Water quality analysis of Puzhehei Lake, China

Wei Li*, Jianying Wang, Shuqiang He
Department of Ecotourism, Southwest Forestry University, Kunming 650224, China

*Corresponding author e-mail: ww0592@gmail.com

Abstract. With the development of urbanization, a decline in water quality has become a major problem all over the world. The present study is conducted in Puzhehei Lake, a soul constituent of the Puzhehei Scenic Area, known for its beautiful scenery and karstic landscapes. Water samples were collected from the upstream, midstream and downstream of Puzhehei Lake, with concentrations of total nitrogen, total phosphorous, lead, cadmium, chromium, mercury and some other major pollutants measured. The results showed that water quality of the upstream of Puzhehei Lake is the worst, which belongs to the category of Grade V. By contrast, the downstream reaches of Puzhehei Lake have the best water quality, which belongs to the category of Grade I, and water quality of the middle reach is in between. Culprits for water pollution include wetland destruction, aquaculture development and agricultural practice. We further put together some suggestions, including the construction of domestic sewage and garbage treatment facilities, the control of pollution load into the lake, the optimization and adjustment of agricultural industry structure, long-term water quality monitoring of Puzhehei Lake, and the encouragement of public participation and involvement in water management.

Key words: Puzhehei lake; water quality; water management.

1. Introduction
The Puzhehei Scenic Area is located in Qiubei County, Wenshan Zhuang and Miao Autonomous Prefecture, Yunnan Province, China. It is a national scenic area and a national AAAA level tourism area, famous for bountiful tourism resources such as beautiful karstic landscapes, interconnected lakes and ponds, rich freshwater biodiversity, and cultural diversity of indigenous and ethnic minority groups [1].

Water is the soul element of Puzhehei Scenic Area, as its signature karst landscape abounds in beautiful waters, and water reflections in the landscape entice people’s eyes into a fairyland with a tranquil environment and beautiful scenery. Actually, Puzhehei Lake (called ‘Pearl Lake’ by the local people) covers the entire Puzhehei Scenic Area, with a distance of more than 20 km between the upstream and the downstream [2]. Every summer, the vast waters of Puzhehei Lake are dotted with blooming lotus flowers and boundless lotus leaves, creating a picturesque scenery that won’t fail to impress hundreds of thousands of tourists.

However, water quality of Puzhehei Lake has been negatively affected by anthropogenic activities such as wetland destruction, aquaculture development, agricultural practice and home laundry. For example, the inlet of Puzhehei Lake is Leshui Cave (e.g., the upstream area). In recent years, local residents near Leshui Cave have directly discharged untreated domestic sewage and livestock manure.
into the lake, resulting in a rapid increase of algae population and a significant decrease in fish diversity, especially the endemic ones. In addition, water that was once crystal clear appears yellow or brown[3].

On the basis of relevant domestic and foreign research, we conducted a site investigation to test water quality of Puzhehei Lake. Water samples were collected from the upstream, midstream and downstream of Puzhehei Lake, then sent back to our laboratory for further analysis. The aim of the present study is to provide a scientific basis for the protection of water resource in Puzhehei and for local economic, social, and environmental sustainability.

2. Methods
Sampling points were set to the upper, middle and lower reaches of Puzhehei Lake. The distance between the upstream and downstream of Puzhehei Lake is more than 20 kilometers, with around 7km between the upper and the middle reaches, and about 13km between the middle and the downstream reaches. The upper reach is Leshui Cave. Due to the lack of tourist facilities, the number of tourists who visit Leshui Cave was quite limited. In other words, only local residents and tourists who are very familiar with the Puzhehei Scenic Area will visit there. The middle reach is Puzhehei Village, where village life and local culture can be experienced by tourists, although local residents outnumber tourist population there as well. The downstream reach is Puzhehei National Wetland Park, which is a gathering place for tourists. The position information of our sampling points is provided in Table 1.

| Sampling points                  | Longitude    | Latitude     | Altitude |
|---------------------------------|--------------|--------------|----------|
| Leshui Cave (the upper reach)   | 104.09345171°E | 24.18334212°N | 1409m    |
| Puzhehei Village (the middle reach) | 104.10964712°E | 24.14742179°N | 1411m    |
| Puzhehei National Wetland Park (the lower reach) | 104.11974415°E | 24.11834473°N | 1415m    |

Surface water samples were collected on December 10, 2020. It was a sunny day with a light wind. Samples were collected by directly filling sterilized and appropriately labeled containers from the surface water body, and proper safety precautions were observed when collecting surface water samples. Two samples from each sampling points were collected, and then stored in a clean cooler to preclude conditions which could alter the properties of the samples.

The alkaline persulfate digestion technique was applied to determine total nitrogen (TN) and total phosphorous (TP) of water samples. This is a well-established approach that provides an environmentally safer alternative to Kjeldahl digestion for the routine determination of nitrogen and phosphorus in water[4]. Heavy metals in water samples were determined using ultrasound-assisted dispersive liquid-liquid microextraction method[5].

3. Results
When concentrations of total nitrogen (TN) of water samples were quantified, it is clear that TN of the upper and middle reaches of Puzhehei Lake was significantly higher than that of the lower reaches ($F_{2,3}=10.24$, $p = 0.035$; Figure 1). According to China’s Environmental Quality Standards for Surface Water (GB3838-2002) and based on measured TN concentrations, water quality of the upstream and middle reaches of Puzhehei Lake was categorized as Grade V and IV, respectively. By contrast, water quality of the downstream was categorized as Grade II.
Similarly, when concentrations of total phosphorous (TP) of water samples were quantified, TP of the upper and middle reaches of Puzhehei Lake was significantly higher than that of the lower reaches ($F_{2,3}=23.72, p = 0.01$; Figure 2). According to China’s Environmental Quality Standards for Surface Water (GB3838-2002) and based on measured TP concentrations, water quality of the upstream and middle reaches of Puzhehei Lake was both categorized as Grade II. By contrast, water quality of the downstream was categorized as Grade I.

It can be seen from Table 2 that regardless of the location, water quality of Puzhehei Lake is categorized as Grade I as far as Cu, Zn and As is concerned. However, as to Pb, water quality of both upstream and middle reaches is categorized as Grade V, whereas water quality of the downstream is categorized as Grade I. Also, water quality of both upstream and middle reaches is categorized as Grade V as far as Pb, Cd, Cr and Hg is concerned.
Table 2. The mean concentrations of some major metal element in water samples

| Sampling points                  | Cu (mg/L) | Zn (mg/L) | Pb (µg/L) | Cd (µg/L) | Cr (mg/L) | As (mg/L) | Hg (mg/L) |
|---------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Leshui Cave (the upper reach)   | <0.001    | <0.001    | 1.195     | 3.10      | 0.43      | <0.001    | 0.0015    |
| Puzhehei Village (the middle reach) | <0.001 | <0.001    | 0.66      | 3.75      | 0.39      | <0.001    | 0.0045    |
| Puzhehei National Wetland Park (the lower reach) | <0.001 | 0.013     | <0.001    | <0.001    | 0.28      | <0.001    | 0.002     |

4. Discussion

The upper reach of Puzhehei Lake has the worst water quality, with nitrogen, lead, cadmium, chromium and mercury as some major pollutants. In general, water quality of the upper reaches belongs to the category of Grade V or worse, and the extent of water pollution is severe. The biggest culprits of this problem include wetland destruction, aquaculture development and agricultural practice[6]. For example, farmyard manure and livestock manure are often piled around villages, which easily enters the water body during the rainy days. In addition, pesticides and fertilizers that are widely applied in farmland eventually reach the water body.

By contrast, water quality in the downstream of Puzhehei Lake is generally good. This is a good sign as in recent years, local government has put a lot of efforts on improving water quality of Puzhehei Lake. For example, tourists can have a barbecue in the park in a designated area, but it is not allowed in pedal boats. Also, activities related to the restoration and protection of Puzhehei Lake is strongly encouraged, such as the establishment of sewage treatment facilities, active treatment of grease-containing wastewater, and tourism management from environmental perspective [7]. The improvement of water quality in the lower reaches of Puzhehei Lake shows that these efforts are worthwhile.

As to the middle reaches of Puzhehei Lake, water quality there is in between. An interesting pattern we found here is that water quality is closed related to population size of local residents. For example, according to the Sixth Census of Qiubei County, population size of the upper and lower reaches of Puzhehei Lake is 75,190 and 31,345, respectively, and this population difference is directly related to water quality. Or, in other words, as population size increases, water quality decreases.

Although water quality of Puzhehei Lake has been greatly approved, many problems still exist and await further improvement. For example, urgent actions need to be conducted to improve water quality of the upper and middle reaches of Puzhehei Lake. To do so, domestic sewage and garbage treatment facilities need to be built and developed, the pollution load into the lake should be reduced or minimized, the structure of the agricultural industry requires optimization and adjustment, and non-point source pollution from livestock and poultry breeding must be strictly controlled. In addition, regularly monitoring water quality is a crucial part of identifying any existing problems, or any issues that could emerge in the future [8]. Therefore, long-term water quality monitoring of Puzhehei Lake is necessary. Last but not least, public participation can enhance water management effectiveness [9].

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