard in China. Cheng et al. (2009) observed that main rivers in China have a similar pollution structure, mostly associated with industrial discharge and municipal wastewater.

Water pollution indicators in Huangbaihe river basin: Key surface water pollution problems identified in a river basin, lead to the need of developing a surface water quality indicator system (Oliveira et al. 2007). Therefore, management strategies can be best considered within a single region/single system (Liu et al. 2017). The most important finding of the assessment results was that the nutrients TN and TP were extremely high and influencing the water quality classification.

The main purpose of this analysis is to investigate if there is any relationship between the WQI, TP and TN and the location of monitoring stations and to apply that relationship for water quality management in the river basin. In order to explore these relationships, WQI was calculated for samples with a common date of sampling and location for TP and TN. All the samples were selected from reservoir water samples (did not include stream water samples). The reason why we prefer to use only reservoir monitoring stations is because the water in the reservoirs are stagnant, thereby allowing the long term accumulation of nutrients in sediments, resulting in a long response time after runoff from the mining watersheds. Conversely, stream and river monitoring stations have a faster response to changes in nutrient loads due to shorter residence time and thus are less important for this analysis.

The analysis results (Fig. 3) showed that the spatial variation of water quality (in terms of WQI) in the reservoir water was closely related to the amount of TP concentration in the reservoirs. A linear regression equation between the WQI and TP concentration at the reservoirs (Equation 10) revealed that there is a strong linear correlation ($r^2 = 0.995$) between the WQI and TP of reservoirs water; low water quality monitoring stations (high WQI values) are correlated with high TP zones. On the other hand, the reservoir water quality did not show any significant dependence (Fig. 4) on TN ($r^2 = 0.001$). This is because of the TN concentrations in the monitoring stations were not significantly different across the reservoir's water.

$$WQI = 1680.8*TP + 11.476 \quad ...(10)$$

Where, WQI is the water quality index in (%) and TP is total phosphorus in (mg/L)

One of the characteristics of indicators is that the indicator must characterize the main water protection problems, being sensitive to management actions, so that its values may reflect the political and management measures undertaken (Oliveira et al. 2007). Therefore, although TP and TN were identified as the most impeached pollutants due to their strong sensitivity to the water quality, i.e. we see a direct causal relationship between TP and water quality of the reservoirs, therefore, TP concentration and the WQI method can be used to identify the most severely polluted zones for prioritizing water quality management measures in HRB.

CONCLUSIONS

The current knowledge of the pollution index assessment (PIA) approach for water quality classification of highly human-impacted river system is limited. Anthropogenic activities are most likely to alter the natural composition of the water. We have applied three methods, SFPI, NPI and WQI for surface water quality classification of a mining affected river basin in China. We found that the holistic approach, a combination of a single factor and multi factor pollution index methods, was able to distinguish pollutant characteristics and used to classify water quality of the river system. Evaluation of the different results showed that the SFPI classification is more conservative and highly influenced by the worst evaluated index. On the other hand, the NPI and the WQI methods classified the water quality into more reasonable grades because they are integrating the combined effects of different indices.

Application of the PIA result for the water quality management purpose in the basin, found that there is a direct causal relationship between the total phosphorus (TP) concentration and water quality of reservoir water; low water quality monitoring reservoirs (high WQI values) were correlated with high TP concentration reservoirs. On the other hand, the reservoir water quality did not show any significant dependence on TN. Therefore, TP concentration and the WQI method can be used to characterize polluted zones for prioritizing water quality management measures in HRB.

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