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Research Article

The Kraal River and Fish Ecological Status Fluctuation Based on the Cascade Dam Building

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2. Keywords:

Kraal river; Karst areas; Eco-hydraulic model system; Dam construction effects

1. Abstract

In China, the Karst water areas and the highest hydropower potential areas are overlapped, which mainly located at the Southwestern regions. In these areas, the Karst water areas have unique geological conditions and fragile environment and are largely affected by dam construction. The cutting-edge perspectives on Karst water environment include dam construction effects, water environment management strategy and aquatic species ecological assessment. The objective of this paper was to assess the dam construction effects and ecological status of Karst areas in the Kraal River basin, Guizhou Province, China. Factors affecting dam construction in karst areas are investigated. The ecohydraulic model system was used to assess the ecological impacts in downstream of Kraal River. The information from this study can be used for water environmental regulation and possible policy development in karst areas.

3. Introduction

In China, Karst areas are mainly located in the southwestern region, including the provinces of Guizhou and Guangxi. Meanwhile, with the hydro power plant construction, the citizen living in Karst areas could profit from their abundance of water resources by producing continuous source of energy. However, Karst areas are susceptible to a greater range of environmental impact problems than any other terrain, because of the additional set of difficulties associated with highly developed subterranean networks and associated fragile ecosystems [1]. In addition, the landforms of Karst processes pose many challenges for power plant construction and many countries with karst rocks has its share of failures such as construction of reservoirs that never held water [2]. In China, similar problems also existed in Karst areas in 1980s. Later, these reservoir problems have been significantly eliminated by the engineering experience which conducted by China Power Construction Corporation. In addition, the dam construction can provide benefits to both local communities and ecosystem status [3]. Despite all of this, reservoir and hydroelectric power plant construction may lead to disastrous impacts on aquatic species and result in numerous ecological problems where the effects of changes go beyond property boundaries. Meanwhile, it is meaningful to develop useful tools to quantify the impact of the ecological variables on aquatic species abundance and diversity.

Since 1980s, physical aquatic habitat models have been developed and applied to ecological management. For example, the Physical Habitat Simulation (PHABSIM) model, EVHA, in stream flow requirements (CASiMiR), Meso HABSIM, River2D, HABSCORE, and WW-ECO-Tools were applied to derive predictive relationships between aquatic species abundance and stream habitat features [4-7].These models are very useful for evaluating the aquatic habitat quality and have great scope of application including Karst areas. These physical habitat models are particularly useful for analyzing the ecological impacts caused by dam constructions, determining the habitat quality alteration caused by dam construction, and evaluating the influence on surrounding environments, such as analyzing the effects of dam construction on fish abundance.

Guizhou, China, which is one of the biggest and unique Karst landform and it, is also one of the most valuable hydropower generating water resource. Thus, constructions of dams are getting priority to be considered. However, the dam construction will pose a challenge for fauna habitat and aquatic species population. Therefore, it is necessary to investigate the effects of dam construction especially the geological stability analysis, large dam's effects on fauna ecological status and possible corresponding measures to avoid the after effects of hydropower development on Karst areas. The ob-

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jective of this paper is to assess the dam construction effects and ecological status of Karst areas in the Kraal River basin, Guizhou Province, China.

4. Methods

Based on the concept of habitat model, an ecohydraulic model system is proposed and applied to in this study to examine the hydro power plant construction effects on Karst water areas, Guizhou Province, China. The ecohydraulic model system contains three different models: hydrodynamic model, hydromorphology model and habitat model. The Kraal River and Garra fish (*Garrapingi*) were selected as target study river and fish species to test the ecological impact on downstream of Kraal River caused by hydroelectric power plant construction. Four important variables were chosen as suitability indicators and used to test the dam construction effects and ecosystem status. These variables are: Suitability Index Curve (SIC), Habitat Suitability Index (HSI), Weighted Useable Area (WUA), and Overall Suitability Index (OSI): Suitability index curves (SIC): SIC are physical parameters (velocity, water depth, and substrates) affecting the aquatic fauna (Garra fish (*Garrapingi*) was choose in here). The SIC ranges from 0 to 1, 0 for the worst and 1 for the best.

Habitat suitability index (HSI): HSI provides a method to assess the existing habitat conditions for fish within a study area by counting how well each habitat variable meets the habitat requirements of target species by life stage [10]. The HSI also ranges from 0 to 1 with 1 for the highest habitat suitability index and 0 for the lowest habitat suitability index.

Weighted useable area (WUA): WUA is the total surface area underling a certain combination of hydraulic conditions, multiplied by the composite probability of use for that combination of conditions (Payne, 2003). It is also can defined as an area of marginal habitat to an equivalent area of optimal habitat (Equ. 20).

Overall Suitability Index (OSI): OSI is defined as the ratio of the weighted usable area and surface area of the water. It's a non-dimensional values like SIC and HSI, which used to evaluate the aquatic fauna overall fitness in the river ecosystem. The value ranges from 0 to 1.

4.1. Study Area

The Karst study area discussed in this paper is located in Guizhou province, in the southwestern region of China (Figure 1).

The Karst area elevation ranges from 1600 to2400 meters above sea level. The area is characterized by unique hydrological and geomorphic features, including caves, peak cluster, peak forest and underground river system [8]. These geomorphic features make the geological condition in karst area more complex.

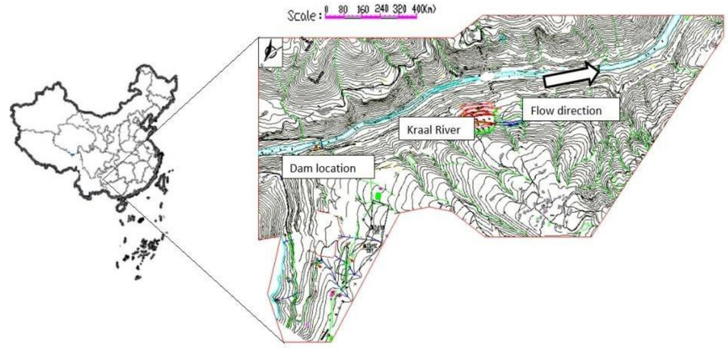

Figure 1: Study area of the karst areas and the location of the Kraal River.

4.2. Ecological Impact Assessment

The new developed ecohydraulic model system was used to assess the ecological impacts in downstream of Kraal River. The ecological impact indices are including Habitat Suitability Index (HSI), Weighted Useable Area (WUA), and Overall Suitability Index (OSI).The ecohydraulic model system is a numerical technique which consists of three components: hydrodynamic model, hydromorphology model and habitat model. The model is mainly used to assess the river hydraulic and aquatic speices ecohydraulic living conditions in the river.

4.2.1. Hydrodynamic and Hydromorphology Model: The dynamic hydraulic model was used to calculate the velocity and water depth in the Kraal River. The 2-dimentional (2D) shallow water equations governing the flow within the Karst areas are the continuity equation and the momentum equations and the k-ε turbulence model was also included. The hydromorphology model is used to calculate the substrate distribution and update the velocity and water depth values in the dynamic hydraulic model. River hydromorphology processes are based on sediment transport which is the transport of sediment particles by flowing water in the form of bed-load and suspended load. The sediment transport depends on the size of the bed material particles and the flow conditions. The sediment transport model is mainly focused on calculating bed-load, suspended load and riverbed deformation. Based on the result of bed-load, suspended load and riverbed deformation, riverbed grain size distribution including main grain size diameters and grain size fractions can be determined. In this paper, the focus is on the grain size distribution which is mainly based on the result of bed-load simulation.

4.2.2. Dynamic Habitat Model: After the velocity, water depth, and substrate load has been obtained from the hydraulic and morphology models, the physical values required by habitat model are obtained. The model is used to evaluate the Garra fish (*Garrapingi*) habitat status alteration caused by Trunk Dam construction. The Garra fish is the main fish species living in Traal River and was selected as a target fish to represent the typical species.

After the velocity, water depth and substrates distributions are calculated, the Suitability Index (SI) of these parameters are computed based on target fish preference. Then, the Habitat Suitability Index (HSI) is calculated based on the SI combination (Equation 1). The Garra fish (*Garrapingi*) HIC mainly rely on literature review, professional judgment, lab studies and field observations [9]. The value for both SI and HSI ranges from 0 to 1, with 1 representing best suitability and 0 representing least suitability. The substrate particle size is between 0.062 and 2.000 mm according to the field survey data and the SI belongs to the 0 to1.0 range based on the suitability index curves (Figure2).The SIC is from literature review.

The dynamic habitat model was developed by applying equal weight to variables of velocity, water depth and substrates Suitability Index (SI). The HSI scoring system shown in (Table 1) and the Habitat Suitability index (HSI) formula for each grid and each time step is as follows:

$$HSI_{i,t} = (SI_v \times SI_d \times SI_s)^{1/3} \quad (1)$$

Where SI_1, SI_2 and SI_R are the related suitability indices obtained from the fish SI curves.

The Weighted Usable Areas (WUA) and the Overall SuitabilityIndex (OSI) were used to do the habitat sensitivity analysis.

$$\text{wuA} = \sum_{i=1}^{M} A_i HSI_i \quad (1)(2)$$

Where A_i is the horizontal surface of mesh cell i(m^2), HSI_i is the habitat suitability index of mesh cell *i* and *M*is the nu2ber of meshes in the studied river stretch. The OSI is defined as the ratio of the weighted usable area and the total computational domain area in the horizontal plane:

$$OSI = \frac{\sum_{i=1}^{M} A_i HSI_i}{\sum_{i=1}^{M} A_i} \quad (2)$$

In order to further understand the habitat quality distribution in the river, the habitat quality can be divided into three classes accordingtothe HSIvalues(Table1): Ideal HabitatProportion(ISP), Middle Habitat Proportion (MSP), and unsuitable habitat proportion(LSP).The ISP,MSP and LSP describe the percentage of ideal, middle and unsuitable habitats in a study site.

Table 1: Categorizations of HSI for Garra fish (*Garrapingi*).

HSI categorization	Suitability for Garra fish (Garrapingi)
Low suitability	0≤HSI<0.3
Middle suitability	0.3≤HSI<0.7
Ideal suitability	0.7≤HSI≤1

$$ISP = \frac{\sum_{i=1}^{M} A_{i(HSI_i \geq 0.7)}}{\sum_{i=1}^{M} A_i} \times 100\% \quad (4)$$

$$MSP = \frac{\sum_{i=1}^{M} A_{i(0.3 \leq HSI_i < 0.7)}}{\sum_{i=1}^{M} A_i} \times 100\% \quad (5)$$

$$LSP = \frac{\sum_{i=1}^{M} A_{i(HSI_i < 0.3)}}{\sum_{i=1}^{M} A_i} \times 100\% \quad (6)$$

The model system was discretized using finite volume method to obtain the numerical solution. The three boundary conditions, i.e., inlet, outlet and wall boundary condition were applied. The stable hydrodynamic conditions were obtained to set as initial condition. The convergence and the accuracy of the model system have been tested and detailed model setup can be found in[10-11].

5. Results and Discussion

The ecohyraulic model system was applied to evaluate changes in the river ecosystem using Garra fish (*Garrapingi*) as an indicator. Values for HSI, WUA, OSI, ISP, MSP and LSP were simulated and used for the analysis of the ecological status. The ecological status of the river after dam construction was compared with the situation before the dam construction (Figure 3).

The simulated Habitat Suitability Index (HSI) distribution indicate that except the tail water areas, the other areas of the river were not much affected by the dam construction [12]. More specifically, ISP value is bigger than 0.3 before the dam has been constructed. Especially the upstream of river was found to be generally more suitable for the fish to living, while the downstream reach of the river are relatively less than ideal. After the dam was constructed, the tail water areas showed low HSI values. However, the area is relatively small (Figure 3).

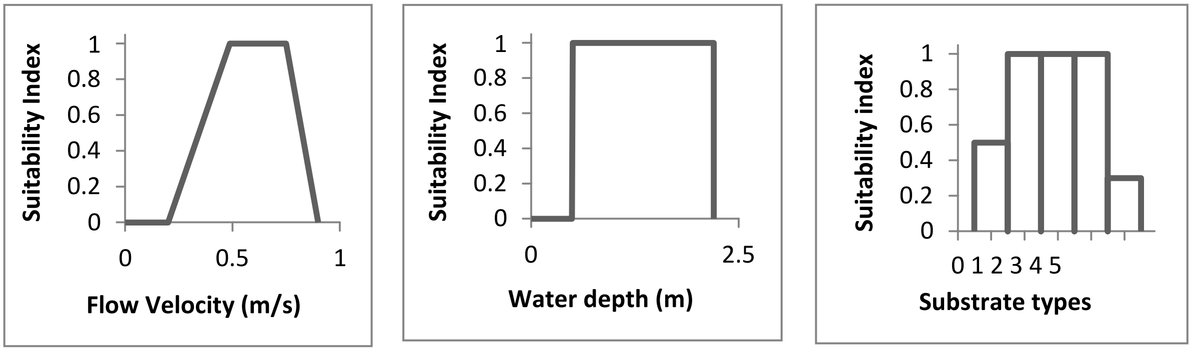

Figure 2: Suitability index curves for Garra fish (GarraPingi). (Substrate types: 1 = fine sand (particle size < 0.062 mm), 2= coarse sand (particle size 0.062-2.000 mm), 3= gravel (particle size 2.0-64.0 mm), 4= cobble (particle size 64.0-250.0 mm), 5= rock (particle size 250.0-4000.0 mm)).

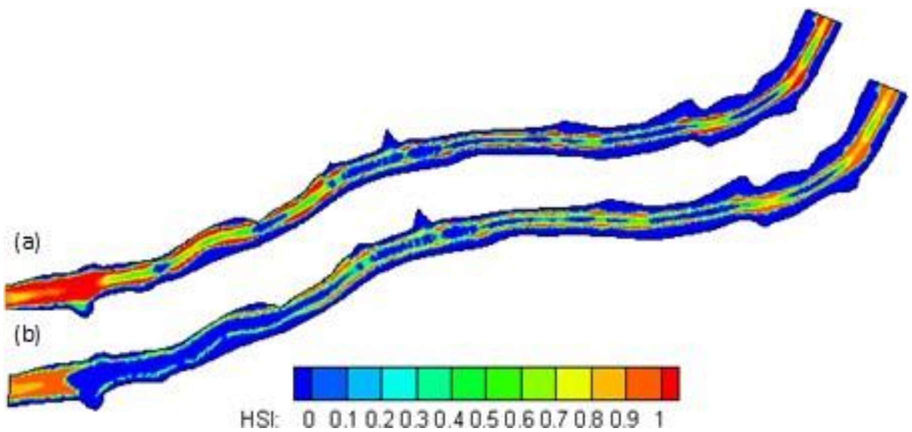

Figure 3: Simulated habitat suitability index (HSI) distribution: (a) before Trunk Dam construction, (b) after Trunk Dam construction.

After the dam was constructed, the WUA and OSI values were 7.35×10^4 m^2 and 0.21, respectively. When the long term ecological effects has been considered (12 months), both WUA and OSI values were shown slightly decreasing trends and then the WUA and OSI were kept at the level of 6.6×10^4 m^2 and 0.19 respectively (Figure 4). For the long term ecological effects, the ISP value was increased from 0.26 to 0.22 and the MSP value was keep unchangeable. However, the LSP value was shown slightly increased trend (Figure5). Overall, the long term ecological effects would not affect the whole river ecological status, which means that the dam construction would not have accumulation effects on the ecosystem of the river. The features and the application of the ecohydraulic model system indicated that dam construction does not affect the short term ecological status and also would not significantly affect the long term ecological status of the Garra fish in Kraal River.

The ecohydraulic model system can be used to determine the Garra fish's ecological status affected by reservoir management. This approach could help to determine ecological assessment standard on Karst water areas, provide guidelines for ecological status monitoring and also provide inputs for the ecohydraulic population model [8]. It should be noted that the ecohydraulic model system could easily adapt to other study areas including both karst and non- karst areas.

6. Conclusion

In this paper, the dam construction effects and ecohydraulic status assessment based on ecohydraulic model system were also analyzed. Indicators including HSI, WUA, OSI, ISP, MSP and LSP were simulated and used to determine the ecological status and ecological sensitivity. The Garra fish (*Garrapingi*) and Kraal River were selected as target fish species and typical karst areas. Through the analysis of typical karst areas, the ecohydraulic model system simulation result indicated that the habitat quality can kept in a relative stable level could meet the habitat requirement of Garra fish (*Garrapingi*) living in there.

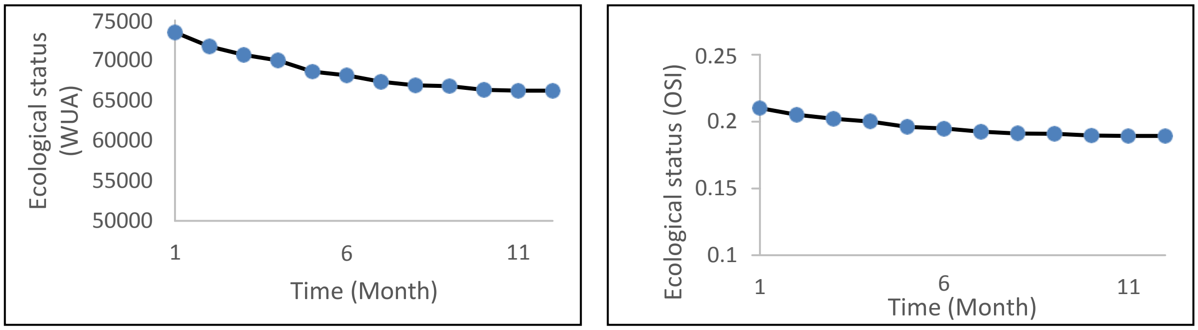

Figure 4: The long term WUA, OSI changes for Garra fish (*Garrapingi*) after the Trunk dam was built.

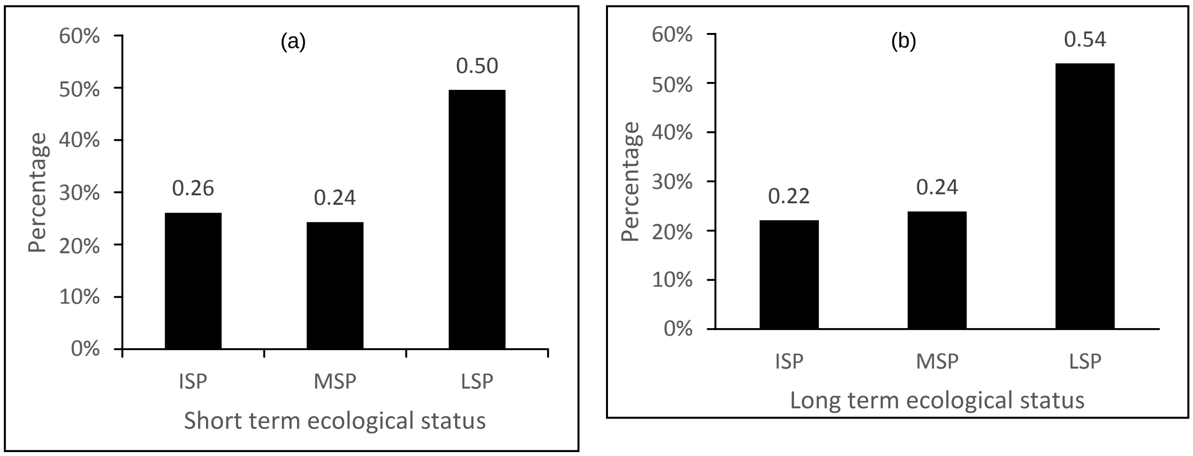

Figure 5: The proportion of ideal, middle and low suitable habitat indexfor before dam construction (a) and after dam construction (b).

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