Prediction Study on the Impact of Engineering Waste Rocks on Water Quality During Reservoir Construction

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Abstract: The impact of dammed reservoirs on the local ecological environment during the operational phases has garnered significant attention. However, there is limited research on the ecological risks posed by reservoirs during the construction period, particularly regarding the waste rock at the bottom of the reservoir. Based on the results of release experiment, the water quality risks of engineering waste rocks to reservoirs were analyzed by a three-dimensional model using the MIKE 3 FM HD and ECO Lab module. The calculation results showed that as the waste rock yards are inundated, SO_4^{2-} and Fe^{3+} in the reservoir are released and gradually affecting the water quality in the area in front of the dam. During the process of water storage, the release of pollutants from the waste rocks at the bottom of the reservoir had a significant impact on the underlying water body after two months and then spread from the bottom to the upper layer of water. After three months of water storage, when the water level of the reservoir reached 867 meters, the pollutants released by the waste rock had an impact on the surface water quality. After four months, the release of pollutants from the waste rock yards essentially ceased, and the pollutants gradually accumulated in the bottom water body in front of the dam after dilution and diffusion. In the future, special attention should still be given to the risk assessment of pollutants in the bottom sediments during long-term operation and management of the reservoir.

1. Introduction

Impounding water through dams and constructing reservoirs is one of the fundamental ways to address water supply issues and advance low-carbon energy on a global scale. However, reservoir construction has both advantages and disadvantages, and it has been criticized for the risks it poses to the ecological environment [1,2]. The safety risks and ecological impacts of dams and reservoirs have been receiving increasing attention. Predicting ecological and environmental problems that may arise during the planning and construction period, and identifying the sources of risk to water security that they may cause, have gradually become important scientific concerns.

Currently, research on the ecological and environmental impacts of reservoir construction primarily focuses on two aspects. The migration and release of residual pollutants from soil and waste in the reservoir are caused by the process of water storage, leading to impacts on water quality and ecological changes [3]. Second, the construction of reservoirs has significantly changed the natural flow and hydrological pattern of the river [4], impacting river aquatic life, fish, and basin habitats. This has also led to changes in river sediment yield due to reservoir construction or sedimentation in the reservoir, resulting in significant environmental impacts. However, these studies primarily focus on water quality and ecological environmental issues following reservoir storage and operation. Studies have highlighted the environmental risks associated with reservoir construction, such as land occupation, earth and stone excavation, rock and slag generation, sewage discharge, dust, flying dust, and on-site construction noise [5]. Several studies have utilized mathematical models and other methods to analyze and clarify the primary environmental risks associated with the reservoir construction process [6]. However, there is still a lack of systematic research and quantitative evaluation of such risks and their sources in the reservoir construction process.

This study focuses on Dahe Reservoir, a newly constructed reservoir in southwest China, as a case study. This study aims to predict and analyze the potential impact of engineering waste containing sulfur (S) and iron (Fe) at the bottom of the reservoir on water quality by developing a three-dimensional water quality model. The findings will offer valuable insights for conducting risk analysis during the construction of similar projects.

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2. Research area and methods

2.1. Study area

Dahe Reservoir is situated in Qiannan, Guizhou Province. There are two waste rock yards located on the right and left banks of the river upstream, at distances of 1.5 km and 2.0 km from the dam, respectively (Figure 1). According to on-site expert identification, thin section examination, and material characterization, it has been determined that the waste rocks mainly consist of mudstone and quartzite. Mudstone accounts for 5% to 10% and may contain pyrite or pyrrhotite. Acidic rock wastewater (ARD) will be generated in a prolonged oxidized environment, which could potentially impact the quality of reservoir water. The cross-sections C1, C2, C3 and C4, were set as shown in Figure 1 in the following study.

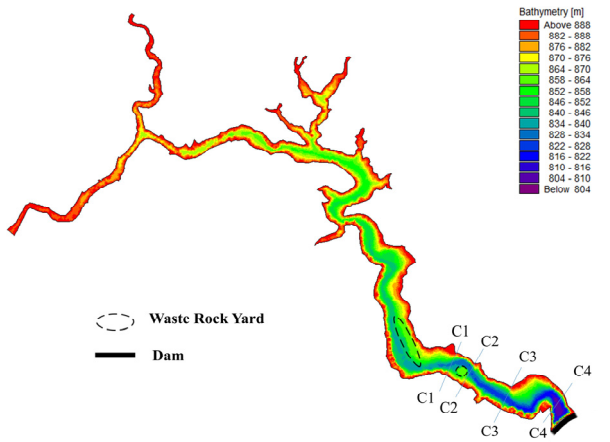

Figure 1 Location of the waste rock yards in the reservoir area

2.2. Hydrodynamic model

Based on the two-dimensional hydrodynamic model [7], a three-dimensional hydrodynamic model of Dahe Reservoir was developed using the MIKE 3 FM HD module, incorporating vertical layering. The control equations include the Navier-Stokes equations with the Boussinesq approximation and the assumption of static pressure. The finite volume method, based on the grid center, is used to spatially discretize the governing equations. In the three-dimensional model, the grid units consist of triangular prisms or quadrilateral bricks in the horizontal plane. The Sigma method was used to divide it into three layers at equal intervals, and the vertical thickness of each layer varies according to the water depth. According to the grid size and water depth conditions, the calculation time step is dynamically adjusted to ensure that the CFL number remains below 1. To meet the stability requirements of the model, the calculation time step size is adjusted within the range of 0.01 s to 30 s. The Smagorinsky formula is employed to calculate the plane eddy viscosity coefficient, with the Smagorinsky coefficient set at 0.28. Additionally, the turbulence model is utilized to calculate the real-time vertical eddy viscosity coefficient. The dry and wet beach processes in the specified area are calculated using the grid-based freezing method. Considering that the reservoir is located in a mountainous canyon, the roughness height was selected as 0.1m by comparing it with the roughness value of the surrounding riverbed. The design data for the water level of the Dahe reservoir was used to compare with the corresponding calculated results of the model. The calculation period spanned from November 1, 2021, to May 20, 2022, and the water level change in the reservoir is illustrated in Figure 2. The predicted water level in front of the dam closely matches the trend of the measured value, and the hydrodynamic model can accurately depict the dynamic process of water storage in the reservoir.

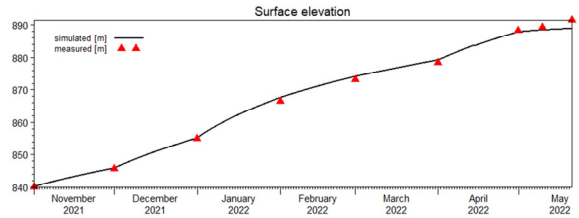

Figure 2 Calibration of simulation results of water level change process in front of the dam

2.3. Water quality model

The ECO Lab module was utilized to consturct the three-dimensional water quality models of Dahe Reservoir. Considering the characteristic indicators of acid rock drainage (ARD), pH, Fe^{3+}, and SO_4^{2-} were selected as the parameters for the water quality model. The initial values were set as follows: pH 7.47; Fe^{3+} 0.01 mg/L; SO_4^{2-} 23.60 mg/L, based on the water quality monitoring data from the dry season in the upper reaches. In the model settings, the quantity of each pollutant released was determined based on the water level when the stockyard was flooded, in conjunction with the research [7]. To analyze water quality risks more effectively, it is assumed, based on the precautionary principle, that the release of pollutants begins when the waste rocks are submerged. The maximum daily release amount was utilized to calculate the maximum release amount of each indicator at different water levels (Table 1), and the model was introduced for the calculation.

Table 1 Release amount of SO_4^{2-}, Fe^{3+} and H^+ for simulation calculation at different water levels

Elevation (m)	SO_4^{2-}(t)	Fe^{3+}(kg)	H^+(g)
840	3.1	46	5.8
845.7	31	452	57
850	42	615	77
8550	42	620	78
860	58	841	106
866.4	58	848	106

During a quality test of the Dahe Reservoir, water storage experiment was conducted, and water samples from the C2 and C4 sections were collected and tested. The deviation between the measured and simulated values of SO_4^{2-}, pH and Fe^{3+} at this water level [7], was -18%. ~15%, indicating that the model accurately simulated the water quality results.

3. Results and discussion

3.1. Concentration distribution of pollutants

Based on the calculation results of the three-dimensional water quality model, Figure 3 shows the distribution of SO_4^{2-} (mg/L), Fe^{3+} (mg/L), and pH in the surface, middle, and bottom layers of Dahe Reservoir at typical water levels after 60 days, 90 days, and 120 days of impoundment, respectively.

In general, the pH value of each layer in the reservoir did not drop below 6.5 during the water storage process. After two months of water storage, the release of pollutants from the waste rock yard significantly impacted the lower water, indicating a trend of spreading from the reservoir bottom to the upper layer. It had a slight impact on the water quality in the middle layer but had no noticeable effect on the surface water quality.

On the 90th day, when the water level of the reservoir reached 867 meters, pollutants continued to diffuse toward the water intake, significantly affecting the quality of the surface water. The highest concentrations of SO_4^{2-} and Fe^{3+} in the surface water are found in the water above the stockyard. The concentrations of SO_4^{2-} in the upper, middle, and lower layers of section C1 are 24.43 mg/L, 26.57 mg/L, and 34.11 mg/L, respectively. The concentrations of Fe^{3+} in the upper, middle, and lower layers of section C1 are 0.03 mg/L, 0.06 mg/L, and 0.16 mg/L, respectively, which does not exceed the Class III water standard specified in the "Surface Water Environmental Quality Standard" (GB 3838-2002).

When the reservoir was impounded for 120 days, the release of pollutants from the waste rock yards essentially ceased. The pollutants released in the early stages gradually accumulated in front of the dam after dilution and diffusion. At this time, the highest concentrations of SO_4^{2-} and Fe^{3+} in the water still occurred at the bottom near the dam. The concentrations of SO_4^{2-} in the upper, middle, and lower layers of the C4 section were 27.63 mg/L, 28.84 mg/L, and 31.63 mg/L, respectively. The concentrations of Fe^{3+} in the upper, middle, and lower layers of the C4 section were 0.07 mg/L, 0.09 mg/L, and 0.13 mg/L, respectively. The concentrations did not exceed the corresponding Class III water standard values and were similar to the values of the upstream water.

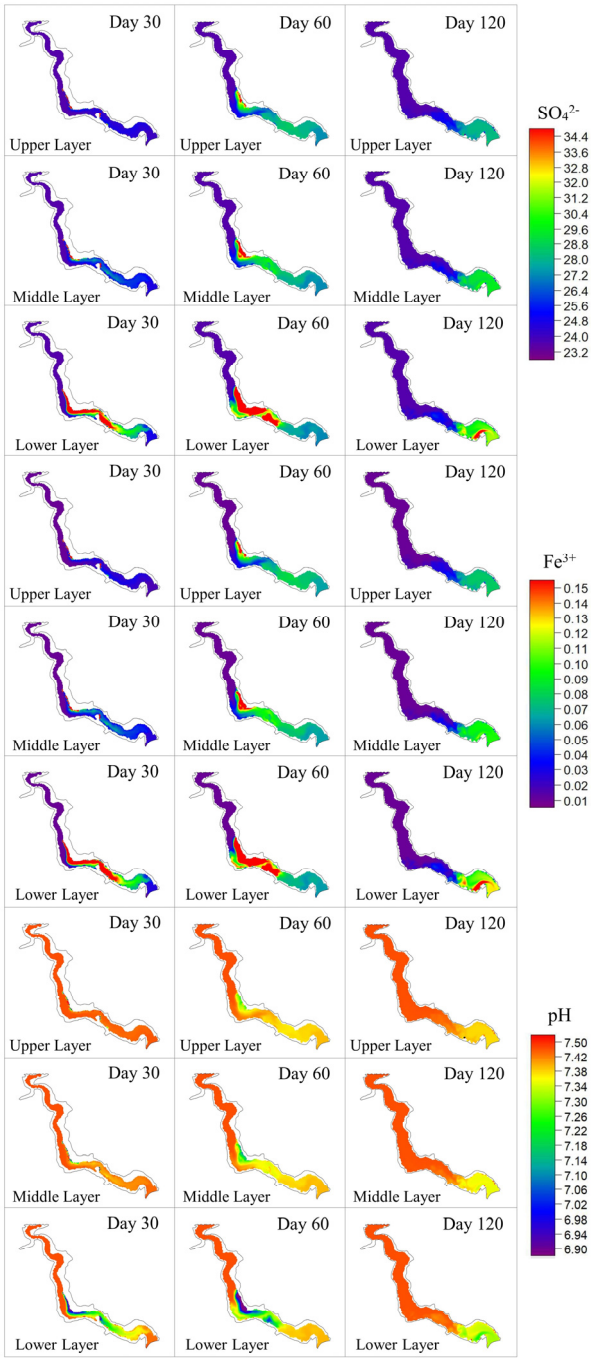

Figure 3 Distribution of SO_4^{2-} (mg/L), Fe^{3+} (mg/L) and pH after 60 days, 90 days and 120 days of water storage in the upper, middle, and lower layers of the reservoir

3.2. Impact on water quality in front of the dam

The distributions of SO_4^{2-}, Fe^{3+} and pH in the C2 section (100 meters downstream of the stockyard) were analyzed after 60 and 90 days of water storage (Figure 4). The trend of pollutants diffusion from the waste rock yards generally indicates vertical dispersion towards the surface water, gradually spreading toward the mid-water line. However, the fluctuations in these pollutants during the actual water storage process cannot be ignored. Tang et al. reported that directly regulating reservoir water levels may have a minimal impact on nutrient release in sediments, while

water level changes can alter pH and the redox potential of the overlying water, thereby indirectly affecting the release dynamics of nutrients in the sediment [8]. Furthermore, it is important to note that this study primarily focuses on characteristic indicators of acid rock drainage (ARD) released from engineering waste, such as pH value and sulfate ions. The presence of heavy metals in the watershed still poses risks. Sarmiento et al. [9] demonstrated that natural water bodies affected by ARD may accumulate significant amounts of heavy metal pollutants in their sediments, such as Fe, As, Cr, Al, Cd, Cu and Zn. This accumulation leads to increased sediment toxicity and poses high and escalating environmental risks. Vriens et al. conducted a ten-year study on the weathering of five large waste rock dumps at the Antamina mine in Peru and found that fine-grained sulfide waste rocks with lower carbonate content exhibited a higher annual sulfide oxidation rate (>1gS/kg) and continued to produce acidic drainage (pH<3) for 7 years. Additionally, the concentrations of copper and zinc remained at the level of grams per liter [10]. In the long-term operation and management, it is important to assess the risk of heavy metal contamination in reservoir bottom sediments. Furthermore, the pH values of the reservoir fluctuate to some extent, and the transportation of metals is primarily influenced by the water body's pH in the presence of ARD. When the pH value is higher or lower than 6.0, it significantly affects the transport of dissolved and particulate metals [11]. Therefore, it is important to enhance the monitoring of pH levels in the vicinity of waste rock yards during daily reservoir management.

The cross-sectional concentration distribution of SO_4^{2-}, Fe^{3+} and pH in front of the dam (C4) after 120 days of water storage was also analyzed (Figure 4). SO_4^{2-} and Fe^{3+} exhibited a noticeable tendency to accumulate at the bottom. Given that the reservoir's abandoned water level of the reservoir is 837 meters, it is crucial to improve monitoring of these indicators during the reservoir's water abandonment operations.

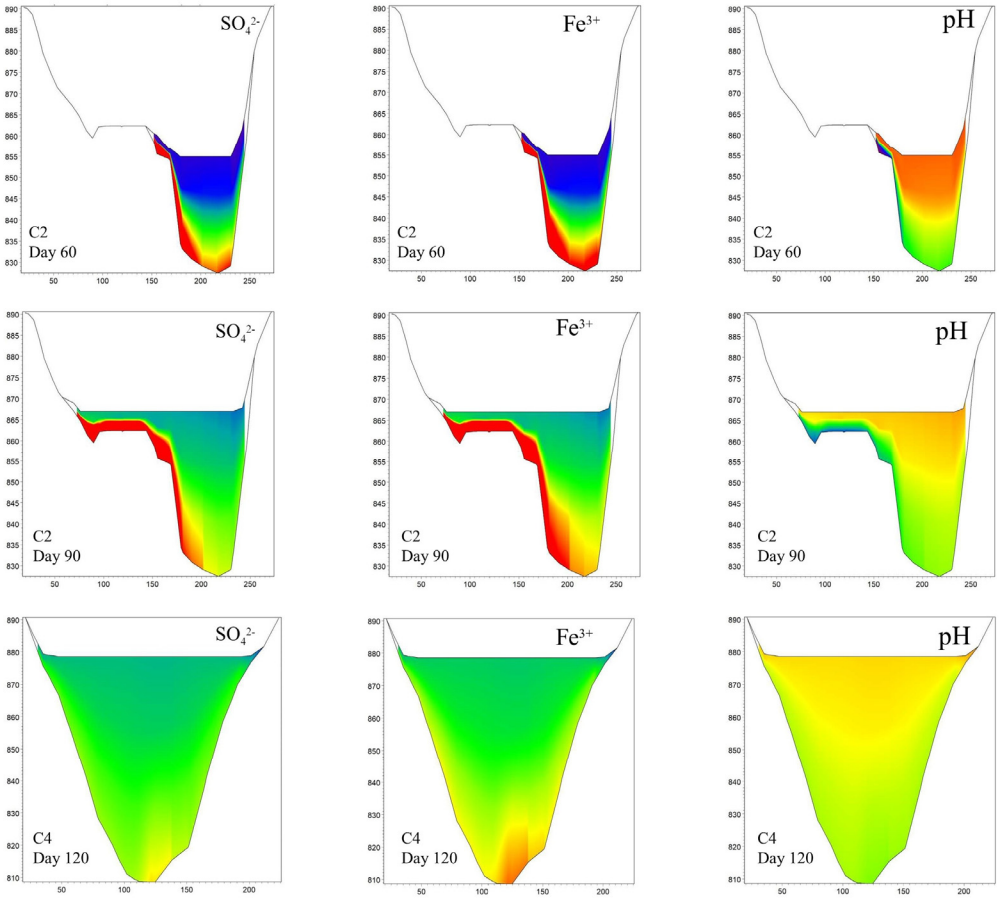

Figure 4 Distribution of SO_4^{2-} (mg/L), Fe^{3+} (mg/L) and pH after 60 days, 90 days of water storage in the C2 section and 120 days of water storage in the C4 section

4. Conclusion

The hydrodynamic and water quality simulations in the study revealed that during the water storage process, pollutants released from the waste rock yards would impact the bottom water after two months. These pollutants would then spread from the bottom of the reservoir to the upper layer, with minimal impact on the surface water quality. After three months of water storage, when the water level reached 867 meters, the pollutants released by the waste rock had an impact on the surface water quality. After four months, the release of pollutants from the waste rock yards essentially ceased. However, the pollutants gradually accumulated in the bottom water body in front of the dam due to dilution and diffusion. At this time, the concentrations of various indicators in the

surface and middle water bodies were close to normal levels. Based on the engineering practices of acid rock drainage, and combined with the model calculation results, this study concludes that the risk of ARD produced by the waste rock on reservoir water quality is minimal. However, attention should be given to the long-term impact on the quality of reservoir water.

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