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An estimation of ecological risk after dam construction in LRGR, China: Changes on heavy metal pollution and plant distribution

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Abstract

Dam construction has become one of the most controversial and wide-debated issues these days, mainly due to the unanticipated ecological risk it brings to river basin. Though the environmental impact caused by dam project has been reported in considerable literatures, most of them were concerned with the condition of aquatic ecosystem (e.g., hydrology, water quality, sediment, and aquatic fauna) with the potential risk of terrestrial ecosystem remaining unsettled. This study estimated the ecological risk on terrestrial ecosystem after dam construction by focusing on the heavy metal pollution and distribution of plant community in Lancang River of LRGR. The heavy metals were determined, and the plants were investigated in the reservoir and downstream of three dams built on the river. The results showed that notable changes had taken place in both objects, which indicated the existence of ecological risk on river ecosystem. This study might serve as the first step of computing dam-induced risk in whole-ecosystem scale.

Keywords: River ecosystem; Ecological risk; Heavy metal pollution; Plant distribution; LRGR

1. Introduction

It is reported that more than 45 000 large dams have been constructed around the world, of which China ranks first with a number of 22 265 and a percentage of 44.80%. Almost all rivers were intercepted by dams in varying degrees. The development of these dams alters the structure and function of river ecosystems, and the related ecological effects of these constructions on flow patterns, water quality, sediment etc. have led to increased concerns in recent years [1-4], especially in the Lancang River Basin, which is also the major concern of this study.

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Manwan, Dachaosheng, and Nuozhadu, are three large dams located on the downstream of Lancang River with the impoundments of water all been completed. The studies on the impact of these dams have become a center of attention recently, of which the changed condition of aquatic ecosystem has been fully assessed by ecologists. However, no inroad has been made hitherto as to the potential ecological risks of terrestrial ecosystem underlying these changes. This cannot be overlooked in that it plays a major role ecological security in the regional scale.

This study accomplished the analyses of heavy metals and plant community in the reservoir and downstream of the three dams respectively, serving as the first step to quantify dam-induced ecological risk in whole-system scale.

2. Study site

The Longitudinal Range-Gorge Region (LRGR), composed of the Hengduan Mountains that are related to the Tibetan uplift and the adjacent mountain-valley regions in south-north direction, lies in south-western China. LRGR is the major longitudinal biological corridors and shelter of Asian continent, and also an important ecological corridor of China towards Southeast Asia. Owning to the occupation of all kinds of ecosystems in the northern hemisphere except deserts and oceans, LRGR is acknowledged to have a high distribution of the world's species and thus serve as the world-class gene pool. Nevertheless, LRGR has its own vulnerability accounting for the scenario such as ecological fragile and disaster-prone; moreover, socio-economic development of large regional differentiation keeps on labializing the development of this region.

Four famous transboundary rivers flow through the LRGR, i.e., Yuan-Red River, Lancang-Mekong River, Nu-Salween River and Irrawaddy River. For three of them, cascade hydropower dams have been planned and some have been already constructed on the main channel. Specially, 15 cascade dams will be operating in Lancang River in 2015, of which 7 dams have already been put into use.

3． Material and methods

The 10m × 10m quadrate, and the 5m × 5m, 1m × 1m sub-quadrates were set to investigate plants of arbor layer, shrub layer and herb layer respectively. The quadrates and sub-quadrates of the same kind here were disposed as one plot for a convenient analysis. The disposal of plant investigation was conducted on reservoir and downstream simultaneously.

Gleason abundance index (I_G), Shannon-Wiener index (I_{SW}) and Simpson index (I_{SP}) were applied to represent the species diversity in the research area. Pielou evenness (uniformity J) was used to reflect the evenness of species abundance. Larger the species number is, evener the individual number distribution is, then higher diversity index will be obtained, and vice versa.

I. Gleason abundance index [22, 23]:

$$I_G = (S-1)/\ln A \tag{1}$$

where S represents species number, and A is the area of the plot.

II. Shannon-Wiener index [22-24]:

$$I_{SW} = -\sum_{i=1}^{S} P_i \log_2 P_i \tag{2}$$

where, $P_i = n_i / N$, is the individual number of the ith species, N theindividual number of all species.

III. Simpson index [22, 23]:

$$I_{SP} = N(S-1)/\sum_{i=1}^{S} n_i(n_i-1) \tag{3}$$

IV. Pielou evenness [22]:

$$J = I_{SW} / \log_2 S \tag{4}$$

Relevant data of the concerned river basin were derived from substantial field work in LRGR and the ensuing experimental analysis of the samples. All statistical analyses were conducted using Microsoft Excel 2007 and SPSS 13.0 software package.

4. Changes on heavy metal pollution and plant distribution

4.1 Heavy metal pollution

Seven soil heavy metals, i.e. As, Cd, Cr, Cu, Ni, Pb and Zn in the reservoir and downstream of the three dams were determined respectively in this study. The result showed that notable changes occurred in Manwan dam (Fig.1). Cr, Cu and Ni content were notably higher in downstream area, and Zn content was significantly higher in reservoir area, whereas no significant differences in As, Cd and Pb were discerned. Cr of downstream soil and Zn of reservoir soil reached a high level. As to Dachaoshan dam, soil heavy metals content were higher in downstream area almost in all elements, among which the differences of Cr, Cu and Zn were significant (Fig.2). Finally, similar with Dachaoshan dam, soil heavy metals content of Nuozhadu dam were higher in downstream area almost in all elements, among which the differences of Cr, Cu and Zn were significant (Fig.3).

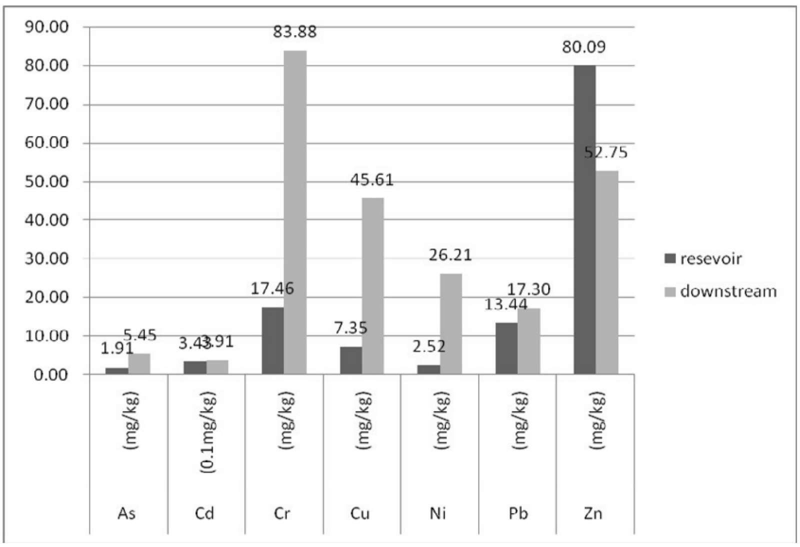

Fig.1 Soil heavy metal of reservoir and downstream of Manwan dam

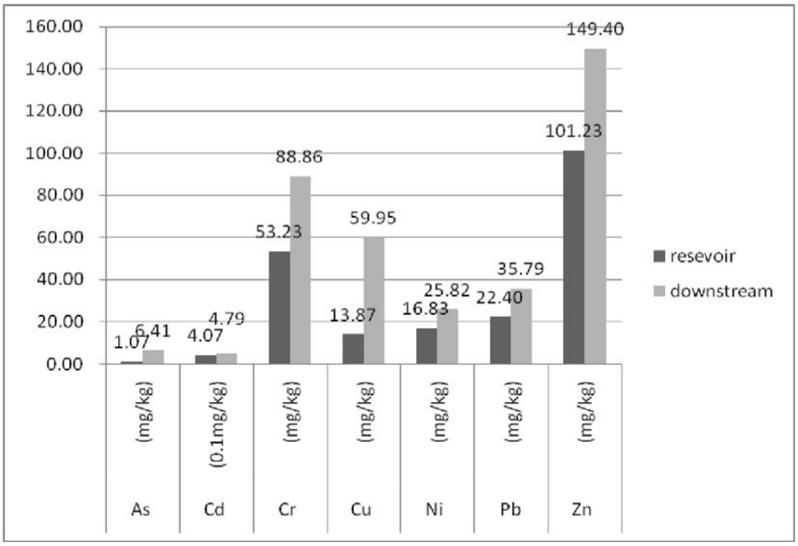

Fig.2 Soil heavy metal of reservoir and downstream of Dachaoshan dam

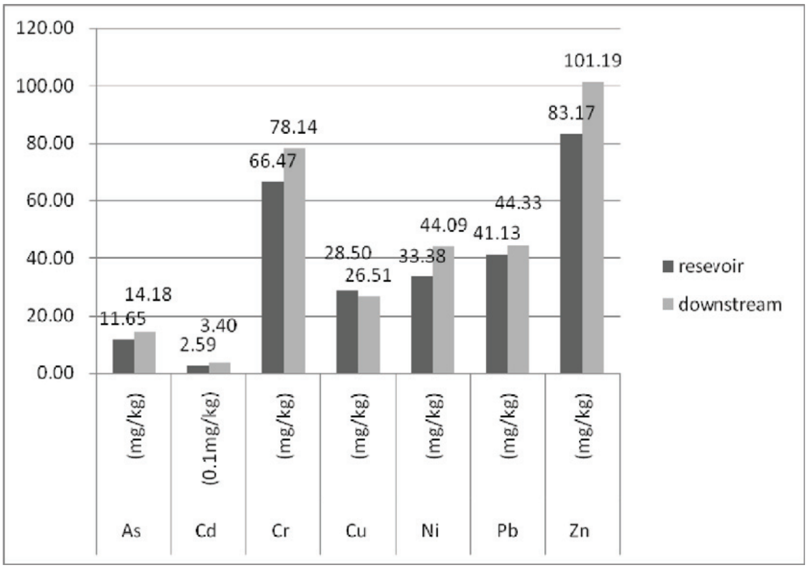

Fig.3 Soil heavy metal of reservoir and downstream of Nuozhadu dam

4.2 Plant distribution

The terrestrial flora species of reservoir and downstream of the three dams were investigated after dam construction parallelly (Table 1-3).

In Manwan dam, the results showed that the total individuals number and species number were larger in the reservoir ecosystem. An enhancement of species diversity index I_G, I_{SW}, I_{SP} and uniformity J were also discerned in reservoir area compared to downstream. In particular, shrub layer were abundant and widely-distributed in the reservoir area, while in downstream area, arbor layer were obvious. These results indicated that a redistribution of plant species during dam construction may occur.

In Dachaoshan dam, the terrestrial flora species number and total individuals number of downstream were larger than those in reservoir. Species diversity index I_G, I_{SW}, I_{SP} and uniformity J of all plant layers were almost all higher in downstream.

In Nuozhadu dam, the terrestrial flora species number and total individuals number of downstream were larger in reservoir than those in downstream. The distribution of plant species was relatively sparse, among which no plants of herb layer were observed. Species diversity index I_G, I_{SW}, I_{SP} and uniformity J of all plant layers were almost all higher in downstream.

Table 1 Terrestrial plant community of reservoir and downstream of Manwan dam

Sampling plots	Plant layer	Species number	Total number	Species diversity index			
				I_G	I_{SW}	I_{SP}	J
Reservoir	Arbor	13	76	2.82	2.55	0.61	0.69
	Shrub	17	107	3.69	3.57	1.50	0.87
	Herb	4	26	0.87	1.77	0.40	0.89
	Total	34	209	7.38	4.38	2.54	0.86
Downstream	Arbor	10	64	2.17	2.51	0.66	0.75
	Shrub	16	40	3.47	3.70	5.66	0.93
	Herb	5	44	1.09	1.93	0.34	0.83
	Total	31	148	6.73	3.82	2.98	0.77

Table 2 Terrestrial plant community of reservoir and downstream of Dachaoshan dam

Sampling plots	Plant layer	Species number	Total number	Species diversity index			
				I_G	I_{SW}	I_{SP}	J
Reservoir	Arbor	8	43	1.52	2.33	0.72	0.78
	Shrub	7	89	1.86	1.10	0.12	0.39
	Herb	2	25	1.44	0.24	0.09	0.24
	Total	17	157	3.47	2.70	0.47	0.66
Downstream	Arbor	8	11	1.52	6.37	4.33	2.13
	Shrub	12	119	3.42	2.59	3.40	0.72
	Herb	7	61	1.09	4.92	2.23	1.75
	Total	27	191	5.65	6.82	6.14	1.43

Table 3 Terrestrial plant community of reservoir and downstream of Nuozhadu dam

Sampling plots	Plant layer	Species number	Total number	Species diversity index			
				I_G	I_{SW}	I_{SP}	J
Reservoir	Arbor	3	12	0.65	0.82	1.27	0.74
	Shrub	9	27	1.95	2.92	2.36	1.33
	Herb	0	0	0.00	0.00	0.00	0.00
	Total	12	39	2.61	4.27	5.15	1.72
Downstream	Arbor	15	25	3.26	3.36	2.29	1.24
	Shrub	12	103	2.61	2.87	2.29	1.16

Herb	5	48	1.09	2.87	2.18	1.78
Total	32	176	6.95	1.43	5.28	0.41

5. Estimation of ecological risk after dam construction

Based on the result above, we can conclude that the three dams analyzed here showed different conditions. The total individuals and species of Manwan dam in the reservoir ecosystem outnumbered those in the downstream, and the plant species diversity index I_G, I_{SW}, I_{SP} and uniformity J showed the similar trend. When it came to Dachaoshan dam and Nuozhadu Dam, opposite changes were discerned, that is, total individuals number and species number of the downstream were larger, and I_G, I_{SW}, I_{SP} and uniformity J were higher. Species diversity can represent the distribution of various species and the succession stage of community and ecosystem. Different variation trends may indicate the different impact stage of these three dams due to completion in different times. Consequently, the ecological risks of terrestrial plant communities caused by dam contribution were at different degrees.

With respect to the heavy metals, Cr and Cu were found all higher in the downstream area of all dams, and all soil heavy metals were detected higher in downstream of Nuozhadu dam and Dachaoshan dam. The continuous dams building of the Lancang River are part of the cascading construction, and thus the degree of contamination of downstream area may be higher than measured respectively. Obviously, downstream suffers more ecological risks, and more likely to be affected by heavy metal contamination. Notwithstanding the influences from thespatial heterogeneity, the impact of dam project should be a major factor or an induced issue.

The different conditions of heavy metal and plant community might suggest that the three dams seem to stay at different stages in terms of ecological security. Notable dam-induced ecological risk of terrestrial ecosystem reflected the existence of threats to the security of Lancang River basin and LRGR. Amongthem, the reservoirs of Dachaoshan dam and Nuozhadu dam were subjected to more intensive risks, whereas the Manwan dam was attempting to strike a balance between the reservoir and downstream.

It is promising that an integral and quantitative ecological risk of the river ecosystem as a whole be estimated with more empirical analyses of dam-induced impact. In order to accomplish this estimation, some mathematical models such as ecological network modelmay qualify as a powerful quantifying method.

6. Conclusion

Presented in this paper is the analysis of changes on heavy metal pollution and plant community caused by dams in Lancang River of LRGR. The result showed that notable changes had taken place in both heavy metal pollution and plant community in all three dams, despite different degrees in different dams. The various stages three dams stayed imply the various scenarios of ecological security condition. The ecological risk on river ecosystem after dam construction might be estimated and predicted more comprehensively in the future via model analysis.

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