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River Water Quality Assessment in Selected Yangtze Tributaries: Background and Method Development

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ABSTRACT: Water pollution is among the most severe environmental problems in China, particularly in the vicinity of residential and urban areas. In almost all Asian countries, river monitoring is predominantly based on the analysis of chemical data. However, biological data are a worthwhile addition for the determination of the long-term ecological status of rivers and are particularly well-suited in case of steep pollution and disturbance gradients. A tool for river water quality assessment using benthic invertebrates has been developed for selected tributaries of the middle reach of the Yangtze River. Site selection was supported by a preclassification considering physico-chemical and hydromorphological conditions. Following a stratified sampling design, 34 samples were taken in small and large streams in the subtropical mountainous area of western Hubei (湖北) (China) covering a pollution gradient, accompanied by an extensive field protocol on stream characteristics and (physico-) chemical water analyses. The proposed assessment system is computed as an average score per taxon. The challenge to further consider the additional impact from global change into the development of such tools is discussed.

KEY WORDS: benthic invertebrate, biological assessment, ecological quality, organic pollution, Hubei, climate change.

INTRODUCTION

Freshwater Ecosystems under Pressure in China

Freshwater ecosystems are increasingly pressured by global change. Water availability, its quality, and its suitability as an aquatic habitat has been ever deteriorating due to an impact mixture from climate change, land use and management change, and direct human impact on water resources. At the same time, water resources are increasingly requested for drinking water, agricultural production, aquaculture, fishery, and transportation. China, with its 1.3 billion inhabitants,

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is the most populous country in the world, covering 9.6 million km^2. With 20% of the world's population, it has access to only 7% of the world's freshwater and thus faces particularly freshwater supply challenges. The large national area is characterized by different climate and geographic regions, resulting in densely populated lowlands and lower mountainous areas (with up to several thousand inhabitants per square kilometer) and only few people in the (western) mountainous parts (with less than 20 inhabitants/km^2). About 30% of the population lives in urban areas, which cover only about 1.5% of the countries area. The World Bank estimates that 1 out of 3 of the world's population with no safe access to drinking water and sanitation lives in China. Almost 90% of the urban population has access to water supply, but only 20% for the rural population (Ministry of Construction, 2005). Broadly, the sanitation coverage is only 40%, resulting in heavy organic pollution of rivers. Although China is generally perceived as a growing and very well going economy, this inevitably means high pressure on the environment. For water related problems, this means a more and more complex pollution mix, from industrial, urban, and agricultural waste to pesticides. Infrastructure investments for water supply have been increasing in recent years, but the management of water and sanitation services is characterized by overdesign, lack of community participation, or lack of concern for water quality.

Technologies for the improvement of water quality are in principal available for different scales, ranging from purification plants using mechanical, biological, and chemical steps to small-scale solutions targeting the wastewater of individual villages or even houses. Also, many Asian countries including China have recently passed state-of-the-art water-quality standards and related legislation: in 2002, the water law was revised, and now, it focuses much more on management of water resources within the river basin context. Besides economical development, the environment and the population situation now needs to be considered, and the new water law enhances water saving principles. At the moment, the implementation is stuck between contradictions of existing laws, including, e.g., the Environmental Protection Law, the Water Pollution Prevention and Treatment Law, the Flood Control Law, the Fishery Law, the National Reserves Management Regulation, and the involvement of different ministries, such as the Ministry of Water Resources, the State Environmental Protection Agency, and the National Development and Reform Commission. The government aims to give everyone access to safe drinking water by 2020 and is now changing its approach to water management, e.g., by a water sector reform, increasing community participation, and adopting integrated river basin management principles.

Assessing Freshwater Ecosystems

Water pollution is thus among the most severe environmental problems in China, particularly in the vicinity of most large settlements and urban areas. Pollution sources are manifold ranging from domestic/ municipal wastewater to various types of toxic substances. In some areas, activities for wastewater purification are underway, but large-scale application is not yet accomplished (Ministry of Construction, 2005). In the 20th century, the large European urban areas have tackled similar water quality problems successfully, thus reducing river pollution to a minimum (BMU, 2006). In most cases, biological methods have been used to monitor organic pollution, since they are not too much affected by diurnal and seasonal variability in pollution, relatively simple to apply, and can easily be adapted to local conditions. Various assessment approaches are available (e.g., Norris and Norris, 1995), as well as knowledge about how to develop integrative assessment systems employing a multimetric approach. In such an approach, a site's overall condition (under different anthropogenic impacts) is assessed by a combination of individual metrics (e.g., saprobic indices, diversity indices, feeding type composition, or current preferences) into a unitless measure (Hering et al., 2006a). However, in almost all Asian countries, river monitoring is predominantly based on the analysis of chemical data. As proven in Europe, Australia, and North America, biological data are a worthwhile addition for the detection of pollution and for the determination of the long-term ecological status of rivers. The EU Water Framework Directive now requires water body specific assessment of the ecological status of streams, lakes, and coastal waters, overall aiming at a ‘good ecological status’ by the year 2015 (EU Commission, 2007). This status is defined through the biota, which judges that it requires the availability of appropriate assessment systems now being widely available.

Biological data are particularly well suited for the determination of steep pollution and disturbance gradients. Thus, they seem to be especially suited for world regions, in which organic pollution is a major problem. Consequently, the first biological indicator systems (Saprobic systems) have been developed in the first years of the 20th century in Central Europe, when pollution was most apparent (Kolkwitz and Marson, 1909). The present situation in many urban areas of China is somewhat comparable to the European situation at that time. Benthic invertebrates are organisms sensitive to water pollution and other stress types affecting rivers, such as hydromorphological degradation, stagnation, and intense land use in the catchment (Hering et al., 2006b). The most obvious one is the effect of organic pollution, which is typically a result of municipal waste water or industries, such as paper mills and breweries. Organic pollution leads to oxygen depletion in the river, which results in the disappearance of some sensitive taxa; as a consequence, taxa being tolerant to oxygen depletion can become much more abundant. Knowledge on biological methods applicable for river quality monitoring is poor in most Asian countries. Nepal is an exception, due to a simple field-based method (NEPBIOS; Sharma and Moog, 1998), which has been used for the generation of first Water Quality Maps. The EU-funded project ASSESS-HKH (INCO-CT-2005-003659) aimed at developing biological water-quality monitoring methods for rivers in the southern foothills of the Hindukush-Himalayan region ranging from Pakistan in the west to Bangladesh in the east. However, the methods generated are not necessarily transferable to other regions in Asia without adaptation.

Until now, there are 251 water environment monitoring centers, 2 861 water quality monitoring stations in China, and all Chinese rivers, lakes, and reservoirs are monitored routinely. However, these monitoring units only focus on chemical parameters, such as pH, conductivity, dissolved oxygen, permanganate, ammonium, etc.. Other ecological factors are not included in the monitoring protocol. Ecological assessment of freshwater ecosystems is just in the beginning stage, with the first results being available from Jiang et al. (2005), Tang et al. (2006, 2004), or Qu et al. (2005).

DEVELOPING AN ASSESSMENT SYSTEM FOR A MODEL AREA

Background

To advance water-quality control by biological monitoring, we aimed to develop a tool for river water quality assessment in China. The tool was set up exemplarily for selected tributaries of the middle reach of the Yangtze River in the western part of Hubei

Figure 1. Thirty-four sampling sites were distributed in the western part of Hubei Province, China.

Province, China (Fig. 1). Since different species are occurring in different parts of the world, a simple transfer of an existing method to another region without adaptation is not feasible. However, existing assessment methods with benthic invertebrates build the basis, which are improved and adapted to the regional conditions in the study area.

These existing methods are as follows: NEPBIOS, a rapid assessment method, that has been developed for Nepalese rivers. It is based on family-level identification; the Screening Method used within the "Guidelines to assess the saprobiological quality of running waters in Austria" ("Module 1"), which has been developed by the University of Natural Resources and Applied Life Sciences in Vienna (Austria) (Department of Water, Atmosphere, Environment; Institute of Hydrobiology and Aquatic Ecosystem Management). Methods and protocols developed in the EU-funded project ASSESS-HKH (INCO-CT-2005-003659).

Approach

Benthic invertebrate sampling was performed at 34 sites in selected tributaries of the middle reach of the Yangtze River in the northwestern part of Hubei Province, covering a gradient from unpolluted (or slightly polluted) to heavily polluted river stretches with a focus on organic pollution by municipal wastewater (stratified sampling design). The sites had been preclassified according to the "Guidance manual for preclassifying the ecological status of Hindukush Himalaya (HKH) rivers" (Moog and Sharma, 2005); they were sampled in the pre- and postmonsoonal season of 2008. Sampling followed a standardized multihabitat sampling approach, where 20 subsamples representing the current habitat composition (total sampling area 1.25 m^2) are taken with a 500 μm shovel sampler. Parallel sampling of chemical and physical parameters (COD, phosphate, nitrate, nitrite, ammonium, oxygen, temperature, pH, and conductivity) was performed at all sites, and an extensive field protocol was filed. Samples were sorted and identified in the lab, mostly to family or genus level.

RESULTS

The measurements of physico-chemical parameters show the expected distribution, i.e., the water quality deteriorates for the sites that had been preclassified as moderate or bad (Table 1). Mean oxygen saturation was surprisingly low in the sites

Table 1 Overview of physico-chemical parameters for sites preclassified as high (*n*=8), moderate (*n*=7) and bad (*n*=5)

Parameter (mean)	Preclassification		
	High	Moderate	Bad
Conductivity (μS/cm)	248.28	269.66	378.20
Oxygen content (mg/L)	9.26	8.95	8.30
Oxygen saturation (%)	89.52	89.85	86.74
Ammonium (mg/L)	0.01	0.03	0.07
Nitrate (mg/L)	0.92	1.03	1.19
Orthophosphate (mg/L)	0.07	0.03	0.16

Table 2 Overview of benthic invertebrate data

Metric	Mean	Min.	Max.
Number of taxa	31.4	16	49
Number of Ephemeroptera, Plecoptera, Trichoptera taxa (sum)	17.9	5	33
Abundance (ind./m^2)	562.6	65.6	1 551.2

Mean, min. and max. are from all 34 samples.

preclassified as high, with values below 90%. Nutrients like orthophosphate and ammonium show a steep increase in the lowest water quality class (preclassified as "bad").

For the benthic invertebrate taxa as a whole, 116 genera were found at the 34 sites (Table 2). Altogether, 23 900 specimens in 70 families were identified. Within the groups of Trichoptera, Ephemeroptera, and Plecoptera, we found 27, 25, and 20 genera, respectively. The community composition for samples from sites preclassified as high or bad is significantly different (Fig. 2). The most obvious one is the decreasing mean abundance in the samples from 1 200 to 750 ind./m^2. Especially, the orders of Plecoptera and Trichoptera decrease, while Diptera increases to 42% in the sites preclassified as bad.

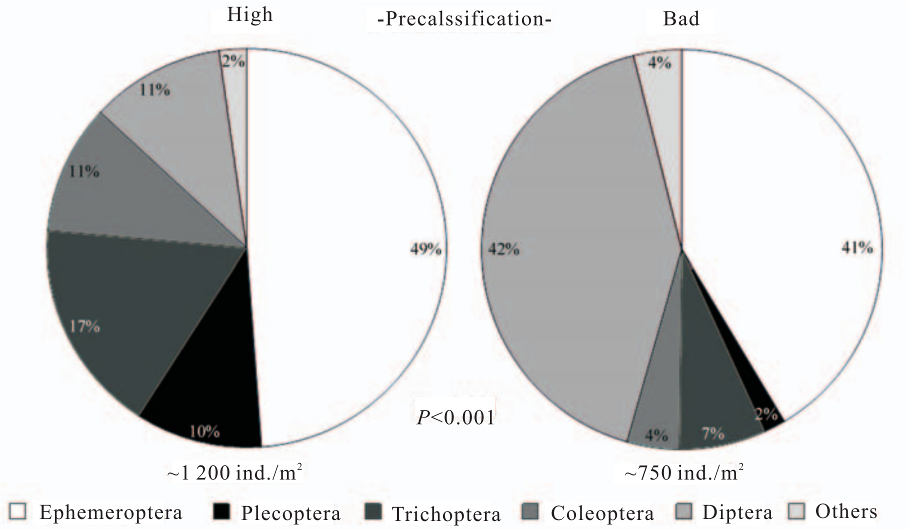

Figure 2. Comparison of community composition for samples from sites preclassified as high or bad.

DISCUSSION

Physico-chemical parameters and invertebrate communities reflect the preclassification of sites satisfactorily. Thus, the following working steps comprise of a correlation analysis of each individual taxon to chemical parameters to identify taxa closely bound to a certain level of pollution. Quality scores will be assigned to taxa or existing scores from NEPBIOS will be adapted, based on the results of the sampling campaign. An assessment formula will be developed, based on the NEPBIOS formula. The proposed assessment system is computed as an average score per taxon. The method based on benthic invertebrates will be supplemented by other parameters, such as environmental parameters recognizable in the field, e.g., waste disposal, foam or odors, or morphological degradation of banks and river bed. Finally, the method developed could be tested and adapted to other regions within China.

A special challenge lies in the consideration of additional impact from global change into the development of such tools. Climate change will impact freshwater ecosystems in many ways, either directly (NAO, temperature, precipitation, radiation, wind, and seasonality) or indirectly (related to land use change, mineralization, floodplain change, and groundwater change). Further complication arises due to interaction with other stressors, such as land use, nutrients, acid deposition, and toxic substances. Further, climate change has significant widespread consequences for the fauna of aquatic ecosystems that are strongly influenced by river channel stability, habitat fragmentation, water temperature, suspended sediment concentration, eutrophication, and riparian geomorphology. Climate change poses especially a considerable threat to aquatic biodiversity of high altitude and latitude ecosystems. It is predicted that aquatic communities are forced to move out of the original area (Parmesan and Yohe, 2003). Due to biogeographical isolation of many mountain ranges, increasing habitat loss and fragmentation and flow reductions migration opportunities for species will be severely reduced. Admittedly, how to consider such additional effects from global change within assessment systems, existing or under development, still remains to be a challenge.

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