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Identifying Key Environmental Factors Influencing Spatial Variation of Water Quality in Upper Shitoukoumen Reservoir Basin in Jilin Province, China

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Abstract: Based on the observed data in monitored drainage areas and GIS spatial analysis tools, watershed basic database of Shitoukoumen Reservoir Basin was built. The multivariate analysis and redundancy analysis (RDA) were used to analyze the spatial and temporal variations of water quality, identify the key environmental factors and their patterns influencing the spatial variation of water quality, and determine the main types and forms of the non-point source (NPS) pollutant export controlled by the key environmental factors. The results show that different patterns of environmental factors lead to great changes in water quality at spatial and seasonal scales. All selected environmental factors explain 64.5% and 68.2% of the spatial variation of water quality over dry season and rainy season, respectively, which shows clear seasonal difference. Over dry season, residential land is the most important environmental factor, which possesses 35.4% of the spatial variation, and drainage area is the second key environmental factor, which possesses 17.0% of spatial variation in the total variance. Over rainy season, slope length and drainage area are the key environmental factors, which possess 29.3% of the spatial variation together. Residential land influences nitrogen export by changing NH_4^+-N and particulate organic nitrogen (PON) discharge over dry season, and drainage area controls phosphorus export by regulating dissolved phosphorus (DP) drainage over dry season and phosphorus associated particulate (PAP) loss over rainy season, respectively. Although slope length is an important environmental factor, it does not influence NPS pollutant export. It is interesting that soil organic matter, as a minor environmental factor, highly determines phosphorus and nitrogen export by enhancing the DP, PAP and PON loss.
Keywords: non-point source pollution; key environmental factor; redundancy analysis; Shitoukoumen Reservoir

1 Introduction

Non-point source (NPS) pollution has a great impact on the quality of water resources (Narunalani et al., 1997). It is well known that eutrophication caused by excessive loadings of NPS pollution into rivers, lakes, reservoirs and estuaries, especially phosphorus and nitrogen, leads to a significant loss of amenity in terms of water supply, fishery and recreation (USEPA, 2000). Nowadays, NPS pollution has become widespread pollution problem in the stream water, particularly in areas with limited water exchange, such as lake and reservoir (de Jonge et al., 2002; Kennish, 2002; Prasad et al., 2005; Velasco et al., 2006). Nevertheless, the NPS pollution problem is far more challenging because it is very difficult to isolate the contribution from individually dispersed sources in a scientific and legally defendable manner. Many efforts have been made in the field of pollution loadings calculating and pollution process modeling (Gikas et al., 2006; Polyakov et al., 2007; Oki and Yasuoka, 2008; Ouyang et al., 2008). At the same time, single environmental factor experiments have been carried out to reveal the

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mechanism of NPS pollution and the quantitative relationship between loadings of NPS pollution and single environmental factor (Budhendra et al., 2003; Lian and Wang, 2004; Gao et al., 2005; Ning et al., 2006). However, NPS pollution is generally attributed to the interaction of numerous environmental factors. In fact, it is impossible to consider the relationship between NPS pollution and all the environmental factors due to complex NPS pollution process, thus it is useful to identify the key environmental factors from the various environmental factors. To the best of our knowledge, few studies have been carried out to identify the key environmental factors and reveal their mechanism, which control water quality and drive different NPS pollutant export at a catchment scale (Sliva and Williams, 2001; Li and Zhang, 2008; Amiri and Nakane, 2008; Li et al., 2009).

The environmental factors data are easy to collect at a small runoff plot scale. Thus, the studies on the relationship between environmental factors and NPS pollution were often performed at such a scale (Dou, 2006; Munodawafa, 2007). Watershed scale was often taken in studies on ecological and hydrological processes (Wang and Yang, 2008). However, quantitative data of environmental factors are difficult to collect at a watershed scale. So researches on the interaction between NPS pollution and environmental factors are limited at watershed scale. Effective analytical tools, such as geographic information systems (GIS) and redundancy analysis (RDA), are capable to deal with spatial data and complex interactions, and become popular uses in watershed/catchment management (Johnson and Gage, 1997; Cao et al., 1999; Sliva and Williams, 2001; Wang and Yang, 2008). A comprehensive knowledge of spatial variation of water quality in relation to topography can also provide a simple approach for subdivision of a watershed into spatial units with homogeneously hydrologic response in distributed hydrologic modeling (Bouraoui et al., 2004; Behera and Panda, 2006).

This study aimed to use the RDA to analyze the relationship between water quality and environmental factors on a watershed scale in an effort to reveal the patterns of environmental factors and the key environmental factors controlling water quality, and furthermore ascertain the main type and form of NPS pollutant export controlled by the key environmental factors.

2 Methods

2.1 Study area

The upper-river catchment of Shitoukoumen Reservoir (43°06′–44°03′N, 125°46′–126°41′E) is located in the middle part of the Songnen Plain in Jilin Province of China (Fig. 1). The area of the catchment is 4,944km^2 and the altitude is 185–1,000m. There are significant topographic variations with middle-low mountain, hill, mesa and plain landforms from southeast to northwest within the study area. The region has a semi-humid continental monsoon climate with an average annual temperature of 2–6℃ and an average annual precipitation of 600mm. However, the precipitation is with great interannual variability. About 67% of precipitation falls between July and September with great spatial variability, while only 33% falls between December and March. The main soils types are dark brown forest soil, meadow soil, lessivage dark brown soil and black soil. The forest dominated by artificial woods accounts for 36.46% of total area in the catchment, including *Juglans mandshurica*, *Fraxinus mandshurica* and *Phellodendron amurense*.

2.2 Environmental factor extraction

The watershed boundary and digital drainage network were extracted using AVSWAT model based on DEM at the scale of 1∶100,000. The 28 sub-basins were obtained through basin-sub-basin-hydrological response unit discretization with a minimum catchment area of 10×10^3ha to reveal the relationship between environmental factors and NPS pollution. The actual drainage network was used to calibrate the simulated drainage network and outlets of sub-basins. The environmental factors related to the spatial variation of water quality were selected based on the analysis of the rule of NPS pollution occurrence and transportation. The sub-basin parameters were obtained (Table 1). All databases were transferred into common coordinate system (Albers) and analyzed in ArcView as vectors.

2.3 Water sampling and analysis

Water quality data were obtained by surface water sampling on the spot at outlet sites of sub-basins. The total of 56 grab samples were collected throughout the upper Shitoukoumen Reservoir in April and July, 2008, respectively (Fig. 1). April and July are regarded as dry

Table 1 Source and processing of environmental data

Data type	Scale	Source	Data description	Data processing [a]	Result
Topography	1∶100,000	Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences	Elevation	Stream network definition, sub-basin discretion and sub-basin parameters calculation by soil and water assessment tool (SWAT) [b]	Maximal relative elevation difference (MRE); average slope (SP); slope length (SL); drainage area (DA); drainage density (DD) [e]
Meteorology	68 stations	China Meteorological Data Sharing Service System; Changchun Flood Control and Drought Relief System	Daily precipitation and rainy days	Rainfall intensity defined as the ratio of daily precipitation and rainy days; Kriging interpolation based on GIS	Daily precipitation (PCP); rainfall intensity (RI)
Soil	1∶1,000,000	Environmental and Ecological Science Data Center for West China	Soil types and physical and chemical properties	Different soils text conversion and soil erodibility factor calculation based on soil type [c]	Soil erodibility factor (K); soil organic matter (OM); soil total nitrogen (TNs); soil total phosphorus (TPs)
Land use	1∶100,000	Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences	Land use types and their area	Geostatistical analyst	Forest (FR, %); residential land (RL, %); farmland (FL, %)
Land cover	19.5m×19.5m	China Center for Resource Satellite Data and Applications (CRESDA)	Remote sensing image from CBERS	Image denoise processing and geometric correction, bands composite and NDVI calculation with the aid of ERDAS IMAGINE 9.2[d]	Normalized difference vegetation index (NDVI)

Notes: a: Data processing was followed by overlay analysis between result data layer and sub-basin boundary layer for environmental factors in sub-basins; b: After Bärlund et al. (2007) and Shrestha et al. (2008); c: After Wei et al. (2007); d: After Suo et al. (2006); e: Calculated as the ratio of drainage length and drainage area in sub-basins; CBERS: the China Center for Resource Satellite Data and Applications

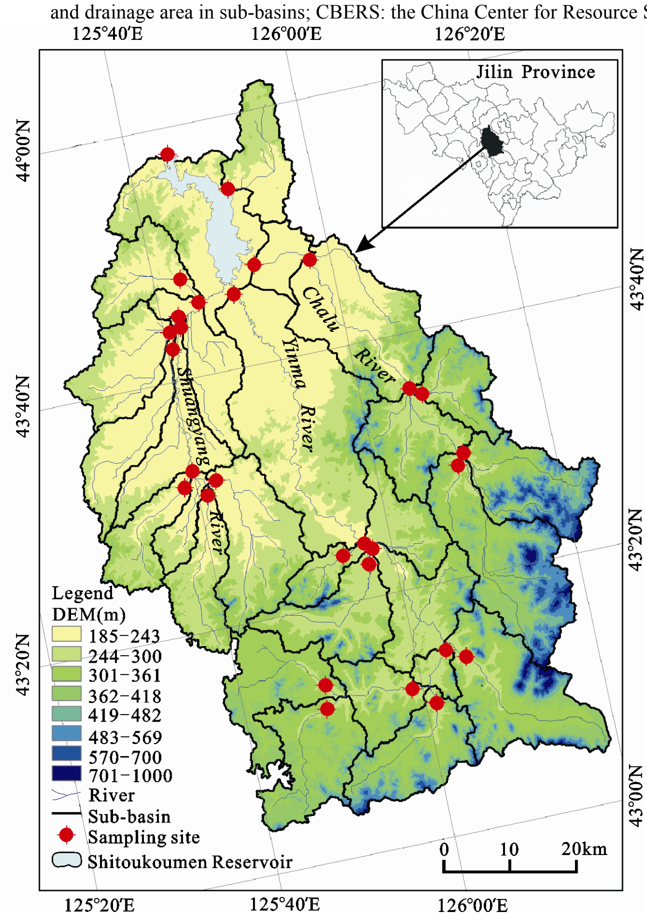

Fig. 1 Location of study area, sampling sites and sub-basins division

season and rainy season, respectively. Each sample was the mixture of three samples from the same section, and collected at the depth of 0.5m beneath the water surface (Huang et al., 1999). In water sample proceeding, 15% (v/v) nitric acid was added to all sample bottles for 24h and then rinsed with Milli-Q water prior to usage. Water total nitrogen (TN_w), total phosphorus (TP_w), dissolved nitrogen (DN) and dissolved phosphorus (DP) were analyzed by uv-vis spectrophotometer (UV-2500), nitrate-nitrogen (NO_3^--N) and ammonium-nitrogen (NH_4^+-N) by continuous flow analyzer (SKALAR SAN++), suspended solids (SS) by gravimetric method. The chemical oxygen demand (COD_{cr}) was analyzed by Potassium Dichromate method (SEPAC, 2002). Particulate organic nitrogen (PON) and particulate associated phosphorus (PAP) were calculated as the difference between the total and the dissolved. Reagent and procedural blanks were determined in parallel to the sample treatment using identical procedures. Each calibration curve was evaluated by analyses of these quality control standards before, over and after the analyses of a set of samples. The analytical precision was within the range of ±5%.

2.4 Statistical analysis

The Kolmogorov-Smirnov goodness of fit test was used to test the normality of distribution of the individual water quality and environmental factors. The Kruskal-Wallis test was used to determine whether there was a significant difference between seasonal concentrations within the 28 sub-basins. RDA was employed based on detrended correspondence analysis (DCA) for water quality parameters (Jongman et al., 1995).

The inclusive forward selection procedure was employed for sorting out the factors explaining the most variance in the water quality data and then, Monte Carlo test with 499 permutation were carried out for significance testing of the selected environmental factors (ter Braak, 1989). In the preliminary analysis environmental factors with an inflation factor larger than 20 were removed (Beyene et al., 2009). The correlation between individual environmental factor and water quality was analyzed using t-test. All multivariate analyses were performed using the software CANOCO, Version 4.5 for Windows (ter Braak and Šmilauer, 2002).

3 Results and Discussion

3.1 Variation of water quality in space and season

The water quality parameters from observation varied greatly in space and season (Table 2). The concentrations of NO_3^--N, PAP and SS showed considerable variability among the sub-basins and significant variability between two seasons (p<0.01). Generally, the highest spatial variation of concentration was observed over dry season. The concentrations of TP_w and TN_w, especially DN, were relatively low in spatial variation, but changed significantly between two seasons (p<0.05). The concentrations of NH_4^+-N, PON, DP and COD_{cr} did not change significantly between two seasons, while they varied considerably in space. The spatial variation in water quality parameters over dry season were larger than that over rainy season, which was most likely caused by the great difference in precipitation between two seasons (Bouraoui et al., 2004). The relationships between environmental factors and water quality parameter were investigated further for explaining the great variation of water quality in space and seasons.

Table 2 Changes of water quality parameters and statistical analysis results (n=28)

Parameter	Dry season				Rainy season				p-value
	Average (mg/L)	CV	Min (mg/L)	Max (mg/L)	Average (mg/L)	CV	Min (mg/L)	Max (mg/L)	
TN_w	2.163	0.85	0.530	7.810	3.058	0.47	1.108	7.188	0.039
NH_4^+-N	0.330	1.90	0.030	2.980	0.185	1.30	0.010	1.170	0.264
NO_3^--N	0.818	0.85	0.010	2.220	1.918	0.72	0.017	8.200	0.001
DN	1.511	0.72	0.222	3.920	2.195	0.56	0.820	5.225	0.029
PON	0.710	1.33	0.010	4.070	0.864	0.65	0.110	2.072	0.366
TP_w	0.127	0.96	0.027	0.459	0.209	0.78	0.041	0.659	0.029
DP	0.069	1.12	0.017	0.257	0.048	0.91	0.007	0.195	0.201
PAP	0.057	1.13	0.001	0.206	0.161	0.90	0.019	0.626	0.001
SS	70	1.03	12	301	181	0.72	56	534	<0.0001
COD_{cr}	22.99	1.06	1.02	102.03	34.10	0.52	12.55	69.03	0.059

3.2 Identification of key environmental factors

RDA enables the identification of the environmental factors that best explain the variance pattern of the response of water quality (Sliva and Williams, 2001). Thus, the environmental conditions which may be monitored can be defined. Subsequently, a combination of 12 environmental factors were identified through the preliminary analysis. Table 3 shows the results obtained for the first four axes over two seasons. The eigenvalues associated with the axis and the water quality-environment correlation indicate that to what extent the environmental factors explain the water quality response. The statistical significance of the relationship between water quality parameters and the selected set of environmental factors based on the sum of all canonical eigenvalues were found to be both significant (p<0.05) for all canonical axes together over two seasons. The sum of all canonical eigenvalues retained 64.5% and 68.2% of the total variance over dry season and rainy season, respectively. The first two RDA axes had 77.2% and 73.4% of water quality-environment correlation over two seasons, respectively. Hence, they could be employed to explain the relationship between the environ-

Table 3 Statistical summary of RDA for dry season and rainy season

Data set*	*p*	Sum of all canonical eigenvalues	Cumulative percentage of canonical variance by axes 1–4			
			1	2	3	4
Dry season	0.022*	0.645	49.6	77.2	88.3	93.3
Rainy season	0.012*	0.682	46.7	73.4	85.7	91.9

Notes: *: The full set of 12 environmental factors was used; *p*: based on 499 permutations, tests of significance of all canonical axes gave identical results

mental factors and water quality parameters..

Table 4 shows the importance of environmental factors in descending order with significance testing results over two seasons. RL is the most important environmental factor, which explaines 35.4% of the spatial variation in the total variance, and DA is the second key environmental factor, which explains 17.0% of the spatial variation in the total variance over dry season. The result implies that RL and DA, as the most important emission source, play a key role in explaining the variance of water quality, which are the key environmental factors of NPS pollution export over dry season (Li and Li, 2008; Liu et al., 2008). Environmental factors have the approximate importance over rainy season, however, SL and DA are the key environmental factors based on *p* value, which explains 29.3% of the spatial variation in the total variance together. The results in this study suggest that the variance of water quality between two seasons is dominated by different key environmental factors, in which RL and DA are the most important predictors of water quality over dry season and the roles are exchanged by DA and SL over rainy season.

Table 4 Importance and significance level of environmental factors

Environmental factor	Dry season Importance	Dry season *p*-value	Environmental factor	Rainy season Importance	Rainy season *p*-value
RL	0.23	0.002	RL	0.10	0.056
DA	0.11	0.022	DA	0.10	0.022
FL	0.05	0.168	SL	0.10	0.036
DD	0.05	0.182	TNs	0.08	0.078
SP	0.05	0.230	NDVI	0.07	0.064
MRE	0.03	0.216	MRE	0.07	0.092
PCP	0.03	0.228	OM	0.04	0.108
OM	0.03	0.340	PCP	0.04	0.232
NDVI	0.03	0.394	SP	0.03	0.276
K	0.02	0.818	K	0.02	0.602
TNs	0.01	0.628	FL	0.02	0.752
SL	0.01	0.830	DD	0.01	0.714

Note: The full names of environmental factor codes are the same as those in Table 1

3.3 Impacts of key environmental factors on water quality

3.3.1 Environmental factor-water quality linkages

In the whole basin, water quality parameters showed different spatial variance between two seasons in the correlation with the first two RDA axes, respectively (Table 5). As for dry season, the first axis revealed quite a few gradients associated with organic pollutants, nitrogen (NH_4^+-N and PON) and phosphorus (DP and PAP). Among the environmental factors, RL was best correlated to this axis, indicating a gradient optimal to these pollutants export, as opposite to PCP and the topographic conditions (SP, MRE and SL) (Table 6). The second canonical axis described a pollution gradient primarily connected with DN, and moreover the other gradients in relation to SS and phosphorus pollutants were also observed. Drainage area showed a preferable gradient to DN, SS and TP_w export, however, PCP gave an opposite interpretation.

Table 5 Scores of water quality parameters with the first two axes of RDA over two seasons

Parameter	Dry season		Rainy season	
	Axis 1	Axis 2	Axis 1	Axis 2
TN_w	0.7441	–0.7070	–0.8094	0.9273
TP_w	0.8554	0.8252	–1.0625	–0.5335
SS	–0.4813	–0.8909	–0.8378	–0.6970
DN	0.4279	1.1597	–0.4772	1.1996
DP	0.8467	0.5958	–0.7588	0.0809
NH_4^+- N	0.8467	–0.5958	–0.6633	0.1541
NO_3^-- N	0.3190	0.3484	–0.5117	1.0259
PON	0.8839	0.2345	–0.9869	–0.1115
PAP	0.9545	–0.2844	–0.9885	–0.6632
COD_{cr}	1.0798	0.0934	–0.2473	–0.3846

Over rainy season, the first axis was characterized by a gradient mainly concerned with the solid pollutants, and furthermore DP also displayed another gradient correlated with this axis (Table 5). The environmental factors poorly correlated with this axis, and the soil conditions (K and TNs) revealed the gradients unfavorable to these pollutants export in contrast with DA (Table 6). The second canonical axis delineated a gradient of dissolved nitrogen, especially NO_3^--N. Both PCP and RL correlated to this axis indicated the gradients preferable to dissolved nitrogen export. This axis could be further explained by scrutinizing one factor (RI), which was excluded due to colinearity.

Table 6 Canonical coefficients of environmental factors with the first two axes of RDA over two seasons

Factor	Dry season		Rainy season	
	Axis 1	Axis 2	Axis 1	Axis 2
PCP	–0.5815	–0.5214	0.0366	0.7060
MRE	–0.6884	–0.0069	–0.0522	–0.2095
SP	–0.8009	0.0538	–0.0252	–0.4146
SL	–0.6765	–0.0712	–0.1429	–0.1464
K	0.2553	–0.3152	0.4459	–0.0618
OM	–0.0809	0.1597	0.0704	–0.2120
TNs	–0.2290	–0.2200	0.4035	–0.2563
NDVI	–0.1216	–0.2502	–0.2045	–0.0632
FL	0.6013	–0.0468	0.1662	0.1862
RL	0.8461	–0.3163	0.2413	0.6037
DA	–0.0146	0.6222	–0.4086	–0.0979
DD	0.0366	–0.1464	0.0955	–0.0509

3.3.2 Pattern of environmental factors and spatial distribution of water quality

In terms of sub-basins, the similar characteristics of water quality in some sites were determined by similar pattern of environmental factors. Thus the RDA-triplot of sub-basins, water quality parameters and environmental factors based on the first two axes were developed to show the relationship among the three ones. The scale in S.D. units was –1.5 to 1.5 for both water quality parameters and environmental factors. Sub-basin assemblages based on the similar characteristics of water quality were observed in a few zones under certain pattern of environmental factors. Over dry season (Fig. 2), zone Ⅰ was situated primarily in the space composed of the first two RDA positive axis. COD_{cr}, NO_3^--N and TP_w, including DP and PAP were in zone Ⅰ and increased with DA and RL. The favourable water quality in relation to DA and the topographic condition appeared in zone Ⅱ. However, it was most likely caused by a little pollution emission source (RL) in despite of steep topographic condition within the sub-basins in the upper basins of the Shuangyang River, the Chalu River and the Yinma River (Fig. 1). Zone Ⅲ showed an export of SS correlated positively with PCP and negatively with DA. The export of NPS pollutant in zone Ⅳ was dominated by nitrogen, especially NH_4^+-N, which was connected greatly with RL.

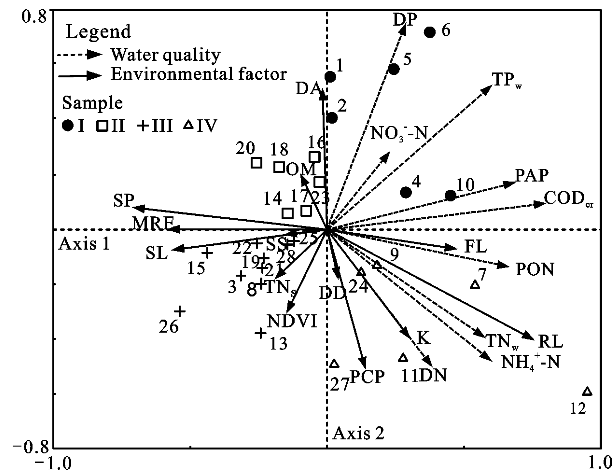

Fig. 2 RDA-triplot of samples, water quality and key environmental factors over dry season

Over rainy season (Fig. 3), zone Ⅰ showed favorable water quality associated mainly with interaction between PCP and RL. Precipitation would decrease the concentration of pollutants in the stream through dilution effect, thus the favorable water quality was mostly likely to be observed in this zone with high precipitation in despite of a great amount of RL. In addition, the same water quality in zone Ⅰ with low precipitation was commonly caused by a little pollution emission source from urbanized areas. The nitrate as the main nitrogen export was observed in zone Ⅱ, which was dominated jointly by PCP, RL and DA. PON, SS and various forms of phosphorus as the predominant pollutants in zone Ⅲ were closely correlated to DA.

Generally, drainage area is correlated with the distance and time of pollutant transportation, namely the dynamic retention and degradation of pollutants will increase with the distance and time of pollutant transportation in a drainage (Li and Li, 2008). However, large catchment area leading to more pollution export in this study was attributed to the positive correlation between DA and SP over two seasons.

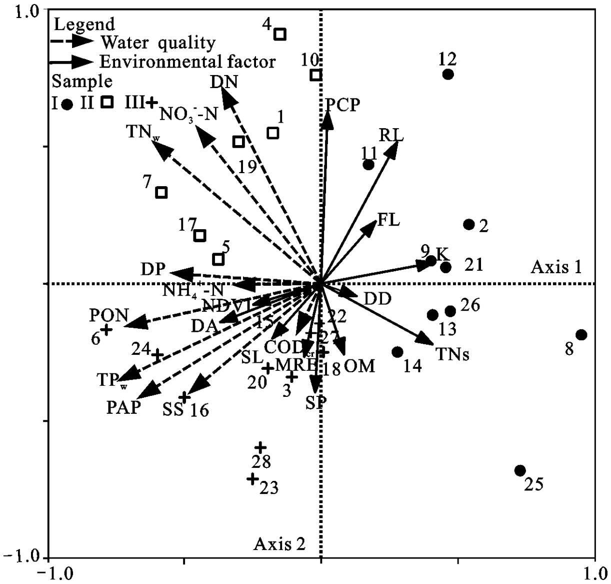

Fig. 3 RDA-triplot of samples, water quality and key environmental factors over rainy season

3.3.3 Influence of key environmental factors on water quality under different patterns

T-values biplot gave the statistical significance between key environmental factors and water quality parameters, and between key environmental factors and other environmental factors. Over dry season, RL was highly positively correlated with SL, K, TNs and negatively correlated with FL, OM, MRE (p<0.05) (Fig. 4). Under the pattern of environmental factors, RL was significant in positive correlation with COD_{cr} and nitrogen export, including TN_w, DN, NH_4^+-N and PON (p<0.05). It suggested that NH_4^+-N was the most important form of DN export and the watershed urbanization would greatly promote nitrogen export by increasing NH_4^+-N and PON discharge. In addition, DA was highly positively correlated with SL, NDVI and negatively correlated with K, FL, MRE (p<0.05). Under the pattern, DA was positively related with COD_{cr} and phosphorus export, including TP_w and DP (p<0.05). It indicated that DP was the main form of phosphorus export, and a large drainage area would greatly enhanced TP_w export by increasing DP drainage. Thus, RL and DA considerably influenced export of nitrogen and phosphorus, respectively, while COD_{cr} was controlled jointly by DA and RL. As for SS, no high correlation with any environmental factor, implying that export of SS was attributed to interaction of environmental factors.

Over rainy season, completely different pattern of environmental factors and characteristics of water quality were observed (Fig. 5). DA was highly positively correlated with FL and DD and negatively with TNs and MRE. Under the pattern, the positive correlation between DA and phosphorus export (TP_w and PAP) indicated that PAP was the main form of phosphorus export, therefore a large drainage area would greatly enhance TP_w export by increasing PAP loss from soil erosion.

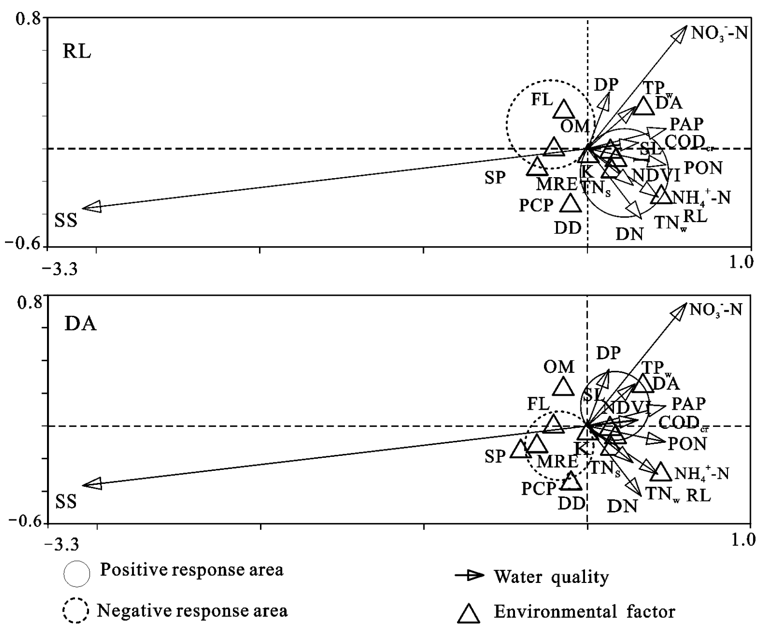

Fig. 4 T-values bioplot for statistical significance testing of key environmental factors over dry season

Furthermore, DA was highly positively correlated to PON rather than TN_w, suggesting that PON was not predominated in nitrogen export. An increase in nitrogen export was not considerable but would still be observed based on PON loss from soil erosion with increasing DA. It should be noticed that OM was a minor environmental factor, while it significantly controlled certain form of NPS pollutant export. OM was greatly positively correlated with MRE, SP and K and negatively with SL, DD, DA, FL and PCP. Uner the pattern, OM was in greatly negative correlation with TN_w and TP_w ($p<0.05$), implying that PON was the most important form of nitrogen export and high content of OM would significantly reduce nitrogen export by restricting PON transport based on soil erosion. Similarly, OM was significantly negatively related to phosphorus export, including TP_w, DP and PAP, indicating that OM in soil could considerably constrain phosphorus export by decreasing DP and PAP loss. Therefore, OM dominated phosphorus export, while DA significantly affected phosphorus and nitrogen export with influence on phosphorus export more than on nitrogen export. OM influence export of NPS pollutant, because adequate levels of soil organic matter are essential to maintain or improve chemical fertility, soil porosity, infiltration capacity, moisture retention and resistance to water erosion (Apezteguía et al., 2009). Furthermore, COD_{cr} and SS were not greatly correlated to individual environmental factor, suggesting that organic pollutant and SS export were attributed to interaction of environmental factors. No NPS pollutants were influenced by SL, although it was one of the key environmental factors.

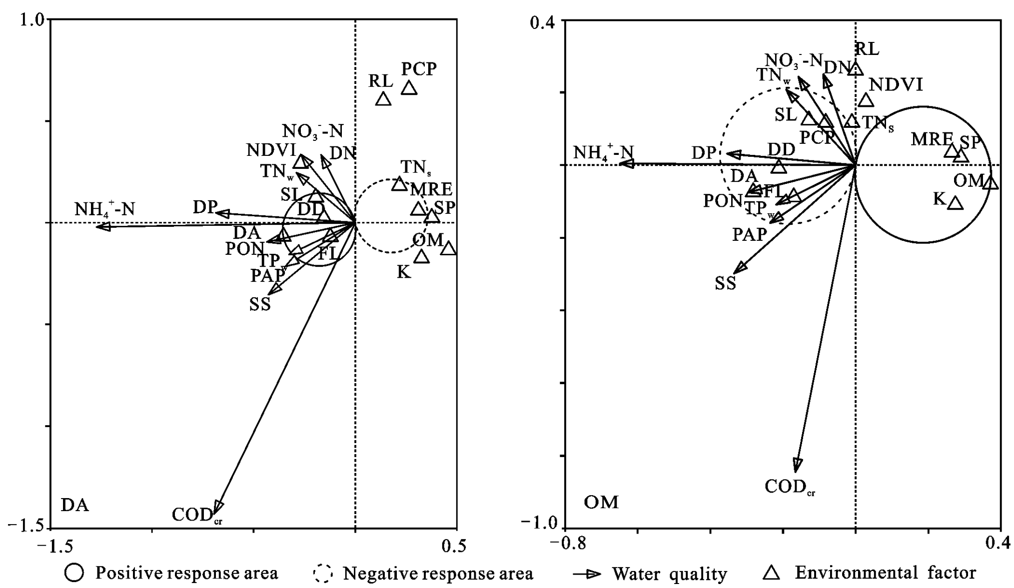

Fig. 5 T-values bioplot for statistical significance testing of key environmental factors over rainy season

4 Conclusions

This investigation identified the key environmental factors under different patterns of environmental factors influencing water quality in the upper Shitoukoumen Reservoir Basin in Jilin Province. It revealed the export-controlling mechanism of the key environmental factors in the NPS pollutants.

The results show that all selected environmental factors accounts for 64.5% and 68.2% of the spatial variation of water quality over dry season and rainy season, respectively. The key environmental factors varies along with environmental factor patterns over dry season and rainy season. Over dry season, RL is the most important environmental factor possessing 35.4% of the spatial variation of water quality, and DA is the second key environmental factor possessing 17.0% of the spatial variation in the total variance. Over rainy season, SL and DA are the key environmental factors possessing 29.3% spatial variation in the total variance together.

RL influences nitrogen export by changing NH_4^+-N and particulate PON discharge over dry season. DA controls phosphorus export by regulating DP drainage over dry season and PAP loss over rainy season, respectively. Although SL is the important environmental factor, no NPS pollutant export is controlled by SL.

It is worthwhile pointing out that OM is a minor environmental factor, however, it highly determines the phosphorus and nitrogen export by enhancing DP, PAP and PON losses. COD_{cr} is subject to RL and DA. Difference in export of SS is attributed to the change in the pattern of environmental factors between dry season and rainy season.

The preliminary result shows that there is clear difference in the pattern of environmental factors, which is worth further investigation. In this study, the use of existing databases that were not thoroughly developed with clear aims can, at best, be used for tentative exploratory and hypothesis-generating purposes. Further investigations will require a better designed spatial and temporal sampling regime as well as higher resolution digital maps with more soil classes and environmental factors, such as animal production, fertilizer and manure applications.

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