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Application of Composite Water Quality Identification Index on the water quality evaluation in spatial and temporal variations: a case study in Honghu Lake, China

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Abstract Composite Water Quality Identification Index (CWQII) and multivariate statistical techniques were used to investigate the temporal and spatial variations of water quality in Honghu Lake. The aims are to explore the characteristics of water quality trends in annual, monthly, and site spatial distribution and to identify the main pollution factors. The results showed that the values of CWQII increased from 2.0 to 4.0 from the years 2001 to 2005, then decreased from 2006 and kept a balance between 2.0 and 3.0 from 2006 to 2011, indicating that the water quality of Honghu Lake deteriorated from 2001 to 2005 and has gradually improved since 2006, which were likely achieved after water protection measurements taken since 2004. The monthly change rules of water quality were influenced by a superposition of natural processes and human activities. In samples numbered 1–9 from upstream to downstream, the maximum values of CWQII often occurred in sample site 9 while the minimum ones often occurred in sample site 2, indicating that the water quality near the upstream tributary was the poorest and that in the core zone was the best. Incoming water from the trunk canal of the Sihu area upstream was the largest pollution source. The sensitive pollution nutrients were mainly caused by the total nitrogen, followed by the total phosphorus.

Keywords Honghu Lake · Composite Water Quality Identification Index · Spatial and temporal · Box plots · Correlation with algal bloom

Introduction

Over the past few decades, water pollution has become a growing threat to human society and natural ecosystems, especially for lake pollution (Semiz and Aksit 2013). Regular implementation of monitoring programs has been recognized to be the essential step to characterize and control lake water pollution (Xu et al. 2012). However, many monitoring programs result in large and complicated data sets, consisting of physical, chemical, biological, and microbiological properties, which are difficult to analyze and interpret due to the latent interrelationships among parameters and monitoring sites. Therefore, it is necessary to extract meaningful information from the data set for effective lake water quality management. Water quality assessment is an important aspect for evaluating the spatial and temporal variations

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of water quality due to the natural or anthropogenic inputs of point and nonpoint sources. From the many water quality assessment methods proposed, the dominating ones include the following: (1) the poorest index selection method based on the environmental quality standard for surface water (EQSSW) (SEPA 2002), (2) pollution index method (Liu et al. 2011), (3) fuzzy evaluation method (Yilmaz 2007), and (4) neural network method (Xue and Liu 2004). These methods are used extensively in China to evaluate water quality, but they also have shortcomings; they are unable to determine whether the composite water quality achieves the environmental functions of surface water (EFSW) or identify which water quality parameters exceed the Chinese national standards (Xu 2005). In addition, few of the methods can quantitatively evaluate the water quality, and the results can be somewhat conservative, such as in the poorest index selection method. The Composite Water Quality Identification Index (CWQII) method, proposed by Xu (2005), depicts water quality both qualitatively and quantitatively by assessing a group of typical items rather than the poorest one. These items combine the national standard comparisons in addition to considering the degree of water quality pollution, and the results can be used to identify the composite water quality grade, the water quality parameters grade, and the EFSW grade. Miao et al. (2009) used this method to evaluate the water quality of Dagu River in Laixi area of Qingdao, China; the results showed that the water quality of this valley reached class III EFSW grade, while the water quality during the wet season was the worst and the water quality of lower reaches was worse than upper reaches. Wang et al. (2007) used the CWQII method to evaluate the water quality of pontoon bridge river reservoir. The results showed that the water quality reached class II EFSW grade, but has a tendency to deteriorate to class III; the main pollution factors were nitrogen and phosphorus. The CWQII assessment may provide an overall understanding of the lake environmental conditions (Chen et al. 2012). In addition, the multivariate statistic method is also used to deal with data sets containing numerous data to explore rules and determine water quality variation trends.

This study uses the CWQII and the multivariate statistic method to explore the characteristics of water quality trends in the annual, monthly, site spatial distribution in Honghu Lake throughout 11 years of monitoring data; the results of which may be used to provide scientific suggestions for lake protection and management in the future. Comparative studies will aid in explaining the differences and similarities in the observed water quality conditions among sample sites, as well as identify the trends and their causes. Collectively, these data may provide insight into how nutrient concentrations have changed over time in the lake, as well as how natural features and human activities have contributed to those changes.

Materials and methods

Study area

Honghu Lake, located at the northernmost area of China's subtropical zones (29° 49 N, 113°17 E as its geographic center), is the largest natural wetland on the Jianghan plain of Hubei Province, with a surface area of 344 km^2 and an average depth of 2 m (Fig. 1) (Yao et al. 2006). The area has a subtropical monsoon climate, rainfall range of 1,100–1,300 mm, and annual mean temperature of 16.3° C (Yang and Cai 1995). Honghu Lake, originally connecting with the Yangtze River, is an obstruction lake which originated from the Yangtze and East Jingjiang Rivers. The lake has been separated from the Yangtze River by several controlling sluices since the 1950s, thus accelerating the natural succession of aquatic vegetation and leading to a reduction of water depth (Wang and Dou 1998). At present, Honghu Lake has become a closed lake with a straight lakeshore and flat bottom and reduced capacities in serving multiple functions, such as water storage, irrigation, fisheries, and navigation (Chen 2001). The ecological environment in the Honghu Lake wetland deteriorated severely from the 1990s to the 2000s due to the rapid population growth and associated human activities, such as cultivation and fishing (Cheng and Li 2006). In order to reduce this deterioration, the Honghu Lake wetland protection and restoration demonstration project has been implemented since 2004. However, have the restoration measures been effective? How is the water quality changing rules in spatial and temporal variations? Which nutrients are sensitive for changing the lake water quality? These questions may only be answered after conducting a scientific investigation of the management and restoration of Honghu Lake.

Data collection

Water samples were collected on either a monthly or bimonthly basis from 2001 to 2011 at nine sampling sites on Honghu Lake (Fig. 1) by sampling the surface water

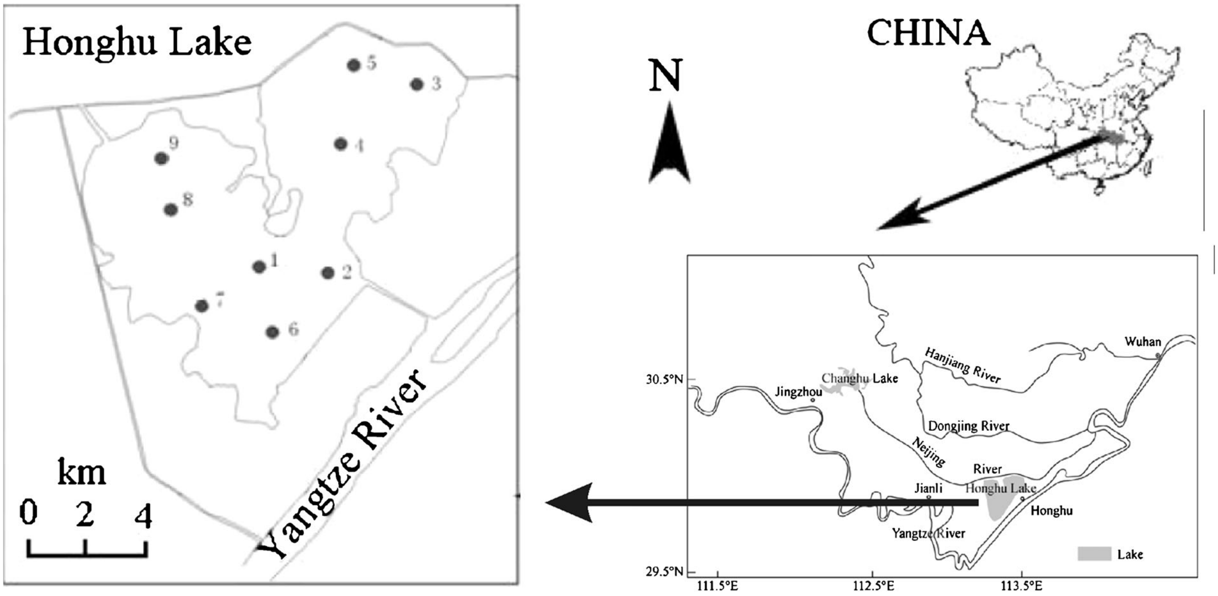


Fig. 1 Study area on map of China and position of the survey points

from 0.5 m below the surface. Considering the physicochemical properties and nutrient constituents as the most important characteristics of the lake water quality (Xu et al. 2012), seven representative parameters were selected, including the dissolved oxygen (DO), chlorophyll-a (Chl), chemical oxygen demand-Mn (COD_{Mn}), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), total phosphate (TP), and transparency. DO, Chl, and transparency were detected in the field using a multiparameter water quality monitoring instrument (Hach DS5, Loveland, CO, USA); others were tested in the environment laboratory of Jingzhou environmental monitor station. COD_{Mn} was measured by the method of permanganate oxidation. TN was measured by persulfate digestion and oxidation-double wavelength (220 and 275 nm) method by a spectrophotometer. NH_4^+-N was determined by Nessler's reagent photometry. TP was analyzed by digestion and a colorimetric method (APHA 1998).

Composite Water Quality Identification Index

The CWQII method is based on EQSSW (Table 1; SEPA 2002), and the Single Factor Water Quality Identification Index (SFWQII) consists of an integer and 2 or 3 digits:

$$CWQII = R_1 \cdot R_2R_3R_4 \tag{1}$$

where R_1 represents the composite water quality grade (Table 2), R_2 is the location of water quality changes in the range of class R_1, and $R_1 \cdot R_2$ is determined by the following equation based on SFWQII:

$$R_1 \cdot R_2 = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} r_1 \cdot r_2 \tag{2}$$

where n is the number of water quality parameters used in the evaluation of the water quality, P_i is the SFWQII, r_1 refers to the water quality grade of the ith water quality parameter (Table 1), and r_2 is determined according to the formula of rounding calculations:

$$r_2 = \left[\left(c_i - c_{ik\mathrm{Low}}\right) / \left(c_{ik\mathrm{Up}} - c_{ik\mathrm{Low}}\right)\right] \times 10 \tag{3}$$

Table 1 Standard value of basic water quality EQSSW items for environmental quality standards for surface water in China (mg/L) (SEPA 2002)

Parameter	Grade of water quality				
	Class I	Class II	Class III	Class IV	Class V
DO	7.5	6	5	3	2
COD_{Mn}	2	4	6	10	15
NH_3-N	0.15	0.5	1.0	1.5	2.0
TP	0.01	0.025	0.05	0.1	0.2
TN	0.2	0.5	1.0	1.5	2.0

EQSSW environmental quality standard for surface water

Table 2 Determination of composite water quality grade (EFSW)

Water quality identification index	Grade of composite water quality	Environmental functions of surface water and targets for its protection for each grade
$1.0 \leq R_1 \cdot R_2 \leq 2.0$	Class I	Mainly for source of water and national nature protection areas
$2.0 < R_1 \cdot R_2 \leq 3.0$	Class II	Mainly for class I protection areas for centralize potable water sources, protection areas for rare fishes, spawning ground for fishes and shrimps and other aquatic animals
$3.0 < R_1 \cdot R_2 \leq 4.0$	Class III	Mainly for Class II protection areas for centralized potable water sources, protection areas for general fishes, and swimming areas
$4.0 < R_1 \cdot R_2 \leq 5.0$	Class IV	Mainly for general industrial water areas and entertainment water areas with no direct body contact
$5.0 < R_1 \cdot R_2 \leq 6.0$	Class V	Mainly for farmland water areas and water areas for general landscape requirements

EFSW environmental functions of surface water

where c_i is the measured concentration of i, $c_{ik\text{Low}}$ is the lower limit value of the class k range, and $c_{ik\text{Up}}$ is the upper limit value of the class k (Table 1).

R_3 is determined according to the result of SFWQII compared with standard values of water quality items in EQSSW (Table 1). The water quality grade (Table 1) is determined by the EFSW of the study area and R_3 is the number of single water quality parameter below EFSW standards. If $R_3=0$, then all functions involved in the evaluation of water quality parameters achieved EFSW standards, and if $R_3=1$, then all those functions failed to achieve EFSW standards.

R_4 is the result of the composite water quality grade compared with EFSW, depending on the pollution degree of composite water quality (Miao et al. 2009). If $R_4=0$, then the composite water quality grade achieves or is better than EFSW; otherwise, $R_4=R_1-f\,(\mathrm{R}_2\neq 0)$ or $R_4=R_1-f-1(R_2=0)$, where f represents the grade of EFSW for the study area.

Statistical analysis method

The box plots were used to assess the dispersion and range of the data trend in the temporal and spatial characteristics. The box plots display differences among the sample points without making any assumptions in terms of the underlying statistical distribution (Sim et al. 2005). The box plots also provide a visual impression of the location and shape of the underlying distributions.

The CWQII was calculated for five representative water quality parameters (DO, COD_{Mn}, NH_3-N, TN, and TP) at each sample point from 2001 to 2011. A total of 2,540 variables were used to calculate the CWQII for all of the 508 monitor sample points. Then, the results were analyzed with the box plots statistical method by using the SPSS® version 11.5 software. There are three steps to plot the box plots for yearly and monthly CWQII values: (1) calculate the median and the quartiles (the lower quartile is the 25th percentile and the upper quartile is the 75th percentile), (2) plot a symbol at the median (or draw a line) and draw a box (hence, the name box plot) between the lower and upper quartiles; this box represents the middle 50 % of the data—the "body" of the data, and (3) draw a line from the lower quartile to the minimum point and another line from the upper quartile to the maximum point. Typically, a symbol is drawn at these minimum and maximum points. The points located outside the ends of the whiskers are outliers or suspected outliers. The spacing between the various parts of the box helps indicate the degree of dispersion and skewness in the data and identify outliers (Frigge et al. 1989).

The percentage diagrams for R_1, R_3, and R_4 in the CWQII were plotted to explore the water quality trend rules in the spatial and temporal variations by using the pivot table in Excel. The pivot table could count the numbers of R_1, R_3, and R_4 in each category.

Results and discussion

CWQII annual change trends

The CWQII was calculated for five representative water quality parameters (DO, COD_{Mn}, NH_3-N, TN, and TP) at each sample point from 2001 to 2011, then the CWQII box charts for the monitor sample points in each year were plotted to observe the changes in the composite water quality in the annual trends. It may be observed that the CWQII outlier value appears in the years 2006, 2008, and 2010 (Fig. 2). The outlier values are those which appear to deviate markedly from the other members of the samples and are often indicative either of measurement error or that the data distribution has a heavy tailed distribution (Sim et al. 2005). These outlier values may be inspected to determine what the reason is (Table 3). The outlier values of CWQII for serial numbers 69, 70, and 219 exceed the class III water quality grade in EQSSW (Table 1); number 69 is located in sample site 1, the center of Honghu Lake and numbers 70 and 219 are located in sample site 9 near the northern inlets of Honghu Lake. It may be found that the TN exceeds most severely and belongs to the class V water quality grade in EQSSW, this is followed by NH_3-N, TP, and COD_{Mn} (Table 3). The outlier value results indicate that the upstream tributary of Honghu Lake easily becomes severely polluted, and this pollution is mainly caused by TN, followed by TP.

The range of the CWQII median value is between the 2.0 and 4.0 (classes II to III water quality grade) (Fig. 2). The annual trends of CWQII show a clear increase from 2.0 to 4.0 from the years 2001 to 2005, then decrease from 2006 and keep a balance between 2.0 and 3.0 from 2006 to 2011. The dispersion of the CWQII shows the highest value in 2005, indicating that the water quality undergoes the greatest change in 2005. These results indicate that the overall trends of water quality are lower than class III, with only 2005 being a special year, when a third of the sample points were the class IV water quality. During the period of 2001 to 2011, 2005 was the year which exceeded the standard most severely. It is referenced that some water protection measurements have been taken to prevent the Honghu Lake wetland from degenerating since 2004 (Mo et al. 2009). These measures include the forbidding of fishing in the core area, restoring aquatic vegetation, wetland habitat rehabilitation, reconstruction engineering, and diminishing the enclosure culture area to reduce the barrier for the water movement within the lake (Li et al. 2013). The results indicate that the protection measurements contribute greatly to improving the water quality of Honghu Lake, which show efficient recovery of the ecosystem functions.

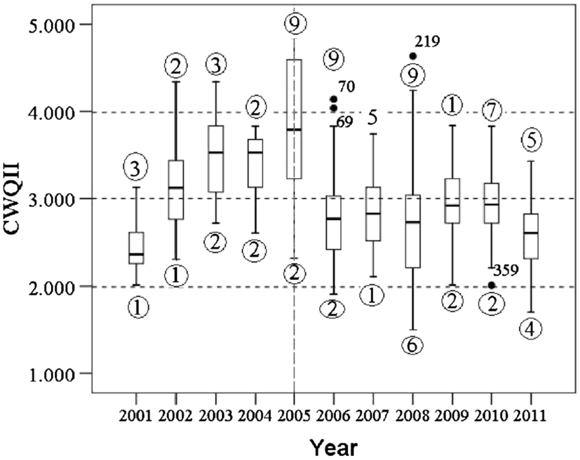


Fig. 2 Annual temporal trends of CWQII. The *numbers in the circles at the top and bottom* of each box chart indicates the sample site numbers of the maximum and minimum values. The *solid black points* indicate the outlier value and corresponding serial number, and the *vertical dashed line* indicates the trend dividing line of the median value of the CWQII

The maximum value of CWQII is between 3.0 and 5.0 (classes III to IV water quality grade), mostly in class III. The maximum value is mostly found in sample site 9, occurring three times, with the frequency there accounting for 27 % of all maximum values; this is followed by sample sites 2, 3, and 5, where the maximum value occurs twice, with a frequency of 18 %. The sample sites showing the least frequent rate are 1 and 7, with only one occurrence, occupying a frequency of 9 %. Sample site 9 is located near the upstream tributary of Honghu Lake, and the upstream water mainly consists of the trunk Canal of Sihu Lake. The water quality is class IV or V most of the time, which is the largest pollution source of Honghu Lake. Sample sites 2, 3, and 5 are located near the bank, where they will be more affected by the human activities; thus, their water qualities are also quite poor. The minimum value of the CWQII is between 1.0 and 3.0 (classes I to II water quality grade), mostly in class II. The minimum value mostly occurs in sample site 2, occurring six times, with a frequency which accounts for 55 % of all minimum values; the second is sample site 1, occurring three times, with a frequency of 27 %; and the third is sample sites 4 and 6, occurring once, with a frequency of 9 %. Sample sites 1 and 2 are both located at the center of the lake, which is also in the core zone of the conservation area. The Honghu Lake Wetland Nature Reserve has very clear divisions in the core zone, buffer zone, and experimental zone. The core zone has the highest coverage of aquatic and beach vegetation. It also has the strongest provision laws for protecting the water quality from human disturbance (Zhang et al. 2012). The results of extreme values indicate that the spatial distribution of

Table 3 Outlier value analysis in the annual box plots

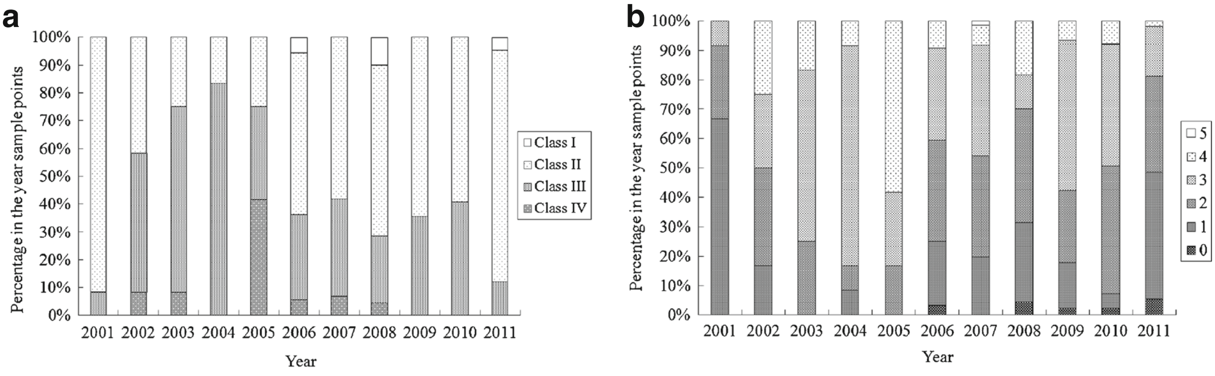
Serial no.	Sample site	Year	$r_1 \cdot r_2$-DO	$r_1 \cdot r_2$-COD_{Mn}	$r_1 \cdot r_2$-NH_3N	$r_1 \cdot r_2$-TN	$r_1 \cdot r_2$-TP	CWQII
69	1	2006	1.0	3.7	5.0	6.0	4.3	4.040
70	9	2006	1.0	3.8	5.2	6.0	4.7	4.141
219	9	2008	2.6	2.7	6.0	6.0	5.5	4.631
359	2	2010	1.0	2.4	2.1	3.1	1.5	2.010

Serial no. refers to the numerical order of all the statistic data for plotting the box charts of Fig. 2, $r_1 \cdot r_2$ refers to the SFWQII

water quality are referenced to the locations, near upstream tributary and banks has poor water quality, the ones near to the core zone has good water quality.

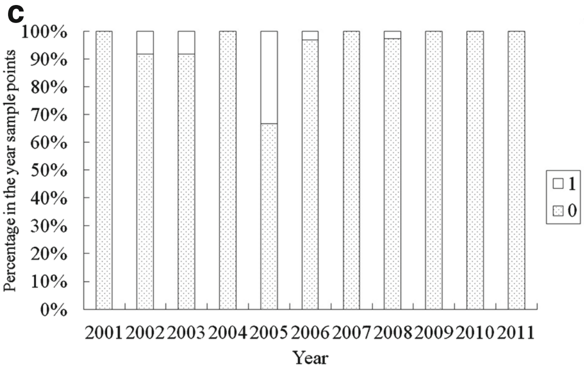
R_1, R_3, and R_4 analyses in CWQII annual trends

The percentage figures are plotted for the monitoring sample points in each year for the three indexes in CWQII to explore the water quality annual trends (Fig. 3). R_1 represents the water quality category in EQSSW. The largest percentage of water quality is class II water quality grade, followed by class III. The percentage of class II water quality decreased from 91.7 to 16.7 % from 2001 to 2005, indicating that the entire lake water quality gradually degraded from class II to III before 2006. In 2005, the largest percentage of water quality was class IV. The results indicate that the overall water quality underwent a deterioration process from 2001 to 2005. Since 2006, the largest percentage of water quality once again returned to the class II water quality grade, and some sites even reached class I. From 2006 to 2011, the class II water quality was mainly in the leading position, and since 2009, the water quality in all the monitored data was above class III, with no class



R_1 annual change trend

R_3 annual change trend



R_4 annual change trend

Fig. 3 Identification index of annual change trends in CWQII

IV water quality. The R_1 results indicate that the water quality has gradually improved since 2006, and that the class II water quality has been mostly in the leading position for all the monitoring points.

R_3 represents the number of the single index which is poorer than the class III EFSW. Two or three items exceeding the standard take large percentage, accounting for 33 % of the total sample points; this is followed by one item exceeding the standard, accounting for 22 %. After plotting the percentage of all water quality parameters which are worse than the class III water quality grade (Fig. 4), it is found that TN is most exceeding the standard water quality parameter, followed by TP, and the last is COD_{Mn}. These results indicate that the water pollution in Honghu Lake is mainly caused by TN, followed by TP. TN is shown to be a critical pollution source for the water quality of Honghu Lake, and the restoration method must focus on reducing the nitrogen source.

R_4 represents the degree of the water quality which is worse than the class III EFSW in Honghu Lake. The years 2002, 2003, 2005, 2006, and 2008 are years which exceed the standard, and the exceeding extent is 1 grade, as a portion of the sample points is class IV water quality. The class IV water quality accounts for 8 % of the total sample points in 2002 and 2003, 33 % in 2005, and 3 % in 2006 and 2008. The year 2005 has the largest percentage of class IV water quality. The R_4 results indicate that the overall trends of water quality are less than class III, and in 2005, only one third of the sample points is class IV, making it the year which exceeds the EFSW standard most severely during the period of 2001 to 2011.

Monthly change trends of water quality

The box charts are plotted with the monthly time axis for each parameter to explore the characteristics of the monthly trends from 2001 to 2011. The CWQII outlier values appear in April, May, June, July, and October (Fig. 5). These outlier values are inspected to determine what the reason is (Table 4). The outlier values of CWQII for serial numbers 9, 10, and 159 all exceed the class III water quality grade in EQSSW; outlier value number 9 is located in sample site 1 and outlier value numbers 10 and 159 are located in sample site 9. All these three points are monitored in May, which is a spring season in Wuhan. Other outlier values of CWQII belong to the class III water quality grade, most of which are located in sample site 9 (see serial numbers 154, 163, and 250), with fewer located in sample sites 7 and 8 (see serial numbers 330 and 336), which are near the upstream inlets of Honghu Lake and the bank of the lake. The results indicate that the upstream tributary of Honghu Lake is likely to experience severe pollution in spring and autumn, and that the pollution source is mainly caused by nitrogen and phosphorus. Because watershed nutrients are the basic source of lake eutrophication, which may originate from many human activities (Keith and Jim 2001). Therefore, the monthly change rules of water quality in Honghu Lake are influenced by a superposition of natural processes and human activities.

The monthly median values of the CWQII mostly range between 2.0 and 3.0 (class II), and only two values in July and October exceed 3.0. The maximum values of

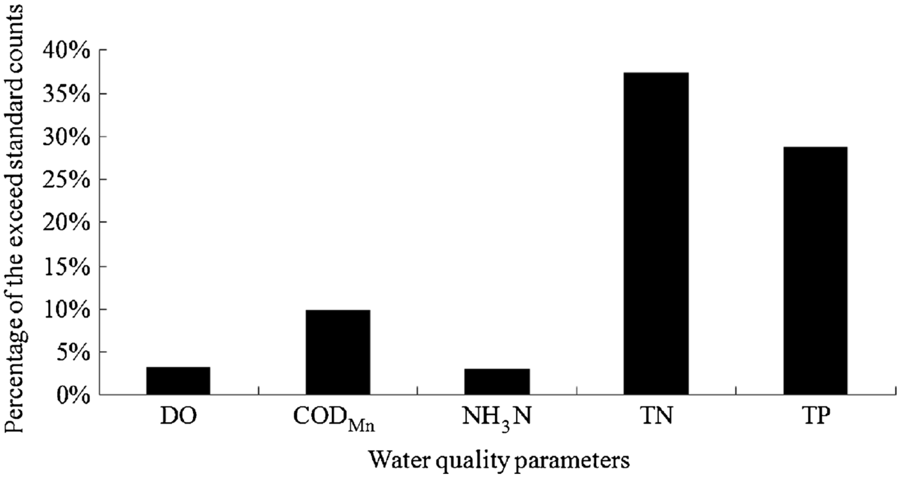


Fig. 4 Percentage of water quality parameters poorer than class III

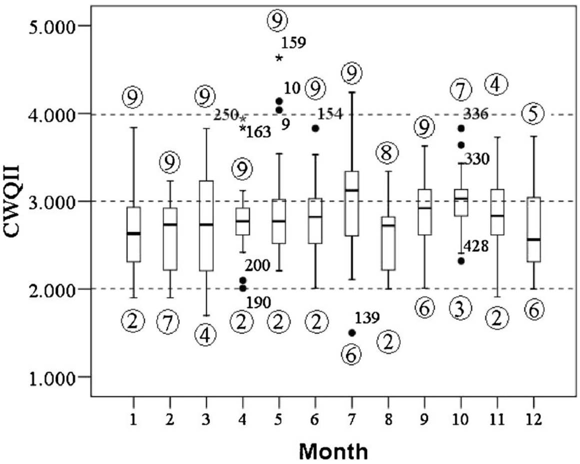


Fig. 5 Monthly temporal trend of CWQII. The *numbers in the circles at the top and bottom* of each box chart indicate the sample site numbers for the maximum and minimum values. The *solid black points and star points* indicate the outlier values and the corresponding serial numbers

the CWQII in all months range between 3.0 and 5.0 (classes III to IV), mostly in class III, with only the one in July exceeding 4.0. The maximum values mostly occur in sample site 9, occurring a total of eight times; the frequency of which accounts for 67 % of all maximum values. The maximum values present an irregular fluctuation trend from January to December; the fluctuation pattern mainly depends on the water quality of the upstream inflow. The maximum value and median both reach the extreme in July, which indicates that July has the poorest water quality of all months.

The minimum values of the CWQII in all months range between 1.0 and 3.0 (Class I to II), mostly Class II. The minimum values mostly occur in sample site 2, occurring a total of six times, with a frequency accounting for 50 % of all minimum values; sample site 6, occurring three times, accounts for 25 % of the total frequency; and the least frequent are sample sites 3, 4, and 7, occurring only once, for a frequency of 8 %. These results indicate that sample site 2 has the best water quality in terms of monthly trend, followed by sample site 6. This is due to the fact that sample sites 2 and 6 are both located at the center of the lake, which is also in the core zone of the conservation area. The minimum values are less than 2.0 from November to March and increase significantly beginning in April, then decrease by May. The minimum values are greater than 2.0 in April, May, July, and October, which indicates that the minimum of water quality has good value during the winter.

The dispersion of CWQII is smaller in April and October, which indicates that the water quality has a smaller variation in these 2 months. The dispersion of CWQII is greater in March, July, and December, indicating that the water quality has a greater variation during these 3 months.

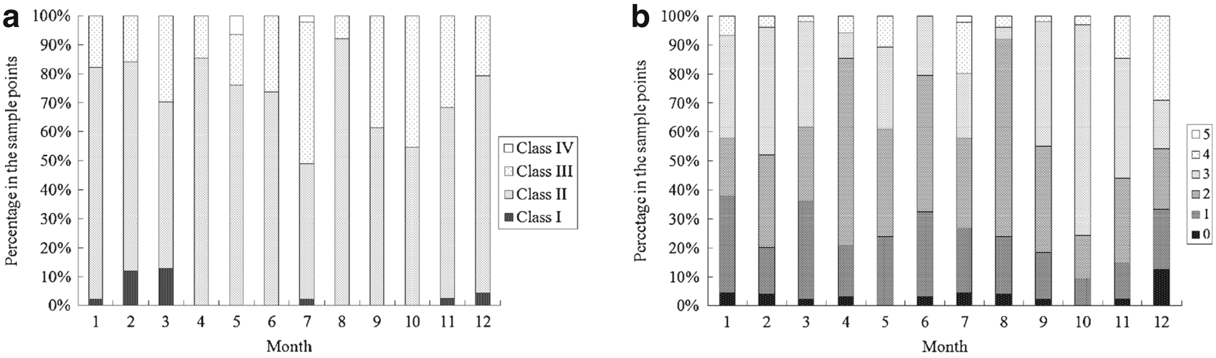
R_1, R_3, and R_4 analyses in CWQII monthly trends

The percentage figures for the monitoring sample points in each month for the three indexes (R_1, R_3, and R_4) in CWQII were plotted to explore the water quality monthly trends (Fig. 6). The largest percentage of R_1 is the class II water quality grade in EQSSW, followed by class III. The percentage of class II water quality presents an irregular variation, and that of the class III water quality presents a regular rule, with the peak values appearing in March, July, and October. The class IV water quality only appears in May and July. These

Table 4 Outlier value analysis for monthly box plots

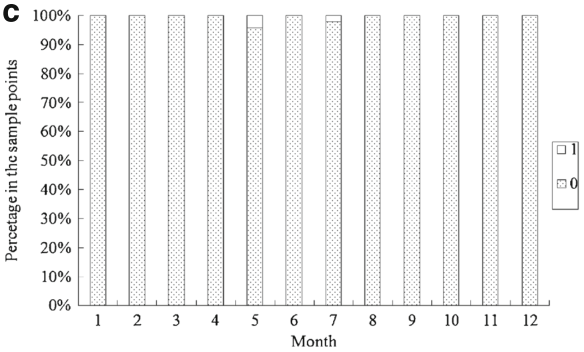
Serial no.	Sample site	Year	Month	$r_1 \cdot r_2$-DO	$r_1 \cdot r_2$-COD$_{Mn}$	$r_1 \cdot r_2$-NH$_3$N	$r_1 \cdot r_2$-TN	$r_1 \cdot r_2$-TP	CWQII
9	1	2006	5	1.0	3.7	5.0	6.0	4.3	4.040
10	9	2006	5	1.0	3.8	5.2	6.0	4.7	4.141
154	9	2008	6	1.0	2.3	4.0	6.0	5.6	3.830
159	9	2008	5	2.6	2.7	6.0	6.0	5.5	4.631
163	9	2008	4	2.5	3.8	3.4	5.5	4.5	3.940
250	9	2009	4	3.4	3.3	3.3	5.8	2.9	3.840
330	8	2010	10	1.0	3.2	3.3	5.7	4.7	3.640
336	7	2010	10	2.3	3.4	3.0	5.9	4.6	3.830

Serial no. refers to the numerical order of all the statistic data for plotting the box charts of Fig. 5, *$r_1 \cdot r_2$* refers to the SFWQII



R_1 monthly change trend

R_3 monthly change trend



R_4 monthly change trend

Fig. 6 Identification index monthly change trends in CWQII

results indicate that the worst water quality appears in July, followed by October. July and October have higher temperatures in Wuhan, as warm water holds less oxygen than cool water. Higher temperatures also decrease the maximum amount of oxygen which may be dissolved in the water if the water receives high amounts of organic matter (Liikanen et al. 2002; Cordoba and Vargas 1996). To a certain point, the higher the water temperature is, the greater the biological activity will be, as the rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity (Steinman and Abbott 2013). So, the nutrients usually get a higher value during high temperature seasons.

Observing the change trend of R_3 in each month, two or three items exceeding the class III EFSW standard take a large percentage, accounting for 33 % of the total sample points; the second is one exceeding standard item, accounting for 22 %. There are five exceeding standard items in July; four in November and December; and three in February, September, and October. These months are the winter and autumn seasons in Wuhan. R_4 in the months of May and July both exceed the standard year, the extent of which is 1 grade, but only a small portion of the sample points are class IV water quality. Among these, the class IV water quality accounts for 2 and 4 % of the total sample points. These results indicate that the overall trends of water quality achieve the class III EFSW, and only a small location in May and July exceeds the standard.

The standard exceeding water parameters of TN and TP present a trend of fluctuations from January to December. TN reaches the peak values in the months of March, April, June, August, and October and TP in July, October, November, and December (Fig. 7). The different change rules of the CWQII in different months involve the combined influences of pollution sources and water self-purification. This shows that a parameter which contributes significantly to lake water quality variation for one season may not be important in another season. Therefore, when selecting the water quality parameters for the establishment of pollutant load reduction goals and the development of total maximum daily loads, it is necessary to consider the seasonal variation of the parameters on lake water quality.

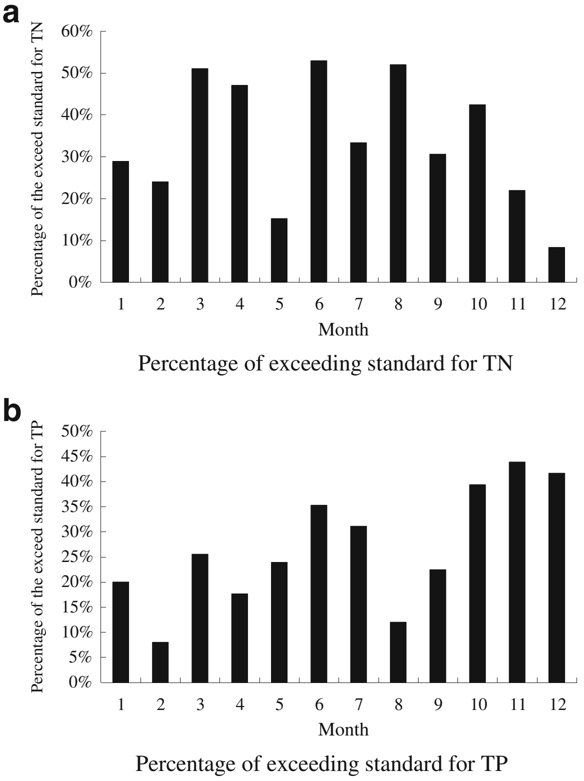


Fig. 7 Percentages of exceeding standard nutrients

Correlation analysis of CWQII with chlorophyll-a and transparency

If it is desired to explore how water quality influences water ecology, then chlorophyll-a and transparency are suitable parameters for representing the water ecology (Kutser et al. 1995). Therefore, the Pearson correlation coefficient is used to explore the relationship of the CWQII with the chlorophyll-a and transparency (Table 5) (Sedgwick 2012). The correlation coefficient between the CWQII and transparency is −0.096. The negative correlation indicates that the larger the CWQII is, the smaller the transparency will be, and it is common sense that poor water quality will result in muddy water. The correlation between CWQII and chlorophyll-a is 0.110. The positive correlation indicates that the larger the CWQII is, the higher the chlorophyll-a level will be, and usually poor water quality will cause an algal bloom. These results indicate that poor water quality will result in lower transparency and higher chlorophyll-a.

Conclusion

The study results provide a consistent description of the spatial and temporal variability of the water quality of Honghu Lake. The water quality deteriorated from 2001 to 2005 and has gradually improved since 2006. The water protection measurements taken since 2004 have contributed greatly to improving the water quality of Honghu Lake, which has shown efficient recovery of its ecosystem functions. The water quality near the upstream tributary was the poorest and that in the core zone of Honghu Lake was the best. The monthly change rules of water quality in Honghu Lake were influenced by a superposition of natural processes and human activities. The water quality in July was the poorest of all months. The overall trends of water quality belong to the class III EFSW, and only a few sample sites exceeded the standard in May and July. The upstream water from the trunk canal of the Sihu area was the largest pollution source of the Honghu Lake. The sensitive pollution nutrients were mainly caused by the nutrients of the TN, followed by the TP. The CWQII has a negative correlation with the transparency and a

Table 5 Pearson correlation coefficient of the CWQII with chlorophyll-a and transparency

		CWQII	Transparency	Chlorophyll-a
CWQII	Pearson correlation	1	−0.096	0.110
	Significance (two-sided test)		0.040	0.022
Transparency	Pearson correlation	−0.096	1	0.061
	Significance (two-sided test)	0.040		0.217
Chlorophyll-a	Pearson correlation	0.110	0.061	1
	Significance (two-sided test)	0.022	0.217	

CWQII Composite Water Quality Identification Index positive one with the chlorophyll-a. The results of spatial distribution analysis show that the nutrient pollution was found to be geographically compact and centered on the inlets and near the bank. The results of this study represent an important reference term for future studies and comparison with other lakes and provide a firm basis for constructing an integrated approach to the management of this complex water ecosystem.

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