Postprint of GLOF Susceptibility Assessment in the Boqu River Basin under Climate Change

Authors: Shuai Xu, Suedong Su, Peng Qiu

Date: 2026-03-24T22:05:26+00:00

Abstract

Against the background of global warming, regional glaciers have retreated significantly, glacial lakes have continued to expand, and the susceptibility to glacial lake outburst floods (GLOFs) has been constantly changing, posing a serious threat to the safety of regional public lives and property. Numerous factors influence glacial lake outbursts and their interactions are complex, presenting major challenges for regional GLOF prediction. Taking the Poiqu River Basin in the semi-arid region of Tibet as an example, this study identifies key indicators affecting glacial lake outbursts based on statistical analysis and predicts the susceptibility of GLOFs in the basin combined with data from the Coupled Model Intercomparison Project Phase 6 (CMIP6).

The results indicate that: (1) In 2024, there were a total of 143 glacial lakes in the Poiqu River Basin, of which approximately 50% decreased in area and 29% increased in area; the expanding lakes were predominantly moraine-dammed lakes. (2) Regional GLOF susceptibility assessment models were established based on Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), and Extreme Gradient Boosting (XGB) models with significant differences, achieving assessment accuracies between 67% and 79%. (3) The Black-winged Kite Algorithm (BKA) optimization was introduced to train and generate BKA-MLP, BKA-SVM, and BKA-XGB base models. The prediction results of these base models were used as the training set for a meta-model, which was then optimized to establish a stacking model. After optimization, the accuracy of traditional machine learning models improved to 79%–82%, the accuracy of the stacking model increased to 83.03%, and the Area Under the Success Rate Curve (AUC value) improved to 0.84. (4) Susceptibility predictions from the stacking model show that under different models and scenarios, the probability of glacial lake outbursts exhibits a fluctuating upward trend, with high-susceptibility glacial lakes concentrated in the Chongduipu, Keyapu, Rujiapu, and Zhangzangbo valleys. The research results provide a reference for scientifically responding to glacial lake outburst disasters under climate change.

Full Text

Evaluation of Glacial Lake Outburst Susceptibility in the Poqu River Basin under Climate Change

XU Shuai, SU Peidong, QIU Peng *(School of Earth Sciences and Technology, Southwest Petroleum University, Chengdu, Sichuan)*

Abstract

In the context of global warming, regional glaciers have undergone significant retreat, leading to the continuous expansion of glacial lakes. The resulting fluctuations in the susceptibility to Glacial Lake Outburst Floods (GLOFs) pose a severe threat to the lives and property of regional populations. Predicting regional GLOFs remains a major challenge due to the numerous influencing factors and their complex interactions. Taking the Poqu River Basin in the semi-arid region of Tibet as a case study, this research identifies key indicators affecting glacial lake outbursts through statistical analysis. Furthermore, data from the Coupled Model Intercomparison Project Phase 6 (CMIP6) are integrated to predict the susceptibility of glacial lake outbursts within the basin.

The results indicate: (1) There are a total of 144 glacial lakes within the Poqu River Basin; approximately 15% have decreased in area, while 42% have increased. The expanding lakes are predominantly moraine-dammed. (2) Regional GLOF susceptibility evaluation models were established based on significantly different architectures, including Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), and Extreme Gradient Boosting (XGBoost), achieving evaluation accuracies ranging from 67% to 79%. (3) By introducing the Black-winged Kite Optimization (BWO) algorithm, optimized base models were generated. The prediction results of these base models were then used as a training set for a meta-model to establish a Stacking ensemble model. Following optimization, the accuracy of traditional machine learning models improved to 79%-82%, while the Stacking model reached an accuracy of 83.03%, with the Area Under the Curve (AUC) increasing significantly. (4) Susceptibility predictions from the Stacking model indicate that under different CMIP6 scenarios, the probability of glacial lake outbursts shows a fluctuating upward trend. Highly susceptible glacial lakes are concentrated in the Chongduipu, Keyapu, Rujiapu, and Zhangzangbo valleys.

Keywords: Natural disasters; Glacial Lake Outburst Floods (GLOFs); Susceptibility; CMIP6; Poqu River Basin.

1 Introduction

As global warming intensifies, glaciers continue to retreat and the environments surrounding glacial lakes undergo constant transformation. Consequently, the susceptibility of these lakes to outbursts is continuously evolving. Glacial Lake Outburst Floods (GLOFs) often generate large-scale sediment-laden floods or debris flows, threatening the lives and property of downstream residents. A typical case is the outburst of the Cirenmaco glacial lake; the resulting flood and debris flow destroyed downstream pastures, bridges, and residential houses. Furthermore, upon entering Nepal, the flood damaged parts of the Sun Koshi Hydropower Station. In recent years, with the acceleration of modernization in the Tibetan Plateau region, GLOFs have become one of the most concerning natural disaster issues in the area.

Numerous factors trigger GLOFs, primarily including ice avalanches, snow avalanches, piping within moraine dams, and the melting of ice cores in moraine dams. Among these, outbursts triggered by surges from ice landslides or ice avalanches entering the lake are the most common. Consequently, the activity of the parent glacier, the morphological characteristics of the glacial lake, and the stability of the moraine dam are often used as key indicators for evaluating GLOF susceptibility.

Existing research on glacial lake evaluation has mostly focused on assessing the overall hazard level or screening for lakes prone to outbursts. However, research related to GLOF susceptibility based on CMIP6 in the Poqu River Basin remains scarce. This study identifies regional glacial lake characteristics and constructs a GLOF susceptibility evaluation model by comparing the performance of various machine learning architectures. The objective is to provide a basis for disaster prevention and mitigation for engineering projects in the study area.

2 Data and Methods

2.1 Study Area Overview

The Poqu River Basin is situated in the central Himalayas. The highest point of the basin is Shishapangma, located northwest of Nyalam County. The region is characterized by three major structural faults: the South Tibetan Detachment System (STDS), the Main Central Thrust (MCT), and the Main Boundary Thrust (MBT). Quaternary strata are primarily distributed along river valleys and consist of Pleistocene and Holocene alluvial, moraine, and glaciofluvial deposits.

2.2 Data Sources

Remote sensing imagery was primarily obtained from the United States Geological Survey (USGS) with spatial resolutions of 30 meters. Topographic data were sourced from the ASRTM GDEM with a 30-meter resolution. Historical climate data were obtained from the Climatic Research Unit (CRU), while future climate data were derived from CMIP6 models (BCC-CSM2-MR and ACCESS-CM2). Three Shared Socioeconomic Pathways (SSPs) were selected: SSP1-2.6, SSP2-4.5, and SSP5-8.5.

2.3 Evaluation Indicators

Based on existing research, factors influencing GLOF susceptibility were categorized into triggering factors (precipitation and temperature) and conditioning factors. The final evaluation indicators include: lake-glacier distance, mother glacier area, mean annual temperature, glacial lake expansion rate, moraine dam downstream slope, moraine dam crest width, and the ratio of freeboard to dam height.

2.4 Machine Learning Models

This study employed Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), and Extreme Gradient Boosting (XGBoost). To address uneven sample distribution, a hybrid sampling approach using the Synthetic Minority Oversampling Technique (SMOTE) was applied. The Black-winged Kite Optimization (BWO) algorithm was used to tune hyperparameters. Finally, a Stacking ensemble model was constructed to merge the strengths of the individual base learners.

3 Results and Analysis

3.1 Characteristics of Glacial Lakes

There are 144 glacial lakes in the Poqu River Basin, with an average area of 0.11 km^2. Moraine-dammed lakes are the most numerous, accounting for 65% of the total number and 82% of the total area. Approximately 15% of the glacial lake area is shrinking, while 42% is expanding.

3.2 Future Climate Trends

From 2015 to 2100, the average annual temperature in the Poqu River Basin exhibits a rising trend, while annual precipitation shows a fluctuating upward trend, indicating a transition toward warmer and more humid conditions. The spatial distribution shows higher temperatures and precipitation in the southwest compared to the northeast.

3.3 Model Performance and Susceptibility

Among the individual models, XGBoost achieved the highest accuracy. After algorithmic optimization using BWO, the evaluation performance of all models improved, with accuracy increasing by up to 6%. The Stacking ensemble model achieved the highest performance, with an accuracy of 83.03%.

The susceptibility of glacial lakes to outbursts shows a fluctuating upward trend. Between 2015 and 2100, the predicted number of high-susceptibility lakes is projected to reach 45. These lakes are concentrated in the Chongduipu and Zhangzangbo valleys, consistent with historical records.

4 Discussion and Conclusion

The Stacking-based ensemble model proves highly effective for assessing regional GLOF susceptibility. As glacial retreat intensifies, the direct influence of glaciers may decrease, but the accumulation of loose moraine material increases the risk of landslides and debris flows into the lakes. Under conditions of heavy rainfall or rapid snowmelt, these factors trigger outbursts.

In conclusion, the Poqu River Basin faces an increasing risk of GLOFs under future climate scenarios. High-risk lakes are primarily concentrated in specific sub-basins, necessitating focused monitoring. The integration of CMIP6 climate projections with optimized machine learning models provides a robust framework for regional disaster risk management. Future research should focus on hydrodynamic modeling of flood routing following an outburst to identify potentially affected downstream areas.

Note: Figure translations are in progress. See original paper for figures.