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Community Characteristics of the Macrozoobenthos and River Health Assessment in Headwater Streams of the Pihe River Basin, China

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ABSTRACT

The Pihe River is one of the main tributaries of the Huaihe River in Anhui Province, China. In recent years, with the socio-economic development, the ecological environment within the basin has been seriously damaged. In order to understand the community structure of macrozoobenthos and assess the river health in headwater streams of the Pihe River, field investigation was conducted in six headwater streams in April 2015. The results showed that: 1) a total of 67 species were collected from the six streams. The species number was relatively higher in Manshui Stream and Maotan Stream, and it was 49 and 47 species, respectively; the species number in the other four rivers (Banhe Stream, Shangdong Stream, Qinglong Stream and Xipihe Stream) had little difference, and they were 30, 31, 29 and 30 species, respectively. 2) The results of one-way ANOVA and similarity analysis showed that there were no significant differences in the average species number in each sample of the six streams, and there was high species similarity among the six streams. 3) The density and biomass of macrozoobenthos in the whole study area were 439 ind./m^2 and 4.54 g/m^2, respectively. The Qinglong Stream showed the minimum density and biomass among the six streams, which were 328 ind./m^2 and 1.85 g/m^2, respectively. However, the result of ANOVA showed that there were no significant difference in the density and biomass of macrozoobenthos in the six streams. 4) The results of redundant analysis (RDA) showed that the main environmental factors affecting the spatial distribution of macrozoobenthos in headwater streams of the Pihe River were the sediment type, stream order, and total nitrogen. The eigenvalues of the first two axes were 0.107 and 0.085 respectively, which contributed to 19.1% of the total variance. 5) The health of the six streams was evaluated based on the arithmetic mean values of four indexes. The results showed that the health status of the Qinglong Stream was general, while other streams were good. The results of this study are of great importance to the protection and management of the Pihe River basin.

INTRODUCTION

Headwater stream is generally located in the high altitude mountainous areas, which is the source tributary of large rivers (Wang et al. 2013). Compared with large river, headwater stream generally shows simple ecosystem structure, low species diversity, and weak resistance to the disturbance, and will be more difficult to recover if suffering human destruction (Grossman et al. 1990). In addition, the health status of headwater streams will directly affect the physicochemical characteristics and species diversity of large rivers, and ultimately affect the health of large rivers. Thus, it is necessary to carry out field monitoring and health assessment of headwater streams. Macrozoobenthos is the important secondary producer in the headwater stream ecosystem, which plays significant roles in material circulation and energy flow (Wetzel 2001). Meanwhile, the macrozoobenthos contain many sensitive species and pollution tolerance species, and has the characteristics such as wide range of distribution, longer life history, and weak migration. Hence, the macrozoobenthos can response sensitively to the changes of external environment (Barbour et al. 1999), and it has been generally considered as an ideal fauna to assess the river health.

The Pihe River located in the territory of Anhui Province, is one of the right bank main tributaries of Huaihe River, and is also an important water source in the middle reaches of the Huaihe River. Considering the high vegetation coverage and abundant precipitation, the Pihe River belongs to the mountain creek-perennial-river (Anhui Local Record Compilation Committee 1999). The Pihe River's headwater streams can be divided into the east and west regions. The east region originates from the northern foot of the Dabie Mountains in Yuxi County, while the west region originates in Tiantang Town of Jinzhai County. The streams in both regions are heading north, after the confluence in Lianghekou of Liu'an City, it is named as the Pihe River (Fig. 1). The Pihe River has a total drop of 456 m and an average annual runoff of 496 million m^3, which accounts

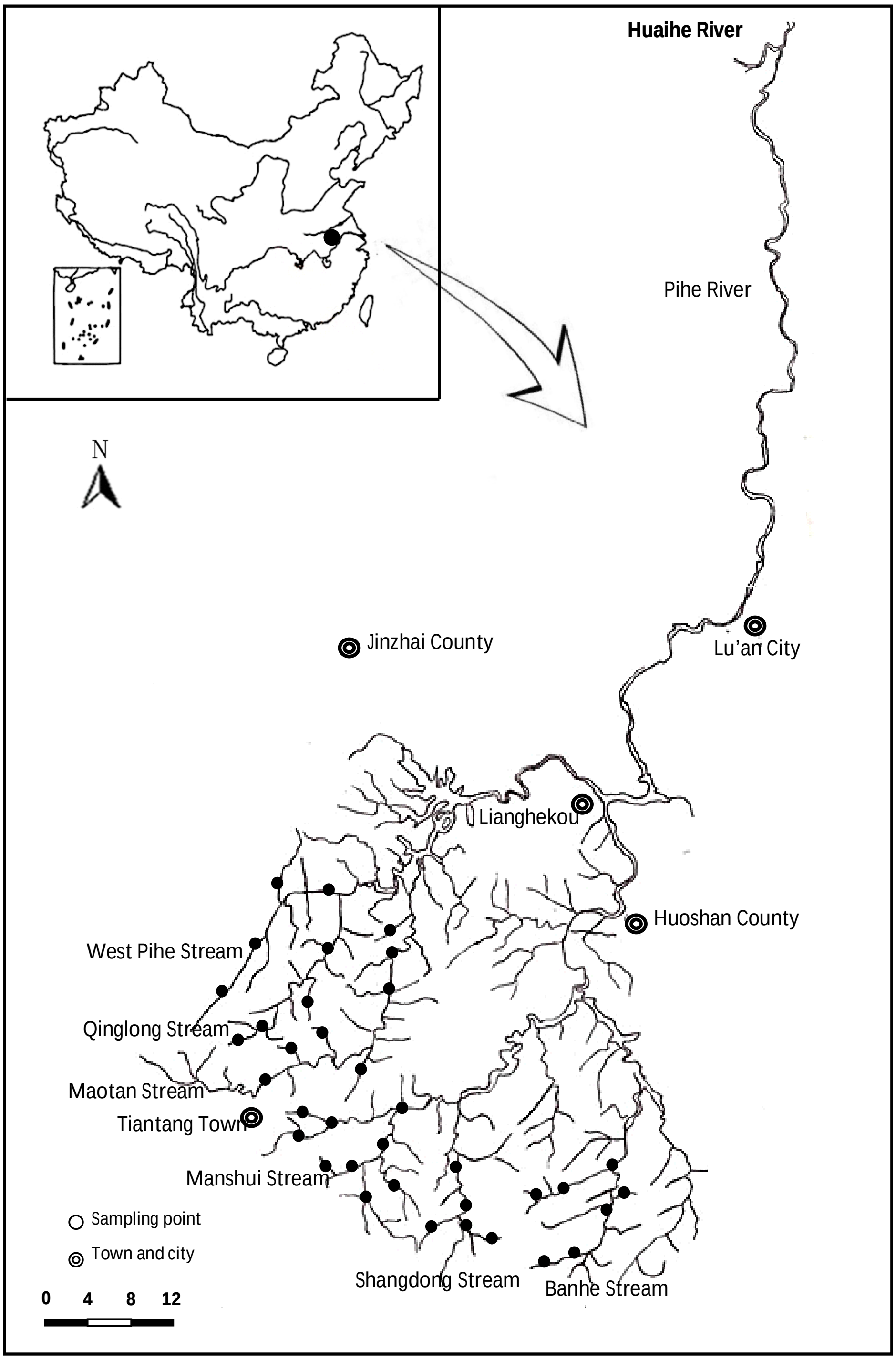

Fig. 1: Distribution of the sampling points in six headwater streams of the Pihe River basin.

for 20.1% of Huaihe River in Anhui Province. The Pihe River basin belongs to the subtropical monsoon climate zone with an area of over 6,000 km^2, and an average annual temperature of 14 to 15°C. Due to the serious sand excavation, dam construction, and irrational use of land in the basin, the Pihe River's ecological health has been seriously damaged in recent years, which was listed as one of the key rivers need to be restored by the government.

At present, the study of macrozoobenthos in the Pihe River basin has not been reported. In this study, the macrozoobenthos in six headwater streams of the Pihe River basin were investigated in April 2015. The main objectives are: 1) To understand the species diversity and community characteristics of the macrozoobenthos in headwater streams of the Pihe River; 2) To determine the main factors affecting the spatial distribution of macrozoobenthos in headwater streams; 3) To assess the health of headwater streams based on the macrozoobenthos data. The results of this study are not only important for the protection and utilization of the macrozoobenthos resources in this basin, but also provide a scientific basis for the management of the Pihe River.

MATERIALS AND METHODS

Sampling method: The macrozoobenthos in six headwater streams of the Pihe River was investigated in April 2015. The streams selected in west region are the west Pihe Stream, Qinglong Stream and the Maotan Stream, and streams selected in east region are the Manshui Stream, Shangdong River and the Banhe Stream. According to the river network complexity and field reachability of different streams, 4-9 samples were set in each stream, and a total of 36 sampling points were set in the whole headwater area (Fig. 1). At each sampling point, a surber net (length × width: 30 × 30 cm) was used to quantitatively collect the macrozoobenthos once at left, middle and right of the river, respectively (Zhang et al. 2014), and the total sampling area was 0.27 m^2. The specimens were manually sorted and placed in a white dissection disc. Then, the macrozoobenthos specimens were fixed with 10% formaldehyde solution, and brought back to the laboratory for identification, counting and weighing. According to the published data (Morse 1994, Wang 2002), most species were identified to the genus or species level, and a small portion was identified to family or class level. The wet weight of macrozoobenthos was measured using a balance with 0.0001g accuracy. Relative density or relative biomass ≥ 3% was considered as the standard for the dominant species.

Measurement of environmental factors: At each sampling point, the macrozoobenthos and the relevant environmental factors were measured simultaneously. The environmental factors were divided into two categories: local habitat parameters and water chemistry parameters. Local habitat parameters contain altitude, water depth, water width, flow rate, water temperature, dissolved oxygen, conductivity, turbidity, and sediment type. The chemical parameters contain pH, total nitrogen (TN), total phosphorus (TP) and ammonia nitrogen (NH_3-N). The altitude was measured using hand-held GPS (Garmin etrex type). The water depth was measured by a laser range finder (Trupulse 200). The water depth and flow rate were measured by a portable flow meter (Global FP211). The water temperature was measured by a digital thermometer. Dissolved oxygen, conductivity and turbidity were measured by portable dissolved oxygen meter (Rex JPB-607A type), conductivity meter (Rex DDBJ-350 type) and turbidity meter (Rex WZS-185 type), respectively. The type of sediment was determined by visual scoring method. It was divided into 6 grades: 1 (< 0.06 mm), 2 (0.06-1 mm), 3 (2-5 mm), 4 (15-63 mm), 5 (64-256 mm), 6 (> 256 mm) (Wang et al. 2013). The water samples were collected at left, middle and right of the river in each point, respectively. Then the mixed water samples were taken back to the laboratory for determining the TN, TP and NH_3-N using standard methods. The pH value was measured *in situ* using a portable pH meter (Rex PHB-4).

Statistical analysis: One-way ANOVA was used to test the difference between environmental factors of the six headwater streams and the difference between the species number, density and biomass of macrozoobenthos. If there was significant difference, Turkey multiple comparisons were used to examine the differences between groups. Sorensen similarity analysis was used to test the species similarity between six streams. The formula was $S = 2c / (a + b)$, where S is the similarity coefficient, c is the number of species shared by two streams, a and b are the numbers of species for each of the two streams, respectively. CANOCO software was used to analyse the relationship between macrozoobenthos and environmental factors. The species matrix is constructed using the density data of macrozoobenthos (Pan et al. 2008). In order to satisfy the assumption of homogeneous and normal distribution of the data, log (x + 1) was used to transform the data. The detrended correspondence analysis (DCA) was first applied to evaluate the type of response model. Based on the results of DCA, the redundancy analysis (RDA) was chosen to determine the relationships between species and environmental parameters. In order to assess the stream health, four indexes were used in this study as follows (Department of Nature and Ecology Conservation, Ministry of Environmental Protection, China 2014):

1. ***Number of classification unit (S)*:** The number of classification unit of all macrozoobenthos present in a sampling point.
2. ***EPT family-level classification unit ratio (EPT)*:** The proportion of family-level classification unit of macrozoobenthos Ephemerida (E), Plecoptera (P) and Trichoptera (T) in the total family-level classification unit in a sampling point.
3. ***BMWP index (BMWP)*:** The formula is $BMWP = \Sigma t_i$, where t_i is the sensitive value of the i species based on the family-order classification in a sampling point.

4. ***Berger-Parker dominance index (D)*:** The formula is $D = N_{max} / N$, where N_{max} is the individual number of the most dominant species in a sampling point; N is total individual number in a sampling point.

The above four indexes were standardized firstly, then the arithmetic mean values of the four indexes were calculated and evaluated according to the following grades: excellent ($0.8 \le N < 1$), good ($0.6 \le N < 0.8$), general ($0.4 \le N < 0.6$), relatively poor ($0.2 \le N < 0.4$), and poor ($0 \le N < 0.2$) (Department of Nature and Ecology Conservation, Ministry of Environmental Protection, China 2014).

RESULTS

Environmental parameters: The environmental parameters of the six headwater streams in the Pihe River are listed in Table 1. The altitude, flow rate, conductivity, TN, TP and NH_3-N levels among the six streams had significant differences ($P < 0.05$). With the increase of altitude, the flow rate of six streams increased significantly, while the conductivity, TN, TP and NH_3-N decreased significantly. There were no significant differences in the other seven parameters (Table 1).

Species composition: A total of 67 species and 66 genera were collected from the six streams. The oligochaeta had 3 species, accounting for 4.5% of the total species; the mollusca had 2 species, accounting for 3.0% of the total species; the arthropoda had 60 species, accounting for 89.6% of the total species; and the others had 2 species, accounting for 3.0% of the total species (Table 2).

The total species number of macrozoobenthos among the six streams had large difference, and the Manshui Stream and the Maotan Stream exhibited the largest number of species, which was 49 and 47 species, respectively. The species number found in the Banhe Stream, Shangdong Stream, Qinglong Stream, and the west Pihe Stream had little difference, and it was 30, 31, 29 and 30, respectively. The analysis of the average species number in each site of the six streams showed that the species numbers of the Banhe Stream, Mandong Stream, Manshui Stream, Maotan Stream, Qinglong Stream, and the West Pihe Stream were 10, 12, 15, 15, 14 and 14 species, respectively, which exhibited no significant difference ($F = 0.856$, $P = 0.522$).

Species similarity analysis: Aquatic insects are the main taxa in the six streams, while other groups are rare. Species similarity analysis showed that the similarity of the six streams was higher than 50% (Table 3). In particular, the Maotan Stream and the Manshui Stream had the maximum similarity of 79%, while the Qinglong Stream and the Banhe Stream had the minimum similarity of 51%.

Density and biomass: The density and biomass of the macrozoobenthos in the whole study area were 439 ind./m^2 and 4.54 g/m^2, respectively. The oligochaeta, mollusca, and arthropoda accounted for 3.7%, 0.1% and 95.1% in density, and 0.1%, 5.8% and 93.6% in biomass, respectively.

The density and biomass of the macrozoobenthos in the six streams are shown in Fig. 2. The Maotan Stream had a maximum density of 492 ind./m^2; while the Qinglong Stream had a minimum density of 328 ind./m^2. The Manshui Stream had the highest biomass of 6.34 g/m^2; while the Qinglong Stream had the smallest biomass of 1.85 g/m^2. However, the ANOVA analysis showed that there were no significant difference in density and biomass of macrozoobenthos among the six streams ($P > 0.05$).

Main influencing factors: The RDA analysis and the Monte Carlo permutation tests indicated that the sediment type, stream order, and TN had significant effects on the spatial

Table 1: Environmental parameters of six headwater streams in Pihe River basin (average ± SD).

	Banhe Stream	Shangdong Stream	Manshui Stream	Maotan Stream	Qinglong Stream	West Pihe Stream
Altitude (m)	552.7 ± 227.2^{ab}	663.8 ± 198.7^{a}	389.9 ± 74.0^{ab}	397.9 ± 127.4^{ab}	392.3 ± 170.7^{ab}	290.3 ± 104.7^{b}
Sediment type	4.6 ± 0.5	4.6 ± 0.6	3.4 ± 0.8	4.0 ± 0.8	3.6 ± 0.9	3.9 ± 0.9
Flow rate (m/s)	1.2 ± 0.7^{a}	0.8 ± 0.2^{ab}	0.4 ± 0.2^{bc}	0.5 ± 0.3^{abc}	0.5 ± 0.2^{abc}	0.3 ± 0.2^{c}
Water depth (cm)	56 ± 24	48 ± 17	32 ± 7	37 ± 11	36 ± 34	40 ±13
Water width (m)	24.3 ± 22.7	14.3 ± 13.1	13.8 ± 10.0	21.5 ± 19.5	9.6 ± 11.0	10.8 ± 6.3
Water temperature (°C)	11.5 ± 1.9	11.4 ± 2.9	13.7 ± 3.0	12.4 ± 2.3	12.3 ± 1.0	15.0 ± 2.8
pH	7.67 ± 0.08	7.50 ± 0.16	7.83 ± 0.21	7.67 ± 0.11	7.54 ± 0.20	7.55 ± 0.35
D.O. (mg/L)	9.3 ± 3.6	10.7 ± 0.5	10.3 ± 0.6	10.3 ± 0.4	9.9 ± 0.2	9.9 ± 0.4
Conductivity (µS/cm)	34.08 ± 11.15^{ab}	27.52 ± 6.41^{a}	52.57 ± 18.13^{ab}	65.43 ± 18.62^{b}	75.30 ± 27.02^{b}	74.10 ± 21.24^{b}
Turbidity (NTU)	4.0 ± 3.2	2.6 ± 1.5	13.5 ± 11.3	6.6 ± 2.1	3.3 ± 1.5	11.8 ± 14.2
TN(mg/L)	0.42 ± 0.45^{a}	0.68 ± 0.63^{a}	1.28 ± 0.65^{b}	0.83 ± 0.48^{ab}	2.22 ± 0.41^{b}	1.58 ± 0.21^{b}
TP(mg/L)	0.045 ± 0.027^{ab}	0.016 ± 0.007^{a}	0.046 ± 0.043^{ab}	0.063 ± 0.041^{b}	0.099 ± 0.050^{b}	0.074 ± 0.069^{b}
NH_3-N(mg/L)	0.04 ± 0.02^{ab}	0.02 ± 0.01^{a}	0.05 ± 0.01^{abc}	0.07 ± 0.03^{bc}	0.08 ± 0.01^{bc}	0.10 ± 0.05^{c}

D.O. = Dissolved oxygen; The different superscript letters in the table indicate significant differences ($P < 0.05$).

Table 2: Species composition of macrozoobenthos in six headwater streams of the Pihe River basin.

	Code	Banhe Stream	Shangdong Stream	Manshui Stream	Maotan Stream	Qinglong Stream	West Pihe Stream
Annelida							
Oligochaeta							
Nais variabilis	Nav		+		+	+	+
Nais sp.	Nas	+	+	+	+		+
Enchytraeidae	Ens		+				
Mollusca							
Gastropoda							
Bellamya sp.	Bes			+			
Radix sp.	Ras			+			
Arthropoda							
Crustacea							
Atyidae	Ats				+	+	+
Potamidae	Pos				+		
Insceta							
Baetis sp.	Bas	+	+	+	+	+	+
Pseudocloeon sp.	Pss	+	+	+	+		+
Heptagenia sp.	Hes	+	+	+	+	+	+
Cinygmula sp.	Cis			+	+		
Epeorus sp.	Eps	+	+	+	+	+	+
Potamanthus sp.	Pot			+	+	+	
Ephemerella sp.	Eps	+	+	+	+		+
Ephemera sp.	Eph			+	+	+	+
Vietnamella sp.	Vis	+	+	+	+	+	+
Leptophlebia sp.	Les	+		+	+	+	+
Rhithrogena sp.	Rhs			+			
Caenis sp.	Cas			+	+	+	+
Perlidae	Pes	+	+	+	+	+	+
Chloroperlidae	Chs	+	+				
Nemouridae	Nes		+			+	
Leuctridae	Les		+		+		
Hydropsyche sp.	Hys			+	+		+
Cheumatopsyche sp.	Chs			+	+		+
Potamyia sp.	Psp	+	+	+	+	+	
Stenopsyche sp.	Sts	+	+	+	+		+
Leptocerus sp.	Lep	+	+	+	+	+	+
Pseudostenophylax sp.	Pse	+	+	+	+	+	+
Molannidae	Mos			+			
Odontoceridae	Ods		+				
Sericostomatidae	Ses				+		
Psychomyiidae	Pss		+	+			
Polycentropodidae	Pol	+					+
Philopotamidae	Phs	+		+	+		
Phryganeidae	Phr	+			+		
Megalogomphus sp.	Mes		+	+	+	+	
Leptogomphus sp.	Lsp			+			
Aeshnidae	Aes				+		
Calopterygidae	Cas			+	+		
Aphelocheiridae	Aps			+	+		
Corixidae	Cos				+	+	
Hydrophilidae	Hys	+	+	+			
Psephenidae	Pep			+	+	+	+
Gyrinidae	Gys	+		+	+	+	+
Stenelmis sp.	Stp	+	+	+	+		+
Eoophyla sp.	Eos				+		
Protohermes sp.	Prs	+		+	+		+
Neochauliodes sp.	Nes			+		+	+
Tipula sp.	Tis		+				

Table cont....

...Cont. Table

Hexatoma sp.	Hes		+	+	+	+	+
Antocha sp.	Ans	+	+	+	+		+
Muscidae	Mus			+			
Tabanidae	Tas			+	+		
Simulium sp.	Sis	+	+	+	+	+	
Bezzia sp.	Bep	+		+	+	+	+
Polypedilum sp.	Pol		+	+	+	+	+
Microchironomus sp.	Mis	+					
Rheotanytarsus sp.	Rhs	+					
Tanytarsus sp.	Tas			+			
Stictochironomus sp.	Sti	+		+			
Parachironomus sp.	Pas			+	+		
Paratanytarsus sp.	Pap	+	+	+	+	+	
Orthocladius sp.	Ors		+	+	+	+	+
Rheopelopia sp.	Rhp	+	+	+	+	+	+
Others							
Turbellaria sp.	Tus	+	+	+	+	+	
Arachnoida sp.	Ars					+	
Total		30	31	49	47	29	30

distribution of macrozoobenthos. Fig. 3 shows the RDA two-dimensional bioplots for species-environmental variables. The eigenvalues of the first and second axis were 0.107 and 0.085, respectively, which contributed to 19.1% of the total variance. The sediment type and TN mainly contributed to the first axis, while the stream order mainly contributed to the second axis.

River health assessment: The assessment results of the six streams based on the arithmetic mean values of the four evaluation indexes are given in Table 4. The mean values of the Banhe Stream, Shangdong Stream, Manshui Stream, Maotan Stream, Qinglong Stream, and the West Pihe Stream were 0.69, 0.65, 0.71, 0.69, 0.56 and 0.62, respectively. In accordance to the set level, except that the health of the Qinglong Stream was general, the other five streams were good.

DISCUSSION

Community characteristics: Water pollution, species diversity decrease, and ecosystem degradation have become the common problems faced by most river basins at present (Zhang et al. 2014). Due to the particularity of headwater streams, the biological diversity and health of headwater streams should receive more attention from human. The results of this study showed that a total of 67 species of macrozoobenthos were collected in the headwater streams of the Pihe River basin, which mainly composed of aquatic insects, while fewer oligochaeta and mollusca. Compared with the adjacent headwater streams from the Qingyi River basin and Changjiang River basin in the southern Anhui mountain, the species number in the Pihe River basin is slightly higher than that in the Qingyi River (56 species) (Zhang et al. 2014), while far below than that in the Changjiang River (116 species) (Hu et al. 2005). Headwater streams are generally located in high altitude area, with low nutrient content and large flow rate (Vannote et al. 1980). In the long term evolution, many aquatic insects have formed the corresponding adaptation strategies, such as the larvae of Heptageniidae with flat body, larvae of *Baetis* with streamlined shape, larvae of Trichoptera with stone shell to resist the water, and some larvae of Diptera with suckers to fix to the stones (Hershey & Lamberti 1998). However, the Oligochaeta and Mollusca exhibit relatively weak ability to adapt to such habitats, and thus the species number was low. Moreover, the main reason for the low diversity of macrozoobenthos in headwater streams of Pihe River may be due to the large number of water conservancy projects. Similar to the Qingyi River basin, many low-head dams (water can diffuse from the dam) appeared in headwater streams of the Pihe River for irrigation and domestic water. They changed local habitat parameters such as flow rate, water temperature and sediment type, which inevitably resulted in changes in macrozoobenthos community structure and species diversity. For the six streams, the Manshui Stream and the Maotan Stream have the largest species number of macrozoobenthos, probably due to more sampling points been set in the two streams. However, the average species number in each point of the six headwater streams had no significant difference, which suggests that the spatial heterogeneity of the macrozoobenthos in headwater streams of Pihe River may be low. Species similarity analysis showed that the similarity of the six streams was higher than 50% (Table 3), and the main reason may be

Table 3: Species similarity of macrozoobenthos in six headwater streams of the Pihe River basin.

	Banhe Stream	Shangdong Stream	Manshui Stream	Maotan Stream	Qinglong Stream	West Pihe Stream
Banhe Stream	100%					
Shangdong Stream	66%	100%				
Manshui Stream	63%	60%	100%			
Maotan Stream	62%	56%	79%	100%		
Qinglong Stream	51%	60%	62%	68%	100%	
West Pihe Stream	63%	56%	68%	73%	68%	100%

Table 4: Results of river health assessment based on macrozoobenthos in Pihe River basin.

	Standardized diversity index					
	Number of classification unit (S)	EPT index	BMWP index	Berger-Parker dominance index (D)	Arithmetic mean	Health status
Banhe Stream	0.56	0.95	0.46	0.79	0.69	Good
Shangdong Stream	0.53	1.00	0.48	0.59	0.65	Good
Manshui Stream	0.63	0.99	0.51	0.70	0.71	Good
Maotan Stream	0.59	0.99	0.51	0.66	0.69	Good
Qinglong Stream	0.36	1.00	0.39	0.49	0.56	General
West Pihe Stream	0.44	1.00	0.45	0.59	0.62	Good

the relatively similar climatic conditions. For the whole headwater area, the density and biomass of macrozoobenthos were 439 ind./m^2 and 4.54 g/m^2, respectively. Compared with some mountain rivers in the Yangtze River basin of China (Qu 2006, Duan et al. 2007, Zhang et al. 2014), the density is significantly lower than that of other rivers, while the biomass is only lower than that of the Qingyi River headwater area and the tributary of the Qingjiang River. It indicated that there is large variability in different rivers at large spatial scales. Among the six streams, the Qinglong Stream had the lowest density and biomass, indicating that it could suffer from more serious human disturbances.

Influencing factors and river health assessment: The relationship between macrozoobenthos and environmental factors has been extensively studied. In this study, the results of RDA analysis showed that the main factors affecting the spatial distribution of macrozoobenthos in the Pihe River headwater area were the sediment type, stream order, and TN. Sediment can provide a variety of habitats for macrozoobenthos and play key role in the growth, reproduction and other important life stages of macrozoobenthos (Duan 2010). Many studies have shown that the sediment was the main environmental factor that affects the community structure and spatial distribution of macrozoobenthos, which is mainly related to the particle size, heterogeneity, stability, compactness, particle gap, and surface structure of the sediment (Pan et al. 2008, Duan 2010, Peng et al. 2013). The stream order may indirectly influence the diversity and species composition of macrozoobenthos, mainly by changing the food particles size. Since the River Continuum Concept has been proposed (Vannote et al. 1980), it has been widely used in the river ecology research. The theory suggests that with the increase of the stream order, the dominant species of macrozoobenthos are shredders, scrapers and collectors from top to bottom, according to their use of corresponding food particles (Vannote et al. 1980), and the species diversity is the greatest in the middle order stream (Minshall et al. 1985). Although some researches have questioned the theory (Melo & Froehlich 2001), its correctness has been widely verified. TN represents the effect of nutrients on macrozoobenthos. Some studies have shown that macrozoobenthos diversity is negatively correlated with TN content in water. With the increase of nutrition level, some sensitive species disappeared while the number of pollution resistance species increased (Duan et al. 2010).

Nowadays, the biological assessment of the river health has been paid more and more attention due to its advantages that the chemical evaluation and monitoring cannot match. In the present study, the assessment results of the six streams showed that the health of the Qinglong Stream was general, while the other streams were good, indicating that the Qinglong Stream might have suffered from more serious human disturbance. Field survey of six streams found that human disturbance was obviously related to the altitude. In

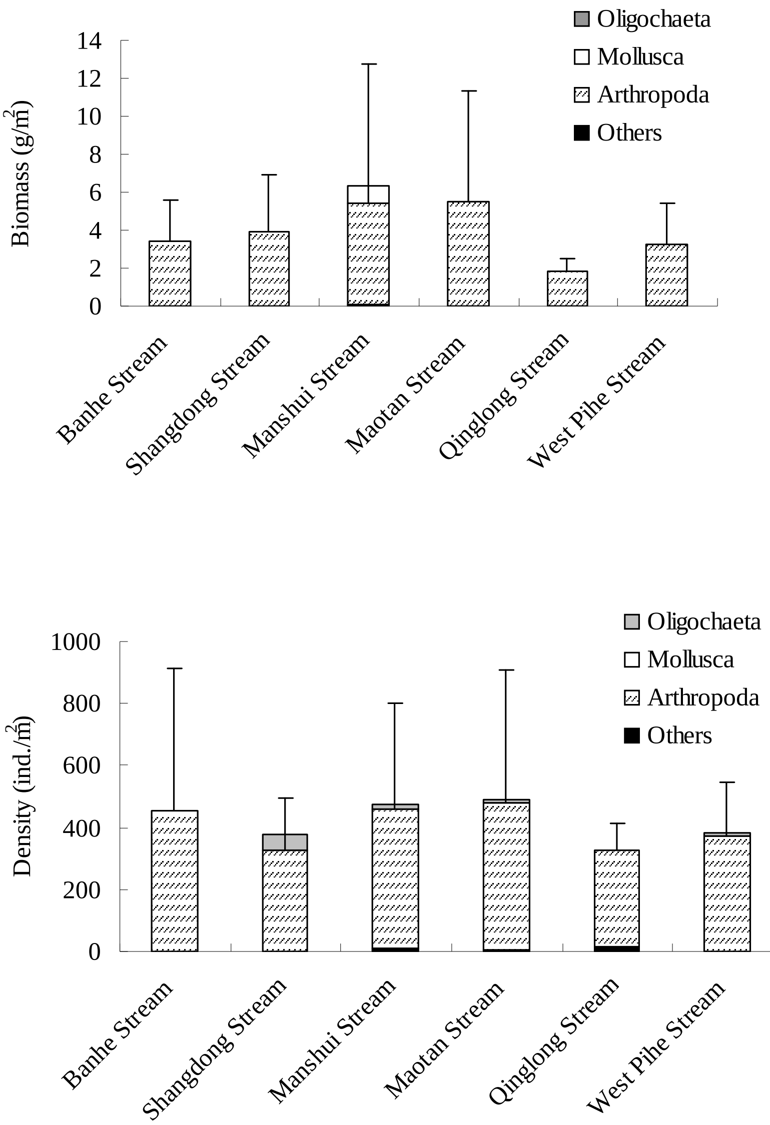

Fig. 2: Biomass and density of macrozoobenthos in six headwater streams of Pihe River basin.

general, low-altitude stream is more suitable for human habitation, resulting in high population density, so the interference is serious, while the high-altitude stream is completely opposite. In this study, the altitudes of the Banhe Stream and the Shangdong Stream were significantly higher than the other four streams, and the TN, TP and NH_3-N levels of them were significantly lower than those of the other four streams, which provide good proof for the point of view mentioned above. In addition, the assessment results are consistent with the water chemistry parameters. The Qinglong Stream and the West Pihe Stream exhibited the highest nutrient content among the six streams, and the health assessment score of them were the lowest. Based on the above results, we propose the following recommendations: 1) Illegal sand mining still exists in the mountain stream. Enforcement should be increased and the illegal sand mining should be banned stoutly; 2) The construction of the low-head dam in the stream obviously changed the community structure and diversity of the macrozoobenthos. Therefore, it is necessary to restore the free hydrological connectivity of the mountain streams, and create a variety of habitats for the aquatic organisms; 3) Low-altitude stream is more suitable for human habitation, which generally suffers greater human disturbances. Watershed management should pay

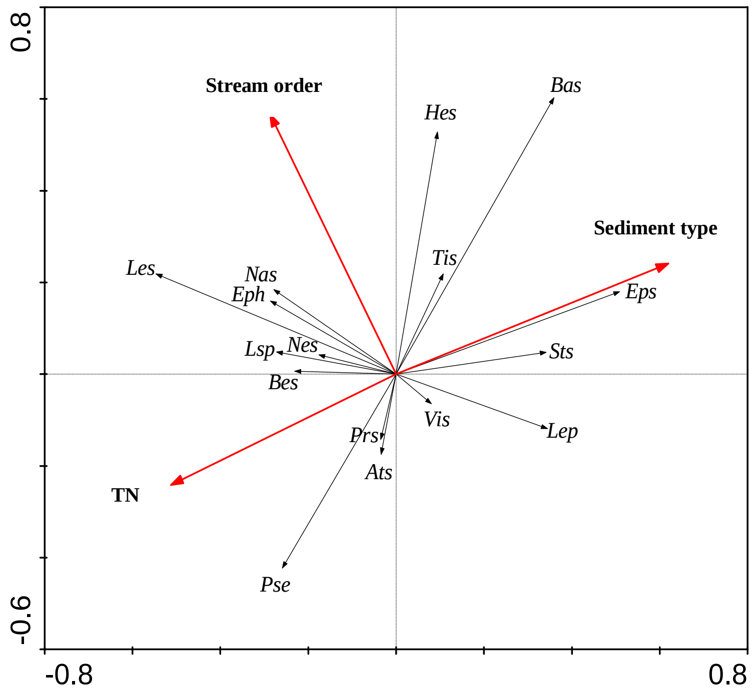

Fig. 3: Redundancy analysis for the correlation between macrozoobenthos distribution and environmental factors (only the significant correlation factors and dominant species are shown, and the full name for each abbreviation can be found in Table 2).

more attention on the low-altitude stream; 4) Although the mountainous agriculture is underdeveloped, the tea plantation is very common in this basin. The input of a large amount of non-point source nutrients also affected the macrozoobenthos community structure. Therefore, it is suggested to actively adjust the agricultural structure and develop healthy, pollution-free, green industry and tourism. If the above measures can be implemented, the health status of headwater streams in the Pihe River can be improved.

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