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Evaluation of spatial and seasonal water quality variation of urban lake by multivariate statistical approaches for water quality improvement

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ABSTRACT

In addition to water volume, quality is also an important factor affecting the use of water resources, which is greatly related to the development of the modern city. This study was conducted to obtain information on spatial-temporal distribution and major sources of pollutants in an urban lake (Yushan Lake, Ma'anshan City, China). The integrated multivariate statistical approaches, including Pearson correlation analysis, cluster analysis (CA) and principal component analysis (PCA) were utilized to analyze the lake water quality in spring, summer, autumn and winter during 2019. CA revealed the spatial and seasonal variation of lake water quality as well as the correlated parameters. PCA provided the pollution sources via figuring out the predominant factors explaining over 70% of the total variation of the variables. Based on the result of the present study, those sites with significant water pollution as well as the corresponding parameters were identified. Subsequently, the strategy, against specific pollution source was offered to improve the lake water quality.

Keywords: Urban lake; Water quality; Multivariate statistical analysis; Comprehensive evaluation; Spatial-temporal variation

1. Introduction

Surface water, as the major water body, plays a vital role in maintaining ecological stability and supporting socio-economic development [1–4]. However, due to various human activities throughout urbanization and modernization, it has been vulnerable to pollution [5–7]. In general, both natural processes and anthropogenic activities can impair the quality of surface water [8–10]. The discharge of wastewater/runoff, which is accompanied by industrial and agricultural activities, is confirmed as a significant contributor to surface water quality degradation [11–13].

Lake is usually in the service of irrigation, recreation, fishing and even source water. However, its quality has been degraded in many places over the world [14,15]. A large number of studies have been carried out to focus on lake water quality. Wu et al. [16] assessed the water quality of Shahu Lake from China and suggested ways, including circulation accelerating and lake water replenishment, which could be taken to improve the water quality. Wang et al. [17] evaluated the eutrophication and water quality in the estuarine area of Lake Wuli (China) and found the east part of Wuli Lake had worse eutrophication levels and water quality status than other parts. Davraz et al. [18] analyzed the relationship between water quality and hydrogeochemical processes of Salda alkaline lake (Burdur, Turkey), observing the water chemical structure was mainly controlled by the weathering processes and anthropogenic

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inputs. Quan et al. [15] studied the mechanism of anthropogenic actives on water quality change of Baiyangdian Lake in North China between 2006 and 2016 and provided a more thorough understanding of the driving mechanism of water quality change. Those studies on lake water quality are the potential to benefit lake water quality improvement and lake ecological function restoration of a specific area.

To evaluate the water quality, regular monitoring is carried out frequently for water environment management [19,20]. In general, a complex parameter matrix, including designative variables, is available. However, it is uneasy to distinguish the most meaningful information comprehensively attributed to the Spatio-temporal variation of monitoring data among sampling sites [21]. As the credible alternative, the statistical analysis, represented by multivariate statistical analysis (MSA), has been used for water quality assessment of river water, groundwater, lake water and mine water [22–27].

MSA can process a large volume of monitoring data from numerous sites. We can group the monitoring stations based on their similarity of water quality and apportion the pollution sources of regional water bodies [28–30]. MSA technique mainly consists of cluster analysis (CA), principal component analysis (PCA), factor analysis (FA) and discriminant analysis (DA) [31,32], among which CA and PCA are the most popular [33,34]. In order to obtain accurate information, several methods are selected simultaneously as the MSA technique is used in practice. Sebastián Gradilla-Hernández et al. [34] using PCA, CA and DA analyzed the water quality of Lake Cajititlán, Mexico, giving the temporal behavior of water quality associated with seasonal transport pathways of pollutants. Via and CA, DA, PCA and FA, Quan et al. [15] assessed the temporal and spatial variations of water quality and figured out the dominant factors of the variations selected in Baiyangdian Lake. Hatvani et al. [35] investigated the Spatio-temporal changes and drivers of trophic status over three decades in the largest shallow lake in Central Europe by using combined cluster and DA and exploratory PCA. MSA has been proved as a vital technology in regional water environment management.

Recently, the Chinese government is sparing no effort to improve the quality of freshwater with tremendous restoration on lakes and rivers [36]. Under this condition, the water quality evaluation on the surface water environment is of critical importance. This research towards an urban lake from the Yangtze River Basin was aimed to (1) reveal the water quality indicator responsible for spatial and temporal variation, and (2) identify both the main influencing factors of water quality and the pollution sources and (3) provide suggestion on water quality management and improvement.

2. Materials and methods

2.1. Study area and sampling

Ma'anshan City, covering 4,049 km^2 with a population of ~2.30 million, is located in the lower reaches of the Yangtze River, China. Within the subtropical monsoon zone, the city has hot and rainy weather in summer while mild and dry in winter. It is recorded that the annual average temperature and precipitation are 16°C and 1,100 mm, respectively. Yushan Lake, the largest urban lake of Ma'anshan City, from the downtown area is an important landscape. Specifically, the lake has an area of 132.47 ha with a perimeter of 9.87 km and an average water depth of 1.2 m, resulting in a water capacity of 829,800 m^3. Water volume is controlled pronouncedly by the land-based runoff. Yushan Lake connects with the Yangtze River via the Yushan River and the Yongfeng River.

Surface water from a depth of ~20 cm of Yushan Lake was sampled in acid-cleaned, 2 L plastic bottles that were rinsed with surface water beforehand. Data sets consisting of 13 variables from 16 monitoring sites in spring, summer, autumn and winter of 2019 were available for the present study (Fig. 1).

2.2. Water quality analysis

Water temperature (WT), pH, electroconductibility (EC) and dissolved oxygen (DO) were measured in situ by using Multiparameter Water Quality Sonde Method. To ensure the accuracy of monitoring results the sensors were calibrated carefully prior to the test. Other indicators comprising chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), total dissolved nitrogen (DTN), ammonium (NH_4–N), nitrate (NO_3–N), total phosphorus (TP), total dissolved phosphorus (DTP) and orthophosphate (PO_4–P) were analyzed in the laboratory within 48 h after sampling. Filtered samples by GF/F filters (Whatman, Kent Great Britain) were used to determine DTN, NH_4–N, NO_3–N, DTP and PO_4–P. The determination of water quality parameters was carried out based on those methods summarized in Table 1.

2.3. Data analysis

We extracted lake water quality information by integrating multivariable analysis consisting of Pearson correlation analysis, PCA and CA. PCA associated Pearson correlation was used to interpret the relationship among variables as well as the pollution sources, while CA for spatiotemporal variation of lake water quality. PCA and CA were operated by using the data through Z-scale transformation to minimize the influence on the classification due to variable size and measurement unit. All mathematical and statistical analyses were done by using Microsoft Excel (Version 2016) and SPSS (Version 20.0).

3. Results and discussion

3.1. Water quality evaluation

Temperature, DO, pH and EC are commonly basic parameters significantly related to the quality of surface water. SS, COD, nitrogen and phosphorus are typical indicators of water pollution by specific substances. 13 Variables involved in the present study are summarized in Figs. 2–4. The result of the Pearson correlation coefficient among 13 parameters is given in Table 2.

WT can influence various physical, chemical and biochemical processes, causing significant environmental impacts [32]. In this study, WT changed from 8.8°C to 33.7°C.

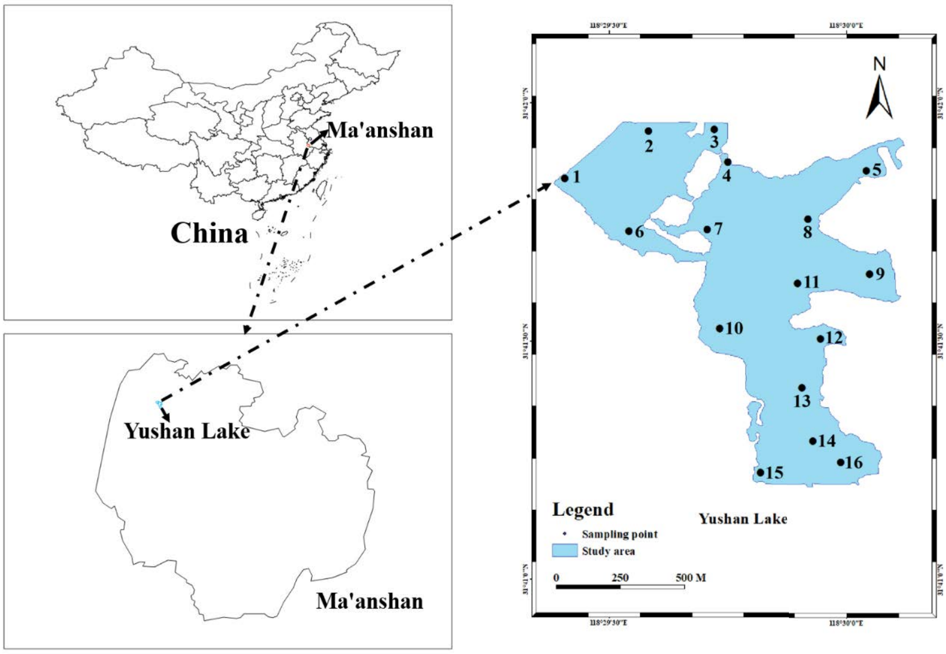

Fig. 1. Sampling sites.

Table 1
Water quality parameters measured and relevant analytical methods

Variables	Analytical methods	Instruments
Water temperature (WT), °C	Multiparameter Water Quality Sonde	SX725 DO/pH Meter (Shanghai San-Xin Instrumentation, Inc., Shanghai, China)
pH	Multiparameter Water Quality Sonde	SX725 DO/pH Meter (Shanghai San-Xin Instrumentation, Inc., Shanghai, China)
Dissolved oxygen (DO), mg L^{-1}	Multiparameter Water Quality Sonde	SX725 DO/pH Meter (Shanghai San-Xin Instrumentation, Inc., Shanghai, China)
Electroconductibility (EC), μS cm^{-1}	Multiparameter Water Quality Sonde	X751 Conductivity Meter (Shanghai San-Xin Instrumentation, Inc., Shanghai, China)
Total suspended solids (TSS), mg L^{-1}	Dryness at 103°C–105°C	XGQ-2000 Electric Blast Drying Oven, (Yuyao Star Instrument Factory, Yuyao, China)
Chemical oxygen demand (COD), mg L^{-1}	Closed Reflux, Titrimetric Method	HACH DRB200 COD Digestion Device (Hach China, Shanghai, China)
Total nitrogen (TN), mg L^{-1}	Potassium Persulfate oxidation	TU-1901 UV-Vis Spectrophotometer (Beijing Purkinje General Instrument Co., Ltd., Beijing, China)
Total dissolved nitrogen (DTN), mg L^{-1}	Potassium Persulfate oxidation	TU-1901 UV-Vis Spectrophotometer (Beijing Purkinje General Instrument Co., Ltd., Beijing, China)
Ammonium (NH_4–N), mg L^{-1}	Nesslerization	L6S UV-Visible Spectrophotometer (INESA Analytical Instrument Co., Ltd., Shanghai, China)
Nitrate (NO_3–N), mg L^{-1}	Phenol Disulfonic Acid Spectrophotometric	TU-1901 UV-Vis Spectrophotometer (Beijing Purkinje General Instrument Co., Ltd., Beijing, China)
Total phosphorus (TP), mg L^{-1}	Potassium Persulfate oxidation	L6S UV-Visible Spectrophotometer (INESA Analytical Instrument Co., Ltd., Shanghai, China)
Total dissolved phosphorus (DTP), mg L^{-1}	Potassium Persulfate oxidation	L6S UV-Visible Spectrophotometer (INESA Analytical Instrument Co., Ltd., Shanghai, China)
Orthophosphate (PO_4–P), mg L^{-1}	Ascorbic Acid Method	L6S UV-Visible Spectrophotometer (INESA Analytical Instrument Co., Ltd., Shanghai, China)

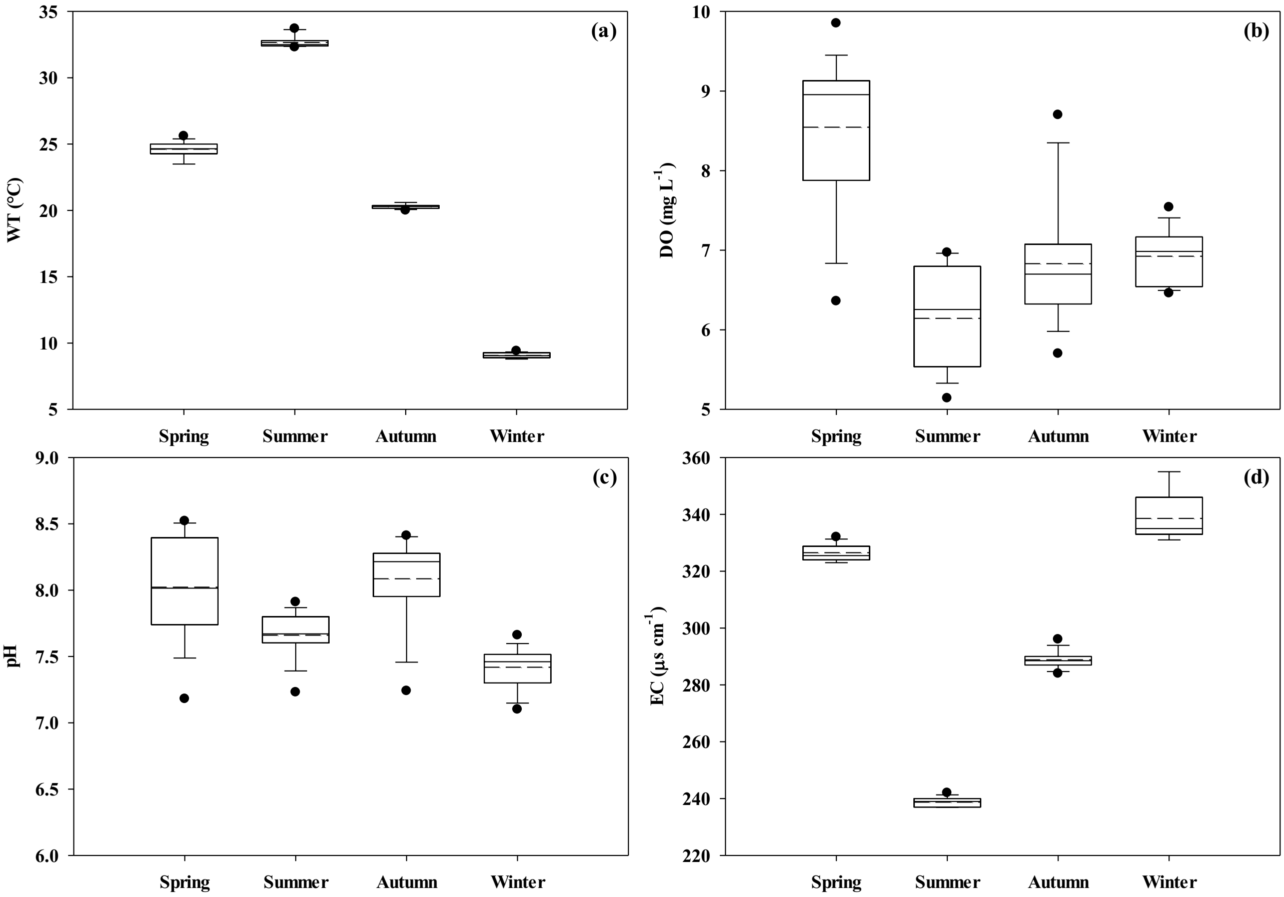

Fig. 2. Water temperature, DO, pH and EC of lake water.

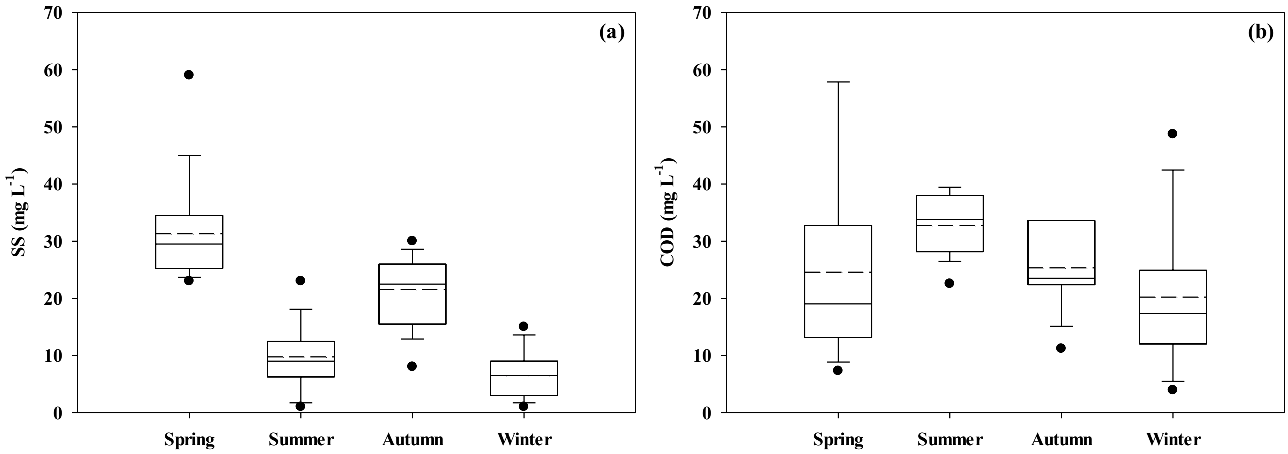

Fig. 3. SS and COD of lake water.

As expected, it had a remarkably seasonal variation with the highest in summer while the lowest in winter. WT had significant relationship with SS, DTN and TP (r = 0.723 for SS, 0521 for DTN and 0.824 for TP, $p < 0.05$) in summer while with pH during autumn ($r = 0.538$, $p = 0.032$).

pH values were observed to vary between 7.10 and 8.52, suggesting the lake water was alkaline, especially during spring. The high pH was detected at Sites 11–15 in spring and at Sites 1–4 in summer. Meanwhile, pH had significantly positive relationship with both WT and SS (r = 0.270 for

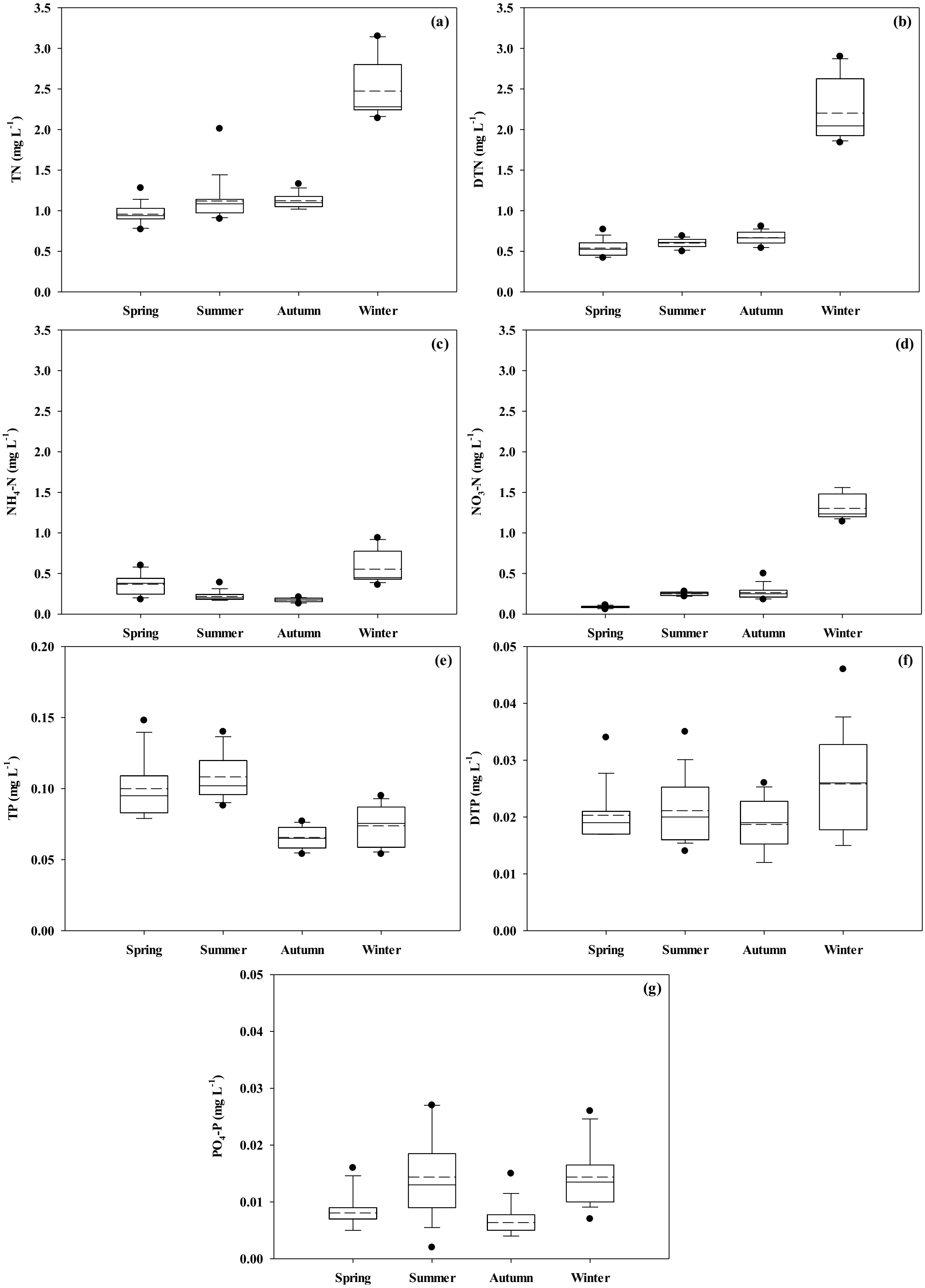

Fig. 4. Nutrients of lake water.

WT and $r = 6.02$ for SS, $p < 0.05$). This indicates that pH and TSS might be affected by the algae growth, related to water temperature. Otherwise, Barakat et al. [32] found pH was negatively correlated with SS in river water.

DO concentrations of Yushan Lake appeared with 6.36–9.85 mg L^{-1} in spring, 5.14–6.97 mg L^{-1} in summer, 5.70–8.70 mg L^{-1} in autumn and 6.46–7.54 mg L^{-1} in whiter, also having an obvious seasonal variation. Specifically, the lowest DO appears at site 2 (5.14 mg L^{-1}) in summer, while the highest at Site 15 (9.85 mg L^{-1}) in winter. The lowest DO level of lake water in summer was attributed to either increased temperature reducing the dissolution of oxygen in water or intensive microorganisms' activity consuming large amounts of DO for organic matter degradation or pollutant transformation [37,38].

EC was observed to have the highest level in winter (338.56 ± 8.45 μS cm^{-1}) followed by spring (326.50 ± 2.78 μS cm^{-1}), autumn (288.81 ± 2.88 μS cm^{-1}) and summer (238.75 ± 1.64 μS cm^{-1}). Meanwhile, it showed an obviously negative correlation with COD while positive with NH_4–N and NO_3–N.

SS concentration had a large range between 1 and 50 mg L^{-1}, with a mean of 31 ± 8 mg L^{-1} for spring, 10 ± 5 mg L^{-1} for summer, 22 ± 6 mg L^{-1} for autumn and 6 ± 4 mg L^{-1} for winter (Fig. 3a). Attributed to low temperatures, the growth of algae was inhibited in winter. Otherwise, in spring with increasing temperature both the growth of algae, causing high SS level. Though algae biomass was significantly higher in summer than in other seasons, daily salvaging for algae reduced SS concentration to some degree. As to autumn, plant litterfall entering the lake increased SS level again.

As the representative of organic matter pollution, COD had values of 3.92 to 71.63 mg L^{-1}, with evidently seasonal variation. Specifically, the highest occurred in summer especially at Sites 5, 7, 12 and 15. Those sites are located near the shore areas, where stormwater was discharged directly. On the other hand, COD had a native relationship with SS, especially in spring ($r = -0.403$), which means that organic matter mainly existed in dissolved forms in the lake.

Nitrogen with various species is given in Fig. 4a–d. TN, DTN, NH_4–N and NO_3–N had the concentrations of 0.77–1.28 mg L^{-1}, 0.42–0.77 mg L^{-1}, 0.18–0.60 mg L^{-1} and 0.06–0.11 mg L^{-1} in spring, 0.90–2.01 mg L^{-1}, 0.50–0.70 mg L^{-1}, 0.17–0.39 mg L^{-1} and 0.22–0.28 mg L^{-1} in summer, 1.02–1.33 mg L^{-1}, 0.54–0.81 mg L^{-1}, 0.13–0.21 mg L^{-1} and 0.18–0.50 mg L^{-1} in autumn, and 2.14–3.15 mg L^{-1}, 1.84–2.90 mg L^{-1}, 0.36–0.94 mg L^{-1} and 1.14–1.56 mg L^{-1} in winter. Surprisingly, they all had the highest level in winter. Furthermore, TN, DTN and NO_3–N occurred with the lowest level in spring. It was found that dissolved nitrogen was the dominant species with the proportion to total nitrogen as 56.57% ± 7.97%, 55.44% ± 9.15%, 59.85% ± 8.21% and 88.77% ± 4.23% in spring, summer, autumn and winter, respectively. The level of nitrogen, especially for dissolved forms, is usually regulated by biological processes. It was found that the water temperature was significantly negatively correlated with TN, DTN, NH_4–N and NO_3–N in this study. So, the conversion/reduction of nitrogen in the lake during winter was depressed by the low temperature. And this is one of the reasons for the lake with the highest nitrogen level in winter.

Fig. 4e–g shows the phosphorus present in the lake water. Different from nitrogen, particle-combined phosphorus was considerable, which accounted for 44.44%–91.67% with an average of 73.61% to the total phosphorus in mass. In summer, TP concentration was the highest due to the contributor of non-point source pollution.

Statistical analysis on those parameters involved in the Chinese Surface Water Quality Guidelines (GB3838-2002) is summarized in Table 3. Despite the strong seasonal variation, the values of pH still were in the range of 6–9, which is required by the Chinese standard. DO has the minimum level of 5.19 mg L^{-1} in summer while the maximum of 9.85 mg L^{-1} in spring, coupled with water quality for the worst-case as class III. Based on averaged COD concentration, the lake water quality can be considered as class IV or V. Both during spring and autumn, TN had a concentration less than 1.0 mg L^{-1}. Therefore, overall, the lake water can be classified as grade III in spring and IV in autumn. While, in winter the concentration of TN was over 2.0 mg L^{-1}, going beyond the limit of class V. During four seasons, NH_4–N changed between 0.13 and 0.94 mg L^{-1}, suggesting the water quality class belonged to I to III. Based on TP, the water quality varied between IV and V depending on sites. On the whole, the water quality of Yushan Lake was class IV in spring, summer and autumn, while poor V in winter.

3.2. Spatial similarity and site grouping

CA is very helpful in sorting out the spatial group based on the water quality similarity of sampling sites. The sites from one group have similar water quality. The results of CA by Ward's methods are available in Fig. 5. For Yushan Lake, 16 sites were grouped into three clusters regardless of the season. Those pollutants present in lake water were derived from external sources (land-based) and internal sources (sediments). The migration of pollutants from sediments was controlled by hydrodynamic and physicochemical conditions of the water environment. The land-based sources, like stormwater, also could not be persistent. Therefore, the contribution of pollution sources varied with season and some sites were grouped into different groups in different seasons. The statistical analysis of water quality data depending on the cluster is given in Table 4.

In spring, with the increased water temperature, the biological activity got intensive. Cluster 1 consisted of Sites 2, 3, 5 and 9, from the stagnant water regions close to the shore with the highest concentrations of COD and DTN, which was related to the leaching of materials from the plant litter (leaves). Cluster 2 was grouped by Sites 1, 4, 6–8, 10, 14 and 15, mainly coming from the places with frequent aquatic activity, coupled with obviously higher values of NH_4–N than Cluster 1. This result is likely due to the washing of mop/clothes of local inhabitants as well as the release from sediments caused by hydrodynamic factors. Cluster 3 included Sites 11–13, 16, having the highest pH, SS and TP. Those sites were within the zone connecting with several ponds, which had bad water quality, near Golden Eagle Business Circle. It represents the effects of the human activities from Yushan Park and business areas on lake water. And the release inside the lake is believed to be the major factor governing the water quality in this season.

Table 2
Pearson correlation coefficient among 13 parameters

	WT	pH	DO	EC	SS	COD	TN	DTN	NH_4–N	NO_3–N	TP	DTP	PO_4–P
WT	1.000												
pH	0.270*	1.000											
DO	–0.096	0.228	1.000										
EC	–0.797**	–0.074	0.524**	1.000									
SS	0.228	0.602**	0.592**	0.199	1.000								
COD	0.365**	–0.046	–0.23	–0.333**	–0.11	1.000							
TN	–0.787**	–0.547**	–0.155	0.516**	–0.559**	–0.183	1.000						
DTN	–0.829**	–0.551**	–0.139	0.578**	–0.543**	–0.189	0.972**	1.000					
NH_4–N	–0.573**	–0.383**	0.204	0.663**	–0.215	–0.192	0.714**	0.759**	1.000				
NO_3–N	–0.825**	–0.565**	–0.216	0.509**	–0.612**	–0.213	0.961**	0.982**	0.690**	1.000			
TP	0.601**	0.016	0.179	–0.324**	0.273*	0.155	–0.250*	–0.296*	–0.028	–0.347**	1.000		
DTP	–0.274*	–0.291*	–0.019	0.227	–0.317*	0.021	0.498**	0.477**	0.478**	0.434**	0.025	1.000	
PO_4–P	–0.043	–0.357**	–0.289*	–0.08	–0.504**	0.186	0.458**	0.421**	0.370**	0.413**	0.082	0.625**	1.000

*correlation is significant at the 0.05 level (2–tailed);
**correlation is significant at the 0.01 level (2–tailed).

Table 3
Statistical analysis on the parameters involved in Chinese Surface Water Quality Guidelines (GB3838-2002)

Class	WT (°C)	pH	DO (mg L^{-1})	COD (mg L^{-1})	TN (mg L^{-1})	NH_4–N (mg L^{-1})	TP (mg L^{-1})
Spring	23.5–25.6 (24.6)	7.18–8.52 (8.02)	6.36–9.85 (8.55)	7.28–71.63 (24.59)	0.77–1.28 (0.96)	0.18–0.60 (0.37)	0.079–0.148 (0.100)
Summer	32.3–33.7 (32.7)	7.23–7.91 (7.66)	5.19–6.97 (6.14)	22.53–39.44 (32.75)	0.90–2.01 (1.12)	0.17–0.39 (0.22)	0.088–0.140 (0.108)
Autumn	20.0–20.6 (20.3)	7.24–8.41 (8.09)	5.70–8.70 (6.83)	11.20–33.60 (25.34)	1.02–1.33 (1.12)	0.13–0.21 (0.17)	0.054–0.077 (0.066)
Winter	8.8–9.4 (9.1)	7.10–7.66 (7.42)	6.46–7.54 (6.92)	3.92–48.72 (20.23)	2.14–3.15 (2.47)	0.36–0.94 (0.55)	0.054–0.095 (0.074)
I	Week increasing in ≤1 Week decreasing in ≤2	6–9	≥7.5	≤15	≤0.2	≤0.15	≤0.01
II		6–9	6–7.5	≤15	0.2–0.5	0.15–0.5	0.01–0.025
III		6–9	5–6	15–20	0.5–1.0	0.5–1.0	0.025–0.05
IV		6–9	3–5	20–30	1.0–1.5	1.0–1.5	0.05–0.1
V		6–9	2–3	30–40	1.5–2.0	1.5–2.0	0.1–0.2

Table 4
Statistical analysis on water quality data depending on cluster (Mean ± STD; Unit: WT, °C; pH, –; others, mg L⁻¹)

	WT	pH	DO	EC	SS	COD	TN	DTN	NH_4–N	NO_3–N	TP	DTP	PO_4–P
Spring													
Cluster 1	24.8 ± 0.8	7.70 ± 0.07	7.09 ± 0.48	329 ± 2	26 ± 3	35 ± 22	0.98 ± 0.07	0.63 ± 0.03	0.31 ± .07	0.10 ± 0.01	0.085 ± 0.006	0.019 ± 0.004	0.009 ± 0.005
Cluster 2	24.4 ± 0.5	7.97 ± .32	9.02 ± 0.40	326 ± 3	29 ± 4	21 ± 13	0.89 ± 0.08	0.50 ± 0.06	0.47 ± .07	0.09 ± 0.01	0.093 ± 0.009	0.022 ± 0.005	0.007 ± 0.003
Cluster 3	24.9 ± 0.1	8.46 ± 0.05	9.07 ± 0.13	325 ± 1	41 ± 11	21 ± 10	1.07 ± 0.13	0.53 ± .14	0.23 ± 0.04	0.07 ± 0.01	0.130 ± 0.014	0.019 ± 0.002	0.008 ± 0.002
Summer													
Cluster 1	32.4 ± 0.0	7.70 ± 0.13	5.80 ± 0.46	239 ± 2	9 ± 3	32 ± 5	1.17 ± 0.33	0.61 ± 0.05	0.21 ± 0.03	0.27 ± 0.01	0.100 ± 0.010	0.024 ± 0.006	0.018 ± 0.006
Cluster 2	32.6 ± 0.2	7.74 ± 0.08	6.51 ± 0.60	238 ± 1	7 ± 4	34 ± 5	1.08 ± .09	0.56 ± 0.04	0.21 ± 0.04	0.22 ± 0.00	0.106 ± 0.006	0.019 ± 0.004	0.012 ± 0.005
Cluster 3	33.4 ± 0.4	7.43 ± 0.16	6.45 ± .46	240 ± 1	17 ± 4	34 ± 5	1.07 ± 0.07	0.66 ± 0.04	0.25 ± 0.10	0.25 ± 0.01	0.136 ± 0.003	0.018 ± 0.001	0.007 ± 0.004
Autumn													
Cluster 1	20.3 ± 0.1	8.19 ± 0.08	6.66 ± 0.52	288 ± 3	23 ± 5	27 ± 5	1.15 ± 0.09	0.69 ± 0.05	0.18 ± 0.02	0.27 ± 0.05	0.067 ± 0.007	0.017 ± 0.004	0.005 ± 0.001
Cluster 2	20.6 ± 0.0	8.40 ± 0.01	6.43 ± 0.19	288 ± 0	17 ± 1	21 ± 7	1.07 ± 0.04	0.71 ± 0.10	0.19 ± .01	0.36 ± 0.10	0.058 ± 0.004	0.018 ± 0.005	0.010 ± 0.004
Cluster 3	20.2 ± 0.1	7.73 ± 0.34	7.34 ± 0.93	291 ± 3	23 ± 7	25 ± 8	1.10 ± 0.09	0.60 ± 0.05	0.15 ± 0.01	0.20 ± 0.02	0.069 ± 0.007	0.022 ± 0.003	0.007 ± 0.002
Winter													
Cluster 1	9.0 ± 0.2	7.50 ± 0.09	6.60 ± 0.14	333 ± 1	11 ± 3	20 ± 12	2.22 ± 0.05	1.95 ± 0.08	0.43 ± .03	1.20 ± 0.03	0.073 ± 0.011	0.019 ± 0.005	0.012 ± 0.002
Cluster 2	9.1 ± 0.2	7.36 ± 0.15	7.19 ± 0.20	335 ± 2	4 ± 3	15 ± 5	2.31 ± 0.08	2.02 ± 0.08	0.45 ± .06	1.24 ± 0.04	0.066 ± 0.012	0.026 ± .006	0.012 ± 0.003
Cluster 3	9.1 ± 0.2	7.43 ± 0.16	6.87 ± 0.28	353 ± 2	6 ± 2	29 ± 14	3.08 ± 0.09	2.84 ± 0.04	0.89 ± 0.04	1.55 ± 0.01	0.089 ± 0.006	0.035 ± 0.007	0.022 ± 0.004

In the downtown area, the control of stormwater has not been put into practice. During summer the influence of stormwater significantly took place. Cluster 1 includes Sites 2–6, 8, 9 and 11, receiving the road runoff from Yushan Park. Those sites had the highest DTP and PO_4–P but the lowest DO concentration. Cluster 2 with Sites 1, 7, 10, 12, 13, corresponding to the lowest DTN level and medium pollution by PO_4–P. While Cluster 3 grouped by Sites 14–16 was related to the discharge of runoff originated from traffic roads. As a result, the highest levels of SS, DTN, NH_4–N and TP were observed.

For autumn, Cluster 1 consisted of Sites 1, 5, 6, 8, 9, 10–12, which are those places with high levels of TN and TP. This was attributed to the soaking of plant litters falling into the lake. Cluster 2 comprised Sites 2–4, arising with the highest pH, NO_3–N and PO_4–P while the lowest COD, TN and TP. This cluster shows the water quality of the northern part with slow water exchange. Cluster 3 containing Sites 7, 13–16 gave the water quality information of those places, with medium contamination by COD, TN and PO_4–P. It can be found that the water quality of the southern part was homogeneous during autumn.

As to winter, the sites were also classified into 3 clusters due to the water quality. Sites 7, 8, 11, 13 and 15 from Cluster 1 represented the water quality from shallow zones with less pollution by nitrogen. Otherwise, Cluster 2 is comprised of Sites 4, 5, 9, 10, 12, 14 and 16 showing the water quality information on deep areas moderately polluted by nitrogen. Cluster 3 consisting of Sites 1–3 and 6 showed the water quality in shallow and relatively isolated areas with heavy pollution brought about by organic matter, nitrogen and phosphorus. In this season, the water quality was mainly determined by the biophysical and chemical processes inside the lake rather than land-based pollution sources.

3.3. Pollutant source identification

Kaiser-Meyer-Olkin (KMO) and Bartlett's Sphericity test were used to check the suitability of data for PCA prior to analysis. As KMO approaches 1, PCA of variables is meaningful; whereas, as it approaches 0, PCA is unsuitable. In the present study, KMO is 0.635. Bartlett's Sphericity test was used to figure out whether the variables are uncorrelated. The significance level was lower than 0.05, indicating that PCA was suitable for variables. In general, PC loadings are categorized as 'strong', 'moderate' and 'weak' corresponding to absolute values of >0.75, 0.75–0.50 and 0.50–0.30, respectively [39]. As shown in Table 5, PCA on four seasons data sets have four PCs for spring and summer, five PCs for autumn and three for winter with eigenvalues >1, explaining 76.83%, 71.08%, 76.57% and 80.02% of the total variance in each respective data set, respectively.

For the spring data set, among four VFs, VF1 accounts for 31.64% of the total variance, with strong positive loading on pH, SS and TP, and moderate positive loading on DO and TN, mainly representing SS and nutrient pollution. The growth of algae in spring, accompanied by the changes of pH, DO, etc. enhancing the release of nutrients from sediments. In addition, VF2 has moderate positive loading on COD, DTN and PO_4–P, which were possibly

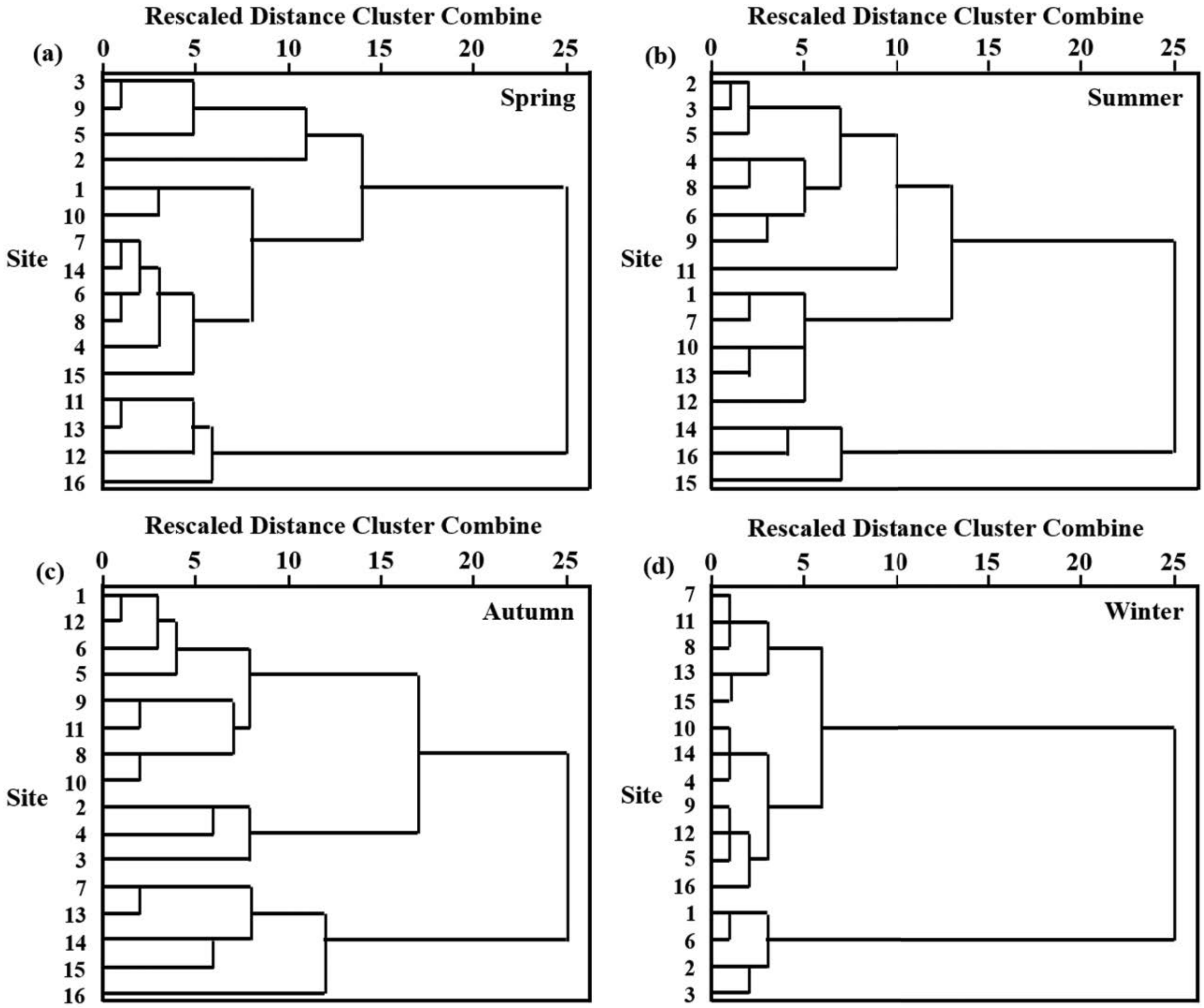

Fig. 5. Dendrogram showing clustering of sampling sites from Yushan Lake.

leached from the degradation of plant debris, previously washed into the lake and accumulated on/in sediments. VF3 is moderately close to EC, which was related to the mineral component of lake water quality.

For the data set of summer, VF1, VF2, VF3 and VF4 explain 31.27%, 14.64%, 13.50% and 11.67% of the total variance, respectively. VF1 has strong positive loading with WT, SS and TP, and VF2 has strong positive loading on NO_3–N. VF1 and VF2 are considered anthropogenic pollution sources because the non-point source pollution got more serious due to the frequent precipitation. VF3 has moderated positive loading on pH and COD, and VF4 on COD and TN, mainly representing organic matter pollution. The input of nutrients enhanced the growth of phytoplankton, which had high biomass in this season. Even though the photosynthesis was strong, DO centration was not high, due to the depletion by increased mineralization of organic matter [40].

As to autumn, the data set was figured out five VFs. VF1 (31.14% of the total variance) having loading on WT, pH and NO_3–N, representing the internal migration and transformation of nitrogen. During the sampling trip, NO_3–N was negatively related to pH while positively with DO, which means that the nitrification might be the important process occurring in the lake. VF3 explaining 11.89% of the total variance, has strong loading on SS, COD, together with VF4 (10.92% of the total variance) governed by COD and TN, attributed to the entrance of plant litter in autumn.

Finally, for the data set related to winter, VF1 explaining 50% of the total variance, has significantly strong loading on EC, TN, DTN, NH_4–N, NO_3–N and PO_4–P, and moderate loading on TP and DTP. VF2 occupying 15.90% of the total variance, is moderately related to pH and SS. Whereas VF3 has strong loading on WT and moderate loading on SS. VF2 and VF3 can explain the mineralization of organic matter using DO, producing suspended solids. Also, the rare precipitation coupled with continuous evaporation resulted in a considerable decrease in water depth. Moreover, the biogeochemical process in the lake was affected by the temperature. Consequently, the phenomenon of high dissolved nutrient levels together with low pH and high EC took place.

3.4. Implication for lake water quality management

Based on the information available from CA and PCA, lake water quality impairment was mainly related to SS, phosphorus and nitrogen pollution, which mainly arose in those places where stormwater was discharged or there was a stagnant area with weak water exchange. In detail, lake water quality was governed by SS and TP at the sites (11–16) grouped into Cluster 3 in spring and summer, NO_3–N at the sites (2–4) from Cluster 2 in autumn, while nitrogen and phosphorus of Cluster 2 (Sites 1–3 and 6) in winter. As a result, the measurement improving water quality is provided in Fig. 6.

Sites 11–14 and 16 are situated on the west edge of a park. Several ditches go across the part introducing land-based plant litter with stormwater into the lake. During both in spring and summer, SS and TP had significant relationship (r = 0.824, p < 0.001 for spring; r = 0.767, p = 0.001 for summer). Therefore, it is suggested to construct ecological engineering in the ditches, eliminating the entrance of phosphorus carried out by stormwater generated from the park. Also, there is a discharge outlet near Site 15 for stormwater from the urban impervious catchment. The input of pollutants can be contained via using post low impact development (LID) strategy. Sites 1–6 mainly represents

Table 5
Loading of variables on significant principal components for seasonal data sets

Variable	VF1	VF2	VF3	VF4	VF5
Spring (four significant components)					
WT	–0.116	0.197	0.247	–0.572	
pH	**0.808**	–0.094	0.027	–0.032	
DO	*0.535*	–0.383	–0.519	0.125	
EC	–0.561	–0.107	*0.603*	0.167	
SS	**0.825**	0.065	0.031	0.209	
COD	–0.349	*0.585*	–0.282	–0.542	
TN	**0.582**	0.459	0.482	0.345	
DTN	–0.196	*0.713*	0.452	0.399	
NH_4–N	–0.378	–0.617	–0.167	0.406	
NO_3–N	**–0.817**	–0.027	0.149	0.274	
TP	**0.878**	0.125	0.222	0.004	
DTP	–0.293	0.392	–0.628	0.436	
PO_4–P	0.022	0.733	–0.6020	0.167	
Eigenvalue	4.113	2.361	2.069	1.446	
% Total variance	31.64	18.16	15.91	11.12	
Cumulative % Total variance	31.64	49.80	65.71	76.83	
Summer (four significant components)					
WT	**0.830**	–0.148	0.018	0.227	
pH	–0.588	–0.411	0.539	–0.030	
DO	0.269	–0.331	–0.622	0.150	
EC	0.354	0.154	0.357	–0.404	
SS	**0.818**	0.389	0.079	–0.266	
COD	0.148	–0.356	0.543	0.542	
TN	–0.290	0.233	–0.458	0.604	
DTN	0.420	0.469	0.271	0.475	
NH_4–N	0.454	–0.005	0.442	0.403	
NO_3–N	–0.231	**0.840**	0.220	–0.158	
TP	**0.897**	0.185	–0.187	0.118	
DTP	–0.542	0.453	–0.215	0.232	
PO_4–P	–0.723	0.281	0.202	0.263	
Eigenvalue	4.065	1.903	1.755	1.517	
% Total variance	31.27	14.64	13.50	11.67	
Cumulative % Total variance	31.27	45.91	59.41	71.08	

(*Continued*)

Table 5 Continued

Variable	VF1	VF2	VF3	VF4	VF5
Autumn (five significant components)					
WT	**0.827**	0.048	–0.249	–0.108	0.238
pH	**0.800**	0.035	0.300	0.024	–0.442
DO	–0.587	–0.468	–0.362	0.147	–0.020
EC	–0.356	0.379	0.198	–0.466	0.590
SS	–0.378	0.154	0.536	–0.041	–0.496
COD	–0.283	0.247	0.606	0.577	0.206
TN	–0.330	–0.237	0.152	0.577	0.451
DTN	0.406	–0.529	0.017	0.042	0.298
NH_4–N	0.620	–0.505	0.073	0.341	–0.083
NO_3–N	**0.785**	0.208	0.144	0.256	0.109
TP	–0.655	–0.222	–0.321	0.163	–0.284
DTP	–0.192	0.653	–0.395	0.480	–0.121
PO_4–P	0.400	0.465	–0.510	0.245	0.027
Eigenvalue	3.918	1.777	1.545	1.419	1.295
% Total variance	30.14	13.67	11.89	10.91	9.96
Cumulative % Total variance	30.14	43.81	55.70	66.61	76.57
Winter (five significant components)					
WT	0.016	–0.433	**0.760**		
pH	–0.031	0.511	–0.713		
DO	–0.042	–0.935	–0.202		
EC	**0.981**	–0.020	–0.043		
SS	–0.101	0.688	0.630		
COD	0.483	0.237	–0.155		
TN	**0.981**	–0.034	–0.018		
DTN	**0.980**	–0.038	–0.090		
NH_4–N	**0.957**	0.082	–0.077		
NO_3–N	**0.961**	–0.089	–0.058		
TP	0.619	0.395	0.359		
DTP	0.740	–0.181	0.213		
PO_4–P	**0.833**	–0.091	–0.007		
Eigenvalue	6.596	2.066	1.741		
% Total variance	50.74	15.89	13.39		
Cumulative % Total variance	50.74	66.63	80.02		

lake water quality of stagnant area during dry the season. Hence, water exchange inside the lake between the stagnant area and the deep-water area should be prompted like optimizing the canal or other measurements. On the other hand, ecological engineering also can be conducted in the stagnant area having Sites 1–6. In addition, the washing activity of residents is taken into the management.

4. Conclusions

With the increasing concern on surface water quality, there is a tremendous need to disclose details of water quality appropriately. In the present study, PCA and CA were integrated to investigate the water quality of Yushan Lake. The major conclusions are as follows:

- The water quality of Yushan Lake had a significant seasonal variation with the heaviest contamination in winter. Overall, the water quality was class IV in spring, summer and autumn, while poor V in winter.
- CA categorized sampling sites into three clusters regardless of the season. In spring the release inside the lake is believed to be the major factor governing the water quality. Due to the lack of stormwater control, the entrance of stormwater from different land-use types affected the water quality deeply over summer. During autumn, leaf litter of trees went into the lake. As it was subjected to soaking, the materials, like nutrients, from plants were leached into the water. As to winter, attribute to the rare precipitation and continuous evaporation, the water volume and depth decreased greatly. Moreover, the

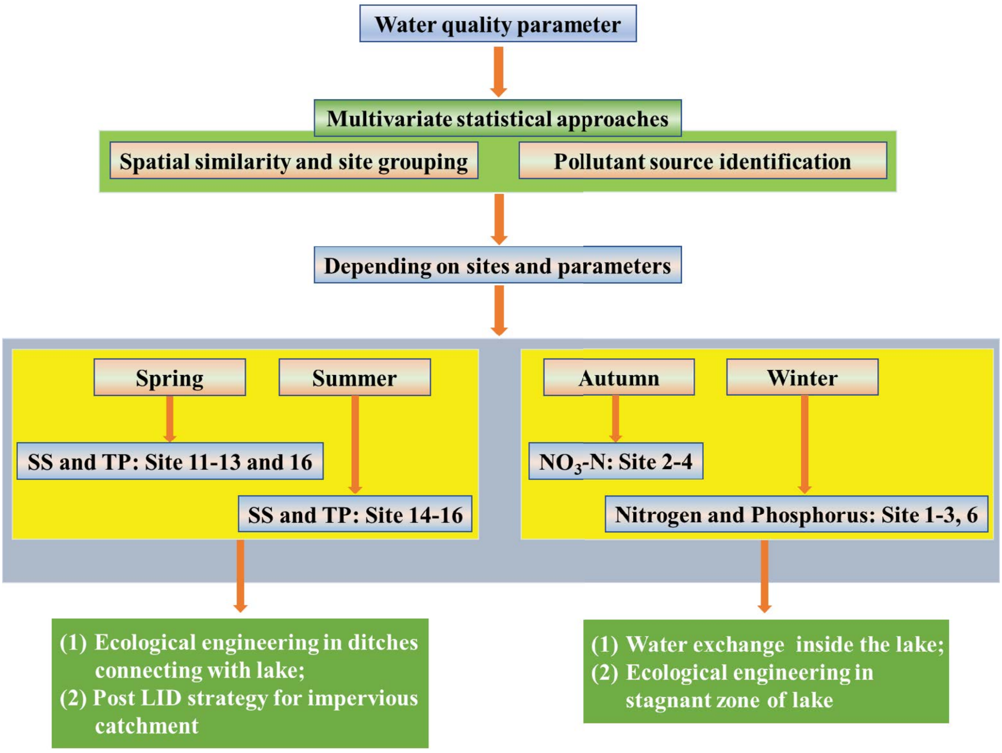

Fig. 6. Strategy improving lake water quality based on multivariate statistical approaches.

biogeochemical process in the lake was suppressed by the low temperature. As a result, a high level of dissolved nutrients was observed.

- Based on the result of multivariate statistical approaches, the strategy to improve the water quality was suggested. Construct ecological engineering in the ditches link with the lake to reduce the input of phosphorus. The post-low impact development strategy should to the taken to contrail the stormwater generated from the impervious areas. Inside the lake, ecological engineering in the stagnant area and the circulation of water also are needed. Also, the plant litter, particularly that from the park, and the washing of residents should be controlled effectively.

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Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that have appeared to influence the work reported in this paper.

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