Available online at www.sciencedirect.com
ScienceDirect
Procedia Environmental Sciences 2 (2010) 868–880
Procedia Environmental Sciences

International Society for Environmental Information Sciences 2010 Annual Conference (ISEIS)

Key Aquatic Environmental Factors Affecting Ecosystem Health of Streams in the Dianchi Lake Watershed, China

YI HUANG [a],*, HANG WEN [a], JIALIANG CAI [a], MANTANG CAI [b], JINHUA SUN [a]

a. College of Environmental Sciences and Engineering, Peking University, 100871 Beijing, P.R. China;
b. School of Government, Peking University, 100871 Beijing, P.R. China;

Abstract

Streams in a lake watershed are important landscape corridors which link the lake and terrestrial ecosystems. Therefore, the ecosystem health of streams is usually used to indicate aquatic biodiversity of the lake ecosystem, as well as being affected by aquatic environmental factors in response to changes in land use cover of the terrestrial ecosystem due to natural geographic characteristics of the watershed with the closure of ridge lines. This study was carried out at a shallow freshwater lake watershed in the Yunnan-Guizhou Plateau of China, the Dianchi Lake watershed (DLW). Field survey of periphytic algal and macrozoobenthic biodiversity during July and August of 2009, as well as monthly monitoring of water temperature, pH, TSS, DO, TN, TP, NH_3N, NO_3N, COD_{Mn}, BOD, TOC, and the heavy metals Zn (II), Cd (II), Pb (II), Cu (II), and Cr (VI) from January to December 2009 was carried out in 29 streams flowing into Dianchi lake. Multivariate statistical techniques such as factor analysis and canonical correspondence analysis were applied to analyze the structure of the aquatic community in relation to aquatic environmental factors in order to provide controlling objectives for integrated watershed management and improvement of stream rehabilitation in the DLW. The results showed that the structure of the periphytic algal and macrozoobenthic communities were dominated by pollution-tolerant genera, namely the bacillariophytes *Navicula* and the annelids *Tubificidae* respectively, and TN, NH_3N and TP were key aquatic environmental factors affecting the ecosystem health of streams in the DLW.

Keywords: lake watershed; water pollution factors; periphytic algae; macrozoobenthos; Lake Dianchi

---

1. Introduction

In a lake watershed, streams are important landscape corridors that link the land and the lake[1]. The ecosystem health of streams is usually used to indicate the aquatic biodiversity of the lake ecosystem, as well as being affected by water pollution factors in response to changes in land use of the terrestrial ecosystem due to natural geographic characteristics of the watershed [2-3]. The closure of ridge lines determines the lake as the sink of the watershed to assemble the discharge of point and non-point source pollutants from the terrestrial ecosystem through streams flowing into the lake. Therefore, streams are ecohydrological channels of the lake watershed to impose anthropogenic stress on the lake ecosystem and eventually to cause the lake eutrophication.

Biological communities reflect overall ecological integrity, integrate the effects of different stressors and provide a broad measure for their aggregate impact [4-5]. Therefore, aquatic assemblages, generally including phytoplanktonic, zooplanktonic, periphytic algal, macrozoobenthic*, fish, and bacterioplanktonic assemblages, have been commonly used as bioindicators for

---

* Corresponding author . Tel/Fax: +86 10 62757867
E-mail: yhuang@pku.edu.cn; wenhangstar@163.com

doi:10.1016/j.proenv.2010.10.098

water quality monitoring to directly assess marine, coastal and estuary, stream, or lake ecosystem health in relation to the water pollution [6-9]. However, there are more advantages of using periphytic algal and macrozoobenthic. For instance, periphytic algal assemblages are sensitive to some pollutants which may not visibly affect other aquatic assemblages, or may only affect other organisms at higher concentrations (i.e., herbicides) [10-11]; macrozoobenthic assemblages provide strong information for interpreting cumulative effects by species that constitute a broad range of pollution tolerances [12]. Hence, it is necessary to identify the key water pollution factors affecting these assemblages in streams of the lake watershed in order to provide controlling action for integrated watershed management and stream rehabilitation activities.

Lake Dianchi watershed (LDW) is a shallow plateau freshwater lake watershed in Kunming City, the capital of Yunnan Province of China. There are 29 streams radially flowing into Lake Dianchi (LD). The water quality of 29 streams continued degrading from the level of drinking water in 1975 to worse than that of landscape-use water in 2009 due to the rapid urbanization and socioeconomic development in the watershed since 1980s, which has resulted in the extinction of fish in all of the streams and annual algal bloom in the LD in the last decade. Numerous studies currently focused on water quality assessment and water pollution control in the LDW paying more attention to the LD [13-16] rather than the streams. Furthermore, seldom information on the correlation of the water pollution factors to the aquatic assemblages in the streams has been published. Therefore, this study intends to figure out the key water pollution factors in 29 streams of the LDW affecting all of the periphytic algal and macrozoobenthic, and then to investigate the relationship of spatial distributions between these assemblages and the integrated water pollution.

2. Methodology

2.1 Site Description

The LDW is located in the middle of the Yunnan-Guizhou Plateau, with a total watershed area of 2920 km^2 and an altitude of 1880 m. Its geographic coordinates are 102°29’ to 103°01’ E in longitude, and 24°29’ to 25°28’ N in latitude. The climate is characterised by a pronounced rainy season from May to October with an annual rainfall of 947mm. The LD is nearly 40.4 km in length from north to south, and 7 km from west to east, with a total area of 309.5 km^2. The 29 streams from north to south are respectively River Wangjiaduiqu (R1), River Xinyunlianghe (R2), River Laoyunlianghe (R3), River Wulonghe (R4), River Daguanhe (R5), River Xibahe (R6),River Chuanfanghe (R7), River Cailianhe (R8), River Jinjiahe (R9), River Panlongjiang (R10), River Daqinghe (R11), River Haihe (R12), River Liujiabaoxianghe (R13), River Xiaoqinghe (R14), River Wujiabaoxianghe (R15), River Xiabahe (R16), River Laobaoxianghe (R17), River Xinbaoxianghe (R18), River Maliaohe (R19), River Luolonghe (R20), River Laoyuhe (R21), River Nanchonghe (R22), River Yunihe (R23), River Laochaihe (R24), River Baiyuhe (R25), River Cixianghe (R26), River DongDahe (R27), River Zhonghe (R28) and River Guchenghe (R29). According to ecohydrological integrity of the LDW, the sampling sites for biosurvey are the same as water quality monitoring selected in the lower reaches of 29 streams, far from 15-20 m of the estuarine region with the LD backwater (Figure 1).

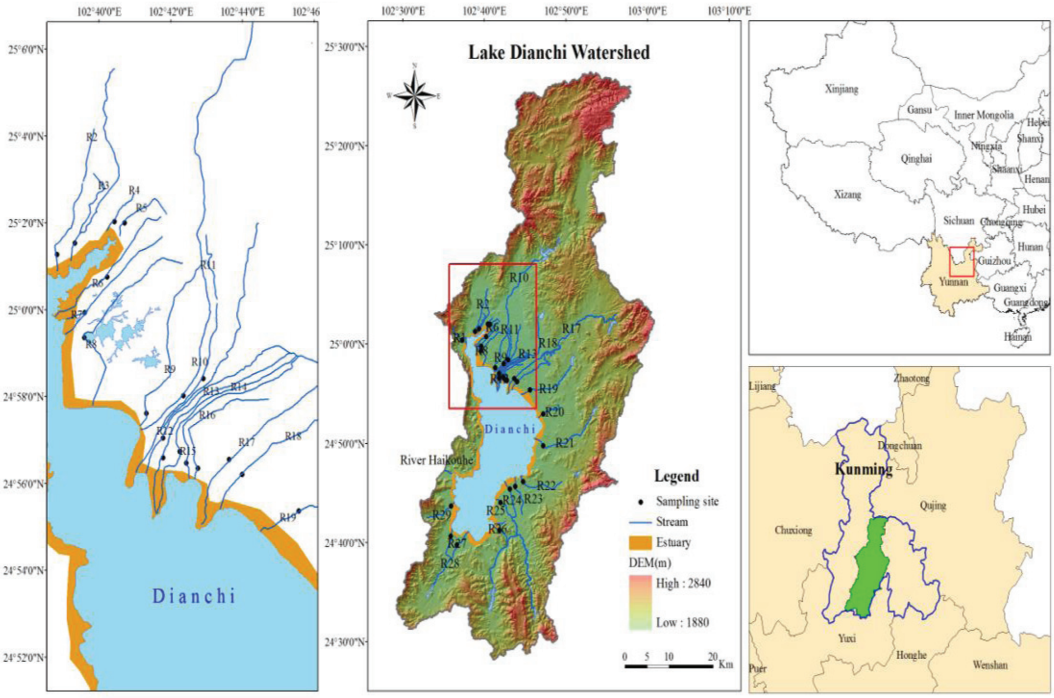


Figure 1 Map of 29 sampling sites in streams of the LDW

2.2 Enviromental data

Water quality monitoring was mensally carried out at 29 sampling sites from January to December 2009. It included 16 physicochemical parameters, which were temperature (WT), pH, total suspended solids (TSS), dissolved oxygen (DO), ammonia nitrogen (NH_3N), total nitrogen (TN), total phosphorus (TP), permanganate indices (COD_{Mn}), biochemical oxygen demand (BOD), nitrate nitrogen (NO_3N), total organic carbon (TOC), and the heavy metals Zn (II), Cd (II), Pb (II), Cu (II), and Cr (VI). Field collection and storage, and laboratory proceeding of water samples followed the procedures of *Surface Water Quality Standards for the People's Republic of China (GB3838-2002)* [17].

2.3 Biological data

Biosurveys of aquatic assemblages during July and August 2009 were carried out at 29 sampling sites, due to the low-latitude plateau monsoon climate causing about 80% of the whole-year precipitation distributed in the wet season during May to October in the LDW.

Periphytic algae investigation and analysis followed the standard laboratory-based approach for multihabitat sampling procedures of periphytic algae with the 15cm×15cm ceramic tiles (artificial substrates) with the surface[18]. By using the wire, the substrates were hung vertically in the streams at about 5-10 cm depth. After 14 days' culturing, the substrates were taken back to the liboratory for analysing. The periphytic algae were collected from the substrate by brushing the surface of the substrate with a stiff-bristled toothbrush into a sample bottle with distilled water. The sample bottles were preserved with Lugols solution. After 24 hours' precipitation, the volume of the samples was set to 30 mL. After 24 hours' standing, 1.2 mL (4%) buffered formalin was added for saving. Sorting procedures were conducted with a stereomicroscope with 20cm×20cm, 0.1mL capacity count box. And the density of periphytic algaewas recorded in the form of the number of algae per square centimeter. All periphytic algae were identified to the genus level according to taxonomic references [19] and [20], because genus provides more accurate information on ecological/environmental relationships and sensitivity to impairment.

Macrozoobenthos investigation and analysis followed the standard laboratory-based approach for multihabitat sampling procedures of macrozoobenthos with a 1/16 m^2 van Peterson grap at each station[18]. All sediment samples for macrozoobenthic identification were washed through a 450μm mesh size sieze and fixed in 7% buffered formalin in 30mL polyethylene bottles. All macrofauna samples were identified to the lowest taxonomic level whenever possible. All macrozoobenthos were identified to the genus level according to taxonomic references [21] and [22].

2.4 Data analysis

There are manymethods of relating species abundance to enviromental data. When various environmental factors have been measured, just like the present study, it is necessary and possible to use multiple regression for the analysis between the multiateral factors.

Factor analysis is a "data reduction" technique that supposes that correlations between pairs of measured variables can be explained by the connections of the measured variables to a small number of non-measurable (latent), but meaningful variables, which are termed factors. FA has been widely used in water research of streams as assessing seasonal variations of water quality and pinpointing pollution sources [23-24]. Therefore, this study opted for principle component analysis and varimax rotation of FA to extract the parameters that were most important in assessing water pollution in streams of the LDW. The statistical analyses were performed by SPSS 17.0.

Detrended correspondence analysis (DCA) was used to dectect the length of the enviromental gradient. After DCA, Canonical correspondence analysis (CCA) was applied because the data set was relatively heterogeneous and the length of ordination axes was relatively long [25]. CCA is one of the main uses of correspondence analysis in ecology, which visualizes a matrix of biological data in relation to a set of concomitant environmental variables, which could be measured on continuous and/or discrete scales [25-26]. To optimise the data for ecological assessment the particular ecology of the taxonomic group should be considered. For periphytic algal and macrozoobenthic species less than 1% to the abundance or less than twice occurrence to the sampling sites were excluded from the analysis; meanwhile, it was also necessary for the canonical eigenvalues and the significance of the relationships between the parameters and the canonical axes tested by Monte Carlo permutations ($p<0.05$), using 499 permulations as implemented in canoco [26]. Hence, this study identified the key water pollution factors in streams of the LDW with CCA, affecting all of periphytic algal and macrozoobenthic assemblages. The statistical analyses were performed by CANOCO for Windows 4.5.

3.Results

3.1 Composition of periphytic algal and macrozoobenthic assemblages

Biosurveys in the wet season totally identified 5 divisions, 18 families, and 24 genera of periphytic algae;and 3 divisions, 7 families, and 8 genera of macrozoobenthos at 29 sampling sites in the study area.

Periphytic algal assemblages consisted of 7 families and 10 genera of Bacillariophyta, 6 families and 7 genera of Chlorophyta, 2 families and 4 genera of Cyanophyta, 2 families and 2 genera of Chrysophyta, and 1 family and 1 genus of Euglenophyta. Among these, *Navicula* (Bacillariophyta) was the dominant genus, and followed by *Pinnularia*, *Synedra*, and *Gomphonema* of Bacillariophyta; *Chlorella*, *Ulothrix*, *Scenedesmus*, *Schroederia*, and *Cosmarium* of Chlorophyta; and *Oscillatoria* of Cyanophyta.

Macrozoobenthic assemblages were constituted of 4 families and 5 genera of Annelida, 2 families and 2 genera of Mollusca, and 1 family and 1 genus of Arthropoda. Among these, *Limnodrilus* (Annelida) was the dominant genus, and followed by *Glossiphonia* and *Branchiura* of Annelida; and *Procladius* of Arthropoda.

3.2 Characteristics of physicochemical parameters of water quality

Based on mensal physicochemical parameters, the average of WT and pH at 29 sampling sites of the LDW in 2009 were 11.8-18.9 ^{o}C and 7.27-8.31, as well as TSS, DO, NH_3N, TN, TP, COD_{Mn}, BOD, NO_3N, TOC, Zn (II), Cd (II), Pb (II), Cu (II), and Cr (VI) were respectively 4.00-86.00, 0.10-7.10, 0.34-28.96, 1.83-35.91, 0.07-2.28, 2.13-25.19, 1.84-94.45, 0.24-5.97, 0.00-1.41, 0.000-1.405, 0.000-0.085, 0.000-0.081, 0.000-0.185, and 0.000-0.003 $mg{\cdot}L^{-1}$ (Table 1).

Table 1 Physicochemical parameters of water quality in streams of the LDW in 2009

	WT (^{o}C)	pH	TSS (mg·L^{-1})	DO (mg·L^{-1})	NH$_3$N (mg·L^{-1})	TN (mg·L^{-1})	TP (mg·L^{-1})	COD$_{Mn}$ (mg·L^{-1})	BOD (mg·L^{-1})	NO$_3$N (mg·L^{-1})	TOC (mg·L^{-1})	Zn (II) (mg·L^{-1})	Cd (II) (mg·L^{-1})	Pb (II) (mg·L^{-1})	Cu (II) (mg·L^{-1})	Cr (VI) (mg·L^{-1})
R1	16.6	7.40	17.70	0.76^{D}	17.15^{D}	24.35^{D}	2.23^{D}	17.49^{D}	23.30^{D}	0.27	27.30	0.024^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R2	16.2	7.50	55.70	0.10^{D}	28.96^{D}	35.91^{D}	2.28^{D}	23.22^{D}	94.45^{D}	0.29	27.10	1.405^{C}	0.085^{C}	0.080^{B}	0.124^{A}	0.000^{A}
R3	17.0	7.30	21.70	3.47^{C}	10.47^{D}	19.59^{D}	1.76^{D}	11.70^{D}	19.53^{D}	2.62	12.40	0.797^{A}	0.068^{C}	0.000^{A}	0.078^{A}	0.000^{A}
R4	15.9	7.40	12.70	4.57^{C}	9.16^{D}	14.54^{D}	0.94^{D}	11.96^{D}	27.56^{D}	0.52	11.30	0.103^{A}	0.001^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R5	16.4	7.50	31.80	4.07^{C}	9.85^{D}	16.20^{D}	1.30^{D}	9.50^{D}	16.55^{D}	0.81	13.40	0.029^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R6	11.8	7.80	86.00	1.43^{D}	13.77^{D}	28.30^{D}	1.12^{D}	19.33^{D}	34.30^{D}	0.38	17.20	0.147^{A}	0.000^{A}	0.000^{A}	0.014^{A}	0.000^{A}
R7	17.0	7.70	4.00	5.08^{B}	7.58^{D}	12.98^{D}	0.47^{D}	9.38^{C}	6.38^{D}	1.10	16.20	0.029^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R8	18.2	7.60	24.60	2.26^{D}	19.69^{D}	25.50^{D}	1.88^{D}	19.59^{D}	32.52^{D}	0.39	17.20	0.016^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R9	16.9	7.60	23.10	1.02^{D}	13.67^{D}	21.85^{D}	1.41^{D}	16.09^{D}	18.50^{D}	0.37	30.60	0.007^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}
R10	18.9	7.40	8.50	3.57^{C}	6.53^{D}	10.96^{D}	0.58^{D}	5.95^{B}	6.60^{D}	1.04	39.00	0.029^{A}	0.000^{A}	0.000^{A}	0.006^{A}	0.000^{A}
R11	16.1	7.60	21.10	1.42^{D}	23.44^{D}	29.68^{D}	2.21^{D}	20.41^{D}	26.23^{D}	0.24	37.40	0.063^{A}	0.000^{A}	0.000^{A}	0.082^{A}	0.000^{A}
R12	16.3	7.60	18.00	1.07^{D}	21.24^{D}	26.45^{D}	1.99^{D}	22.04^{D}	24.05^{D}	0.47	24.30	0.146^{A}	0.003^{A}	0.000^{A}	0.022^{A}	0.000^{A}
R13	16.4	8.00	27.90	2.72^{D}	17.73^{D}	22.13^{D}	1.42^{D}	25.19^{D}	30.77^{D}	0.28	23.30	0.061^{A}	0.000^{A}	0.000^{A}	0.093^{A}	0.000^{A}
R14	16.5	7.90	15.20	2.31^{D}	15.26^{D}	21.68^{D}	0.91^{D}	19.25^{D}	19.23^{D}	0.48	25.20	0.005^{A}	0.000^{A}	0.000^{A}	0.001^{A}	0.000^{A}
R15	16.4	7.90	15.30	4.29^{C}	5.62^{D}	8.94^{D}	0.66^{D}	18.09^{D}	19.25^{D}	0.46	22.70	0.100^{A}	0.000^{A}	0.000^{A}	0.023^{A}	0.000^{A}
R16	16.7	8.00	22.10	3.38^{C}	2.21^{D}	5.02^{D}	0.29^{C}	22.76^{D}	14.37^{D}	0.43	20.70	0.000^{A}	0.000^{A}	0.000^{A}	0.125^{A}	0.000^{A}
R17	16.8	8.10	11.40	7.11^{A}	1.46^{C}	2.79^{D}	1.56^{D}	6.45^{C}	5.71^{C}	0.74	16.40	0.005^{A}	0.000^{A}	0.000^{A}	0.090^{A}	0.000^{A}
R18	17.1	7.90	11.80	5.92^{B}	4.30^{D}	7.73^{D}	0.60^{D}	10.38^{D}	9.73^{D}	0.80	15.70	0.049^{A}	0.000^{A}	0.000^{A}	0.185^{A}	0.000^{A}
R19	17.0	8.00	14.10	4.99^{C}	7.85^{D}	12.66^{D}	0.71^{D}	12.61^{D}	11.71^{D}	3.14	14.20	0.000^{A}	0.000^{A}	0.000^{A}	0.000^{A}	0.003^{A}
R20	18.1	7.80	17.30	4.82^{C}	0.36^{A}	4.58^{D}	0.08^{A}	2.13^{A}	1.84^{A}	1.43	12.90	0.008^{A}	0.000^{A}	0.000^{A}	0.003^{A}	0.001^{A}
R21	17.0	7.80	50.40	6.08^{A}	0.34^{A}	7.06^{D}	0.12^{B}	3.74^{A}	2.37^{B}	4.31	7.50	0.051^{A}	0.000^{A}	0.000^{A}	0.007^{A}	0.002^{A}
R22	17.0	7.60	43.90	6.54^{A}	0.81^{B}	10.26^{D}	0.14^{B}	5.88^{B}	3.40^{B}	4.97	7.40	0.216^{A}	0.000^{A}	0.000^{A}	0.050^{A}	0.001^{A}

R23	18.1	7.70	47.30	7.01^{A}	1.19^{C}	4.45^{D}	0.10^{B}	4.88^{B}	2.97^{B}	1.65	18.50	0.126^{A}	0.000^{A}	0.000^{A}	0.008^{A}	0.000^{A}
R24	16.7	8.30	43.90	5.66^{B}	1.99^{D}	3.78^{D}	0.23^{C}	10.25^{D}	7.33^{D}	0.57	10.80	0.373^{A}	0.001^{A}	0.010^{A}	0.045^{A}	0.000^{A}
R25	17.6	7.70	37.80	6.30^{A}	1.52^{D}	5.22^{D}	0.18^{B}	6.84^{C}	3.64^{B}	1.80	17.80	0.174^{A}	0.001^{A}	0.020^{A}	0.018^{A}	0.000^{A}
R26	17.0	7.60	43.40	6.43^{A}	4.95^{D}	14.38^{D}	0.36^{D}	4.37^{B}	3.33^{B}	5.97	12.10	0.337^{A}	0.002^{A}	0.030^{A}	0.075^{A}	0.000^{A}
R27	17.8	7.90	30.50	6.90^{A}	0.48^{A}	1.83^{D}	0.07^{A}	3.53^{A}	2.78^{B}	0.52	7.60	0.080^{A}	0.000^{A}	0.080^{B}	0.000^{A}	0.000^{A}
R28	18.1	7.40	86.00	3.04^{C}	4.15^{D}	9.54^{D}	0.28^{C}	5.46^{B}	8.04^{D}	1.99	13.00	0.109^{A}	0.000^{A}	0.010^{A}	0.003^{A}	0.000^{A}
R29	15.5	7.60	4.00	5.79^{B}	0.59^{B}	3.29^{D}	0.39^{D}	3.71^{A}	3.79^{B}	0.94	8.60	0.064^{A}	0.000^{A}	0.020^{A}	0.008^{A}	0.000^{A}

* A, B, C, and D meant the results of water quality assessment as clean, slight pollution, medium pollution, and heavy pollution respectively according to *Surface Water Quality Standards for the People's Republic of China* (GB3838-2002)[17].

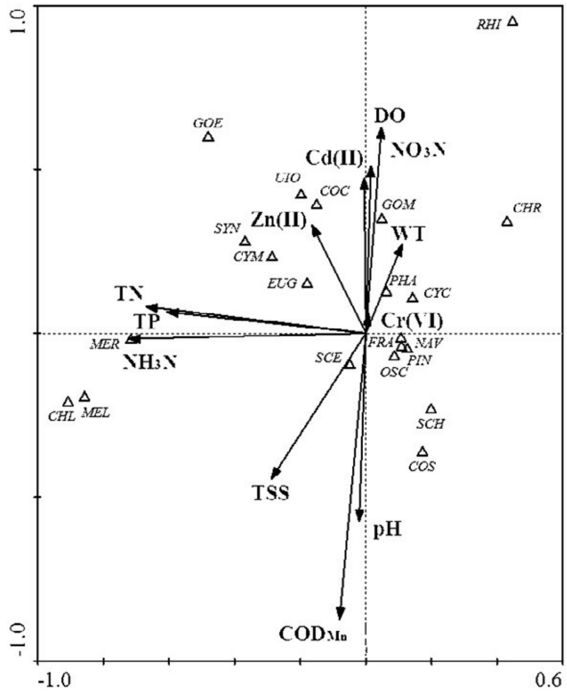
3.3 Identification of the key water pollution factors affecting aquatic assemblages

FA was computed for all the environmental viriables shoun in Table 2. The data were tranformed for standardization in order to produce a greater spread of the sites. Five significant factors (eigenvalue>1) were extracted from 16 physicochemical parameters by FA to assess water pollution in streams of the LDW, accounting for 83.728% of the total rotated variance. Meanwhile, the absolute loadings of varimax-rotated factor matrix were used to indicate the strong, moderate, or weak correlation of physicochemical parameters to water pollution factors. Liu *et al* classified that factor loadings as ‘strong’, ‘moderate’, and ‘weak’ while the absolute loading values were >0.75, 0.75-0.50 and 0.50-0.30, respectively [27]. Table 2 demonstrated that except for BOD, TOC, Pb (II), and Cu (II), the other parameters were the dominant indicators in assessing water pollution in streams of the LDW with the absolute loadings of over 0.750.

Table 2 Loadings of rotated water-quality physicochemical parameters in streams of the LDW

Rotated matrix	F1	F2	F3	F4	F5
NH_3N	**0.940**	0.195	0.051	-0.104	-0.071
TN	**0.921**	0.190	0.191	0.019	-0.175
DO	**-0.910**	-0.035	-0.093	0.173	0.157
TP	**0.880**	0.169	-0.074	-0.103	-0.036
COD_{Mn}	**0.857**	-0.016	0.143	-0.167	0.322
BOD	0.736	0.536	0.222	-0.123	0.084
TOC	0.690	-0.117	-0.309	-0.325	-0.020
Zn (II)	0.222	**0.930**	0.103	0.066	0.020
Cd (II)	0.325	**0.877**	-0.041	0.092	-0.008
Pb (II)	-0.181	0.740	0.183	-0.265	-0.060
WT	-0.342	0.088	**-0.813**	0.047	-0.181
TSS	-0.109	0.335	**0.809**	0.086	-0.190
Cr (VI)	-0.126	-0.165	0.016	**0.860**	0.072
NO_3N	-0.428	0.159	0.023	**0.752**	-0.217
Cu (II)	-0.289	-0.307	0.092	-0.041	**0.797**

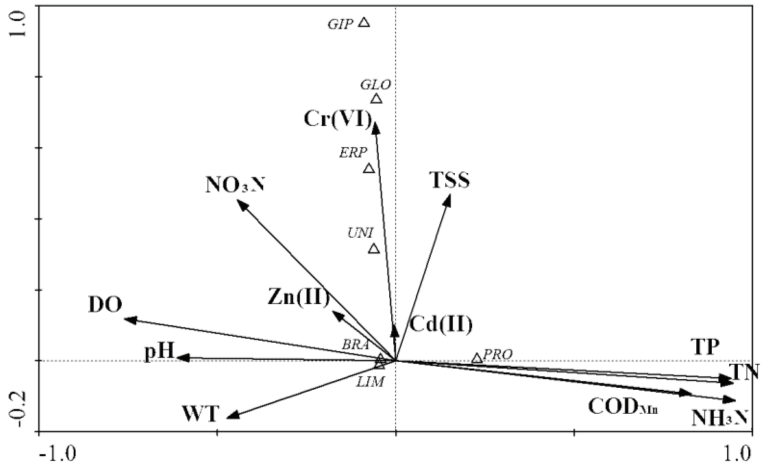
The CCA between 12 dominant water quality indicators as WT, pH, TSS, DO, NH_3N, TN, TP, COD_{Mn}, NO_3N, Zn (II), Cd (II), and Cr (VI), and periphytic algal and macrozoobenthic assemblages in the wet season respectively were used to indentify the key water pollution factors affecting aquatic ecosystem health in streams of the LDW integratedly. In Figure 2, the eigenvalues of axis 1 and axis 2 were 0.386 and 0.111 respectively, which explained cumulative 49.3% of the total variance. Eigenvalues calculated for each axis show the degree of species separation along the axis and serve as a measure of the axis significance, so axis 1 and axis 2 indicated the influences of dominant indicators on periphytic algal assemblages, as well as axis 1 was better to explain the dominant factors as higher eigenvalues. Meanwhile, the two species axes were nearly vertical to each other as their correlation coefficient was -0.0078, and the correlation coefficient of the two environmental axes was 0, which denoted the reliability of the CCA results. Enviromental variables represented as arrows from the orgin in the line of most effect. And the length of arrow is proportional to its influence on the sites and species. Considering the distances of the environmental arrows and the angles between them and axis 1, the correlation order of the dominant factors affecting periphytic algal assemblages in the wet season was NH_3N>TN>TP>TSS> Zn (II)>WT>COD_{Mn}>NO_3N>DO>Cd (II)>pH>Cr (VI).



* Abbreviations: CHL- *Chlrella*, CHR- *Chrysocapsa*, COC- *Cocconeis*, COS- *Cosmarium*, CYM- *Cymbella*, EUG- *Euglena*, FRA- *Fragilaria*, GOE- *Goelosphaerium*, GOM- *Gomphonema*, MEL- *Melosira*, MER-*Merismopedia*, NAV- *Navicula*, OSC- *Oscillatoria*, PHA- *Phaeothamnion*, PIN- *Pinnularia*, RHI- *Rhizosolenia*, SCE- *Scenedesmus*, SCH- *Schroederia*, SYN- *Synedra*, and ULO- *Ulothrix*.

Figure 2 CCA results of dominant water quality indicators and periphytic algal assemblages in the wet season in streams of the LDW

In Figure 3, the eigenvalues of axis 1 and axis 2 were 0.870 and 0.535 respectively, which explained cumulative 77.3% of the total variance. So axis 1 and axis 2 indicated the influences of dominant indicators on macrozoobenthic assemblages, and axis 1 was better to explain the dominant factors as well. Meanwhile, the two species axes were nearly vertical to each other as their correlation coefficient was 0.0201, and the correlation coefficient of the two environmental axes was 0, which denoted the reliability of the CCA results. Considering the distances of the environmental arrows and the angles between them and axis 1, the correlation order of the dominant factors affecting macrozoobenthic assemblages in the wet season was TP>TN>NH_3N>Cr (VI)>COD_{Mn}>pH>DO>WT> NO_3N>Zn (II)>TSS>Cd (II).



* Abbreviations: BRA- *Branchiura*, CIP- *Cipangopaludina*, DIN- *Dina*, GLO- *Glossiphonia*, LIM- *Limnodrilus*, PRO- *Procladius*, and UNI- *Unio*.

Figure 3 CCA results of dominant water quality indicators and macrozoobenthic assemblages in the wet season in streams of the LDW

After tested by the Monte Carlo permutations of CCA, 3 dominant water quality indicators TN, NH$_3$N and TP had significant impact on all of the periphytic algal, macrozoobenthic, and bacterioplanktonic assemblages (Table 3). Therefore, TN, NH$_3$N and TP were the key water pollution factors in streams of the LDW.

Table 3 Correlation coefficients of dominant water quality indicators to periphytic algal and macrozoobenthic assemblages in streams of the LDW

Dominant water quality indicators	Periphytic algal assemblages	Macrozoobenthic assemblages
WT	0.101	-0.4714
pH	-0.0186	-0.6107^{m}
DO	0.0441	-0.7572^{n}
COD$_{Mn}$	-0.0736	0.8256^{n}
NH$_3$N	-0.6628^{n}	0.9480^{n}
TP	-0.5566^{m}	0.9421^{n}
TN	-0.6152^{m}	0.9363^{n}
TSS	-0.2645	0.1521
NO$_3$N	0.0142	-0.442
Zn (II)	-0.1505	-0.176
Cd (II)	-0.0049	-0.0041
Cr (VI)	0.0074	-0.058

* M and n represented p<0.05 and p<0.01 respectively.

4. Discussion

The integrated water pollution was assessed by the normalized assignment of the key water pollution factors TN, NH_3N and TP in streams of the LDW according to *Surface Water Quality Standards for the People's Republic of China (GB3838-2002)* [17]. Table 4 showed the 4 categories as clean, slight pollution, medium pollution, and heavy pollution respectively evaluated from 1 to 4 with different concentrations of TN, NH_3N and TP, as well as the integrated water pollution index that was the sum of the normalized TN, NH_3N and TP. Thus, the spatial distribution of the integrated water pollution in streams of the LDW was distinctly divided into the north LDW from R1 to R19 and the south LDW from R20 to R29, and the integrated water pollution in streams of the north LDW was more severe than the south LDW (Figure 4).

Table 4 Normalized assignment of TN, NH_3N and TP, and the integrated water pollution index in streams of the LDW

Value	Category	TN ($mg \cdot L^{-1}$)	NH_3N ($mg \cdot L^{-1}$)	TP ($mg \cdot L^{-1}$)	Integrated water pollution index
1	clean	≤0.5	≤0.5	≤0.1	3
2	slight pollution	(0.5, 1.0]	(0.5, 1.0]	(0.1, 0.2]	4, 5, 6
3	medium pollution	(1.0, 1.5]	(1.0, 1.5]	(0.2, 0.3]	7, 8, 9
4	heavy pollution	>1.5	>1.5	>0.3	10, 11, 12

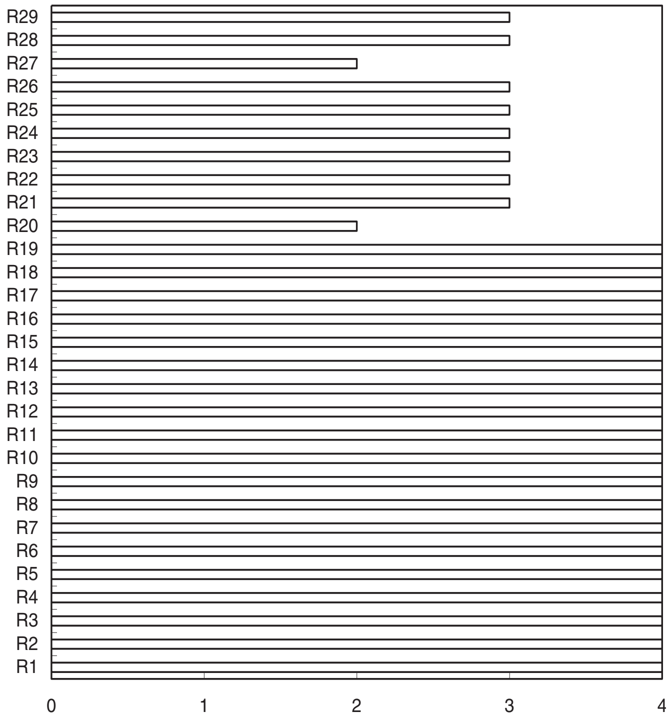
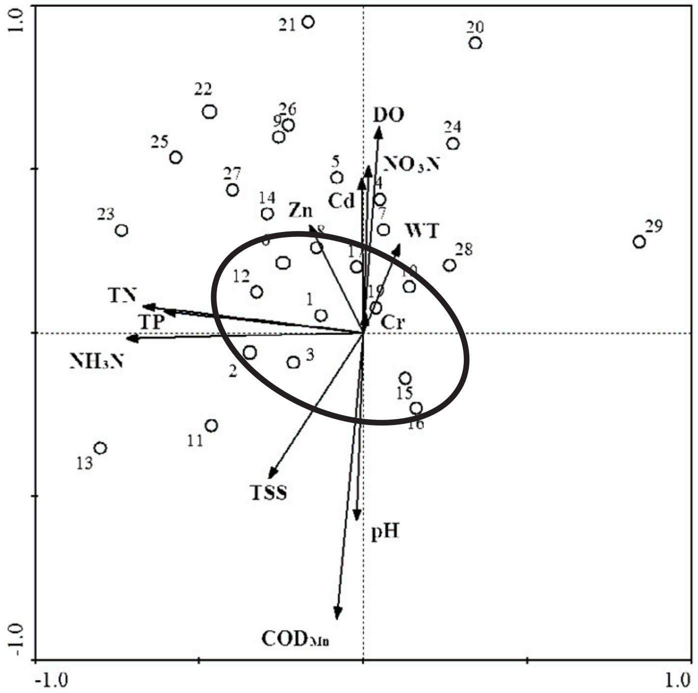


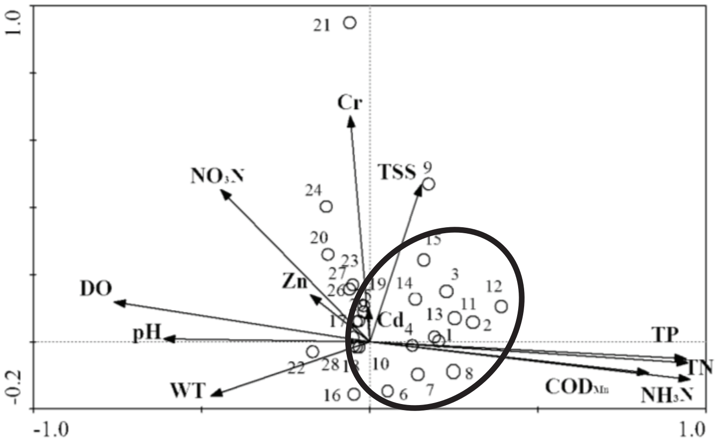
Figure 4 Spatial distribution of integrated water pollution in streams of the LDW

Figure 5 and 6 indicated the spatial distributions of the key water pollution factors TN, NH_3N and TP affecting periphytic algal and macrozoobenthic assemblages in streams of the LDW respectively. They were approximately the same as the spatial distribution of the integrated water pollution. Therefore, the ecosystem health in streams of the north LDW from R1 to R19 was weaker than the south LDW from R20 to R29, while the integrated water pollution in streams of the north LDW was more severe than the south LDW.



* The number of 1-29 represented R1 to R29 respectively.

Figure 5 CCA results of spatial distribution of TN, NH_3N and TP affecting periphytic algal assemblages in streams of the LDW



* The number of 1-29 represented R1 to R29 respectively.

Figure 6 CCA results of spatial distribution of TN, NH_3N and TP affecting macrozoobenthic assemblages in streams of the LDW

Acknowledgements

This research was supported by National Key Technologies R & D Program of China (2008ZX07526-02-006). We thank Dr. Iain Bruce from University of Hong Kong for grammatical polishment. We thank three anonymous reviewers who provided helpful comments. Farong Li, Shuping Yang, and other field and laboratory crew from Kunming Environment Monitor Center (Yunnan Province, China) graciously assisted with research.

References

[1] Fisher SG, Grimm NB, Marti E, Holmes RM. Jones JB. Material spiraling in stream corridors: A telescoping ecosystem model. *Ecosystems* 1998; ***1*(1)**: 19-34.

[2] Sigua GC, Tweedale WA. Watershed scale assessment of nitrogen and phosphorus loadings in the Indian River Lagoon basin, Florida. *Journal of Environmental Management* 2003; ***67*(4)**: 363-372.

[3] Lohse KA, Brooks PD, McIntosh JC, Meixner T, Huxman TE. Interactions Between Biogeochemistry and Hydrologic Systems. *Annual Review of Environment and Resources* 2009; ***34*(**65-96.

[4] Yoder CO, Rankin ET. The role of biological indicators in a state water quality management process. *Environmental Monitoring and Assessment* 1998; ***51*(1-2)**: 61-88.

[5] Gurrieri JT. Distribution of metals in water and sediment and effects on aquatic biota in the upper Stillwater River basin, Montana. *Journal of Geochemical Exploration* 1998; ***64*(1-3)**: 83-100.

[6] Nayar S, Goh BPL. Chou LM. Settlement of marine periphytic algae in a tropical estuary. *Estuarine Coastal and Shelf Science* 2005; ***64*(2-3)**: 241-248.

[7] Baffico GD. Variations in the periphytic community structure and dynamics of Lake Nahuel Huapi (Patagonia, Argentina). *Hydrobiologia* 2001; ***455*(**79-85.

[8] Guasch H, Admiraal W, Sabater S. Contrasting effects of organic and inorganic toxicants on freshwater periphyton. *Aquatic Toxicology* 2003; ***64*(2)**: 165-175.

[9] Zettler ML, Bochert R, Pollehne F. Macrozoobenthos diversity in an oxygen minimum zone off northern Namibia. *Marine Biology* 2009; ***156*(9)**: 1949-1961.

[10] Rier ST, Stevenson RJ. Response of periphytic algae to gradients in nitrogen and phosphorus in streamside mesocosms. *Hydrobiologia* 2006; ***561***:131-147.

[11] Reavie ED, Jicha TM, Angradi TR, Bolgrien DW, Hill BH. Algal assemblages for large river monitoring: Comparison among biovolume, absolute and relative abundance metrics. *Ecological Indicators* 2010; ***10*(2)**: 167-177.

[12] Reiss H, Kroncke I. Seasonal variability of benthic indices: An approach to test the applicability of different indices for ecosystem quality assessment. *Marine Pollution Bulletin* 2005; ***50*(12)**: 1490-1499.

[13] Gray AV. Li W. Case study on water quality modelling of Dianchi lake, Yunnan Province, South West China. *Water Science and Technology* 1999; ***40*(2)**: 35-43.

[14] Lu JJ, Yang H, Gao L. Yu TY. Spatial variation of P and N in water and sediments of Dianchi Lake, China. *Pedosphere* 2005; ***15*(1)**: 78-83.

[15] Liu ZH, Liu XH, He B, Nie JF, Peng JY. Zhao L. Spatio-temporal change of water chemical elements in Lake Dianchi, China. *Water and Environment Journal* 2009; ***23*(3)**: 235-244.

[16] Hu J, Liu JT. Liu YD. Phosphorus in suspended matter and sediments of a hypertrophic lake. A case study: Lake Dianchi, China. *Environmental Geology* 2009; ***58*(4)**: 833-841.

[17] State Environmental Protection Administration. Surface water quality standards for People's Republic of China. In *Water Science and Technology*, China Environmental Science Press: Beijing, 2002.

[18] Barbour MT, Gemitsen J, Snyder BD. al e *Rapid bioassessment protocols for use in streams and wadeable rivers:periphyton, benthic macroinvertebrates,and fish, second edition (EPA 841-B-99-002)*; U. S. Environmental Protection Agency: Washington, D. C. , 1999.

[19] Foudy B. *Phycology*. Shanghai Science and Technology Press: Shanghai, 1980.

[20] Institute of Hydrobiology, Chinese Academy of Sciences. *Chinese freshwater algae*. Shanghai Science and Technology: Shanghai, 1980.

[21] Liu YY, Zhang WW, Wang YX. *Economic fauna of China-freshwater mollusk*. Science Press: Beijing, 1979; p 1-130.

[22] Zhang HT. *Studies on Taxonomy, distribution and ecology of Microdrile ologochaetes of China*. Higher Education Press: Beijing, 2002.

[23] Singh KP, Malik A, Mohan D, Sinha S. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India) - a case study. *Water Research* 2004; ***38*****(18)**: 3980-3992.

[24] Bengraine K, Marhaba TF. Using principal component analysis to monitor spatial and temporal changes in water quality. *Journal of Hazardous Materials* 2003; ***100*****(1-3)**: 179-195.

[25] Terbraak CJF. Canonical correspomdence -analysis - a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 1986; ***67*****(5)**: 1167-1179.

[26] Dodkins I, Rippey B. Hale P. An application of canonical correspondence analysis for developing ecological quality assessment metrics for river macrophytes. *Freshwater Biology* 2005; ***50*****(5)**: 891-904.

[27] Liu CW, Lin KH, Kuo YM. Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment* 2003; ***313*****(1-3)**: 77-89.