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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Glaciers serve as invaluable natural freshwater reservoirs for downstream regions worldwide, with glacial meltwater playing a significant role in various functions, including domestic use, agriculture, hydropower generation, and environmental health. As global warming persists and precipitation patterns become more variable, the accelerated melting and retreat of glaciers, dramatically reshape the hydrological systems and ecological landscapes. This is of particular importance for tropical glaciers, especially in the tropical Andes where more than 99% of tropical glaciers are located, due to the vulnerability of glaciers to climate change and the significant cumulative specific mass reductions they have experienced since the 1960s, with even more pronounced retreat observed in small glaciers at lower elevations. This further leads to the emergence of new lakes and wetlands, profoundly affecting water availability, ecosystems, and the susceptibility to disasters in the region.

While numerous studies related to tropical glaciers primarily focus on the glacier dynamics, glacial runoff, and the risk of glacial lake outburst floods (GLOF), there remains a substantial deficiency in the comprehensive understanding of lake evolution in this region. Moreover, the analysis of spatiotemporal changes in the multitude of glacial lakes and their potential implications for water resources is notably lacking, although obtaining continuous lake dynamics records would help explore the relationship between key hydrological factors, including precipitation and supply of meltwater from glaciers, and lake evolution patterns.

Yet, current methodologies in glacier mapping still encounter challenges, including incorrectly mapping seasonal snow and misclassifying cloud cover and shadows cast by the steep terrain as glaciers. Similar defects exist in the mapping of glacial lakes, where these methods confront issues such as misclassifying shadows as lakes and being unable to capture spatial information such as pixel proximity and the geometric characteristics of classes, which is crucial for effective water classification. This highlights the critical need for a precise and rapid method to effectively capture changes in glaciers and lakes and their interactions. Such an approach is essential to conduct comprehensive research aimed at understanding the dynamic nature of these water bodies and the intricate interplay of critical climate change factors impacting them.

This study presents a semi-automated methodology developed on the cloud platforms Google Earth Engine and Google Colab to effectively detect dynamic changes in the glaciers as well as glacial and non-glacial lakes of the Cordillera Real, Bolivia, using over 200 Landsat images from 1984 to 2021. Through the calculation of streams and catchments, we establish hydrological connections between glaciers and lakes, enabling an analysis of the correlation between glacier-fed lakes and their source glaciers while considering the influence of multiple climate factors, including temperature, precipitation, and evaporation.

The study updated the glacier area data in the Cordillera Real and clarified the trend in glacier melting with a uniform five-year interval. Over the study period, glaciers reduced their total area by 42%, a significant portion of glaciers shrank before 2010, especially those situated below 5400 m.a.s.l. However, as the distribution of glaciers is more concentrated at high elevations, and thus

more resilient to the rising temperature of recent years, the rate of glacier recession has slowed down in recent years.

Similarly, after a consistent increase since 1985, the area of natural glacier-fed lakes stabilized after 2010. A strong correlation between glacier area and the extent of natural glacier-fed lakes highlights the significant downstream impact of glacier recession on water bodies. Even though the overall area of lakes shows a continuous increase over the years, the increase almost entirely comes from the contribution of human-affected lakes, aligning with the recent stabilization observed in the area of natural glacier-fed lakes. Despite these overall trends, many smaller lakes, especially non-glacier-fed ones, decreased in size, attributed to seasonal and inter-annual variations in lake inflow caused by climate variability.

Catchment level analysis shows that lakes in close proximity to glaciers exhibit a higher correlation with glacier retreat, indicating a direct impact of glacier melt on these water bodies. In contrast, lakes farther from glaciers were more influenced by non-glacial factors. The spatiotemporal analysis revealed significant warming, especially at higher elevations, and contrasting evaporation rates, with higher rates on the eastern side. Although overall precipitation increased, it was insufficient to sustain downstream lakes due to the combined effects of temperature rise and enhanced evaporation. The accelerated melting of glaciers, coupled with changes in precipitation patterns, threatens the stability of water supplies in the region.

This study reveals the response of glaciers and lakes to climate variations, including the contribution of human-constructed water reservoirs, providing valuable insights into crucial aspects of future water resources in the Cordillera Real. This enhances our understanding of the impact of climate change on glaciers and lakes within the Cordillera Real region and its potential implications for downstream water resources and future water management strategies. The findings in this study suggest the potential decline of natural lakes amid ongoing climate changes, prompting alterations in natural landscapes and local water resources. Our research underscores the urgent need for comprehensive monitoring and sustainable water management strategies to mitigate the adverse effects of climate change on glacial and hydrological systems in the Andean region.