INAIGEM

MULTI-ANNUAL CHANGES OF GLACIAL LAKES IN PERU AND THEIR LINKS TO CLIMATE CHANGE AND GLOFS

Turpo Cayo E.(4,5); Jara Infantes, H.(1); Melgarejo, E.(1); Tinoco Meyhuay T.(3); Torres, J (1); Caballero, A.(1); Villafane, H.(1); Araujo,J.(1); Yarleque, C.(1); Garay, D. (1); Stephan,H (2); Wood,J (2); Glasser, N.(2); Ryan W.(2); Bennett, J.(2); Shannon, S.(2); Espinoza, R.(5) and De Almeida, C.(6,5)

(1) National Research Institute for Glaciers and Mountain's Ecosystems (INAIGEM); (2) University of Exeter; (3) Santiago Antúnez de Mayolo National University

ABSTRAC

The effects of climate change are causing a profound reduction in glacier's coverage in the Cordilleras of the Peruvian Andes, giving rise to the development and growth of proglacial lakes. These glacial lakes can represent a significant hazard in the form of Glacier Lake Outburst Floods (GLOF) that have the potential to impact vulnerable populations and infrastructure located downstream of glaciated areas. In this study, we present a long-term spatio-temporal analysis of glacial lakes across the Peruvian Andes and address possible connections with GLOF events and climate change. Accessed and processed using Google Earth Engine and QGIS, this analysis was conducted using Landsat 5, 7 and 8 satellite data (Surface Reflectance Tier 1) acquired between 1984 and 2019. We detected and estimated

METHODOLOGY

The pre-processing and image processing procedures for the multi-temporal mapping of glacial lakes were based on an adaptation of the Mapbiomas project methodology (MapBiomas 2017) and other references (Pekel et al. 2016, Cayo Turpo et al. 2019, Souza et al. 2019). The main characteristics of the proposed methodology include:

- usage of the Landsat collection (30 m spatial resolution),
- pixel-based image processing (empirical decision tree),
- organized by Cordilleras,
- cloud-based computing (Google Earth Engine),
- multi-year validation and field survey.

Figure 1 Methodological flowchart

RESULTS

According to Figure 4, we showed the evolution of the surface extension of the glacial lakes in the 20 Cordilleras of the Peruvian Andes in the period 1984-2019; where the La Viuda Cordillera has the greatest surface extension. The Cordilleras that presented the greatest increase in the surface of glacial lakes are Ampato, Volcánica, Apolobamba, and Chonta, while the Huytapallana and Huagorucho Cordilleras have a decreasing trend. In the case of the Barroso Cordillera, a significant increase was found, related to the activity of damming and regulation of lakes. In the rest of the Cordilleras, there are less representative changes, however, in the lakes individual analysis, important changes were found in most of the studied Cordilleras of the Peruvian Andes.

Figure 3. Classification of glacial lakes based on empirical decision tree.

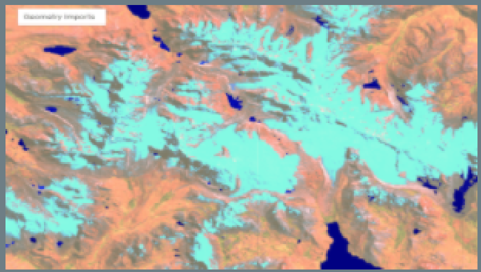
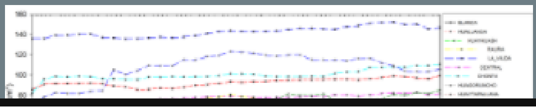


Figure 4. Glacial lakes area evolution in the 20 Cordilleras of the Peruvian Andes.



DISCUSSION

There are several methodologies to classify water bodies in satellites images, of which empirical decision trees are one most used due to their easiness of use and implementation (Souza et al. 2019, MapBiomas Amazonía 2019). However, empirical decision trees can be subjective in the parameters setting at each decision node, leading to temporally inconsistent results, requiring the application of different post-classification filters. For this research, it was decided to use empirical decision trees due to their superior quality when compared to other classifiers such as Random Forest in the Andes mountain range, where there is a general confusion between the classification of water and relief shadows.

The results of the glacial lakes classification in the period from 1984 to 2019 have overall accuracy greater than 85%. This indicates that the methodology is appropriate for the study area. It ought to be noted that the quality of the classification depends on the variables than are used

CONCLUSIONS

This study applied a methodology based on empirical decision trees, to the entire Andes mountains. The classification was based on Landsat satellite images and was carried out in the 20 Peruvian Cordilleras in the period 1984-2019. In general, in all Andes mountains, the overall accuracy surpassed 85%. This indicates that the results of this study are an important source of information for the analysis of glacial lakes, their evolution, and trends in the latest three decades.

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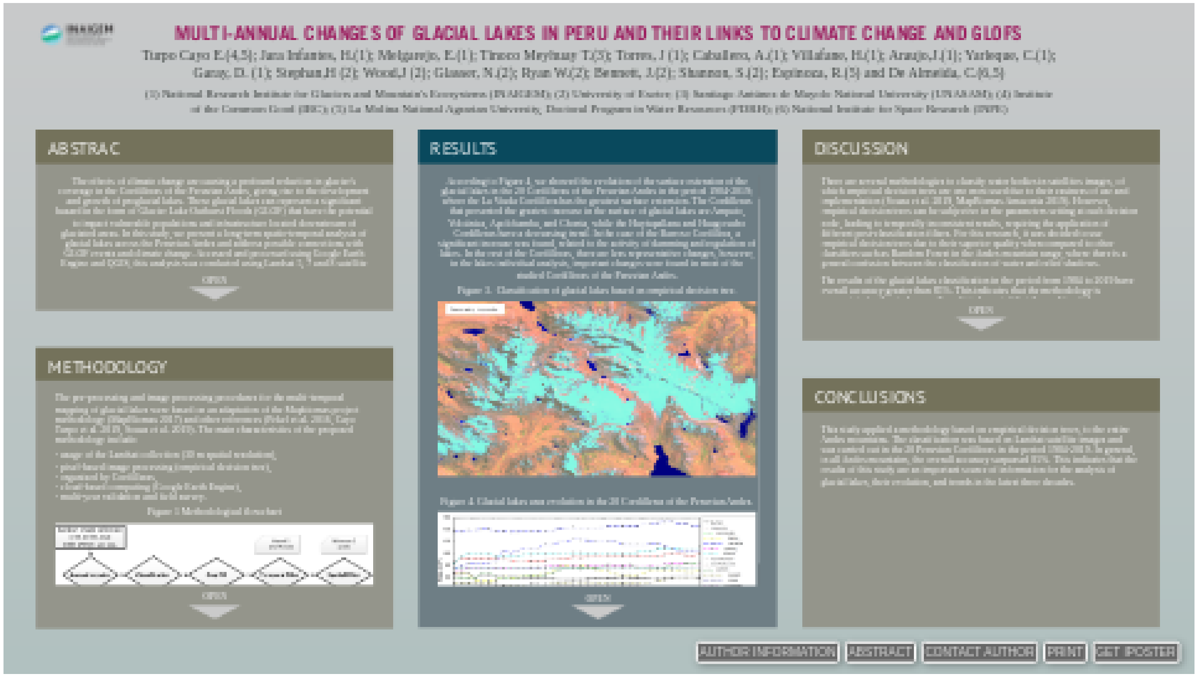

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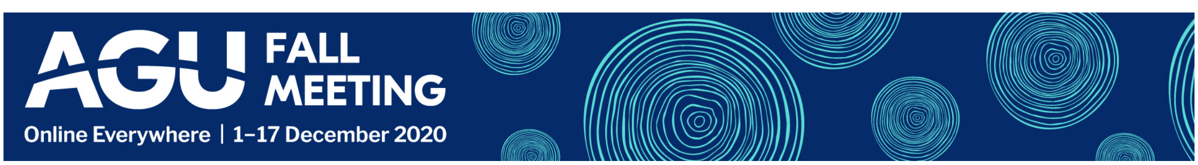

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The effects of climate change are causing a profound reduction in glacier's coverage in the Cordilleras of the Peruvian Andes, giving rise to the development and growth of proglacial lakes. These glacial lakes can represent a significant hazard in the form of Glacier Lake Outburst Floods (GLOF) that have the potential to impact vulnerable populations and infrastructure located downstream of glaciated areas. In this study, we present a long-term spatio-temporal analysis of glacial lakes across the Peruvian Andes and address possible connections with GLOF events and climate change. Accessed and processed using Google Earth Engine and QGIS, this analysis was conducted using Landsat 5, 7 and 8 satellite data (Surface Reflectance Tier 1) acquired between 1984 and 2019. We detected and estimated glacier lake surface area changes using a robust semi-automated method which coupled empirical decision trees, sub-pixel analysis, spectral and topographic indices with many temporal and spatial filters to improve the quality of the glacial lake classifications. Using this classification as a result, we were able to categorize the glacial lakes based on their surface change dynamics over the past three decades. Results highlight a distinct spatial variability in glacial lake changes across the 20 Cordilleras of the Peruvian Andes. Overall, 12 Cordilleras experienced an increase in glacial lake area during the observation period (with increases oscillating from 1% to 38%), whilst the remaining 8 experienced a reduction in area (with decreases ranging from reductions of -2% to -57%). A multi-temporal validation of the semi-automated glacier lake classification method, utilising manually digitized data, revealed glacial lake mapping overall accuracy above >80% across the study area.

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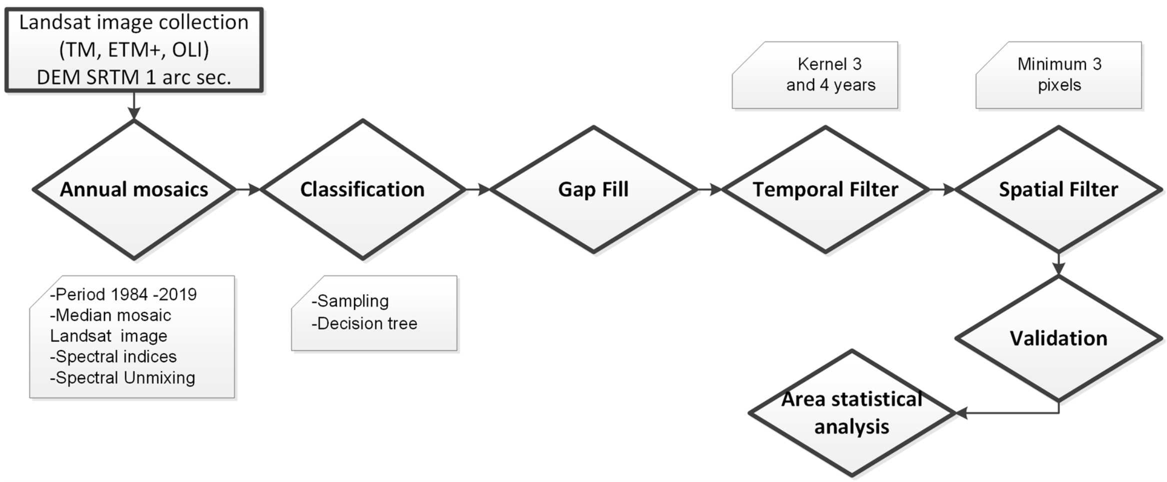
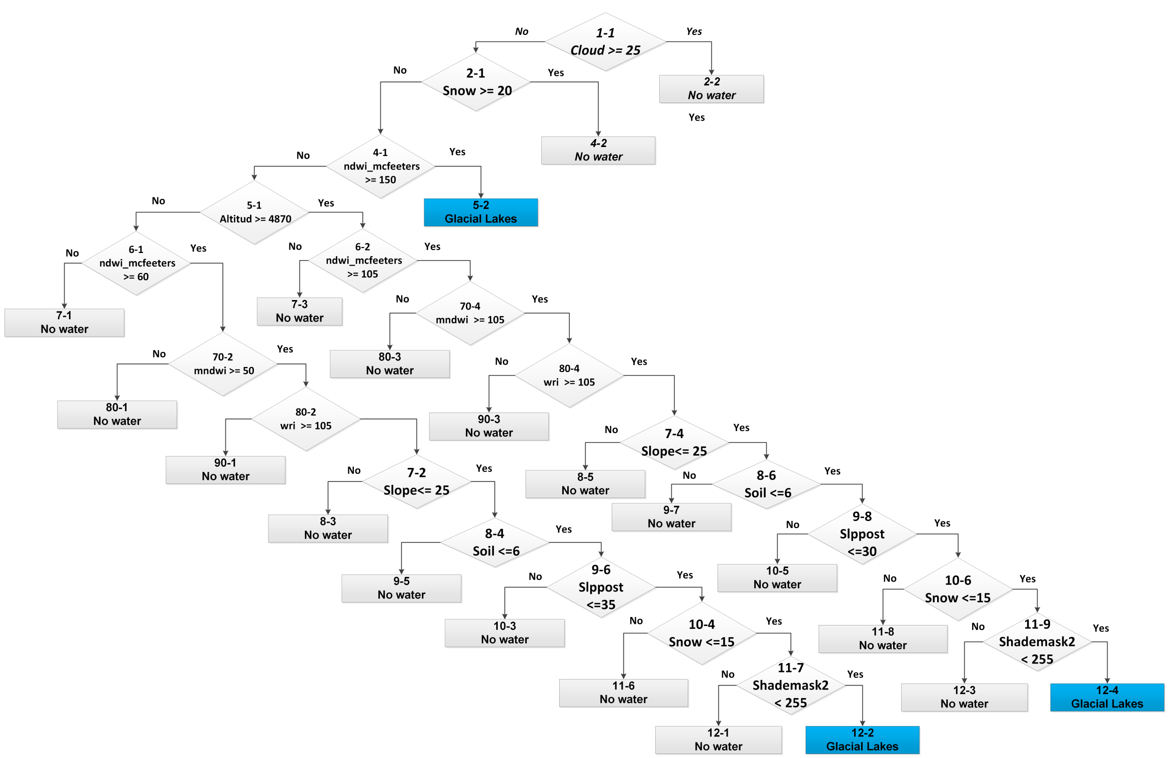


Figure 2 Empirical decision tree.



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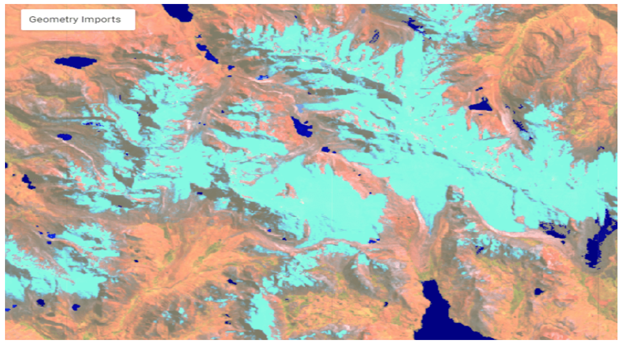
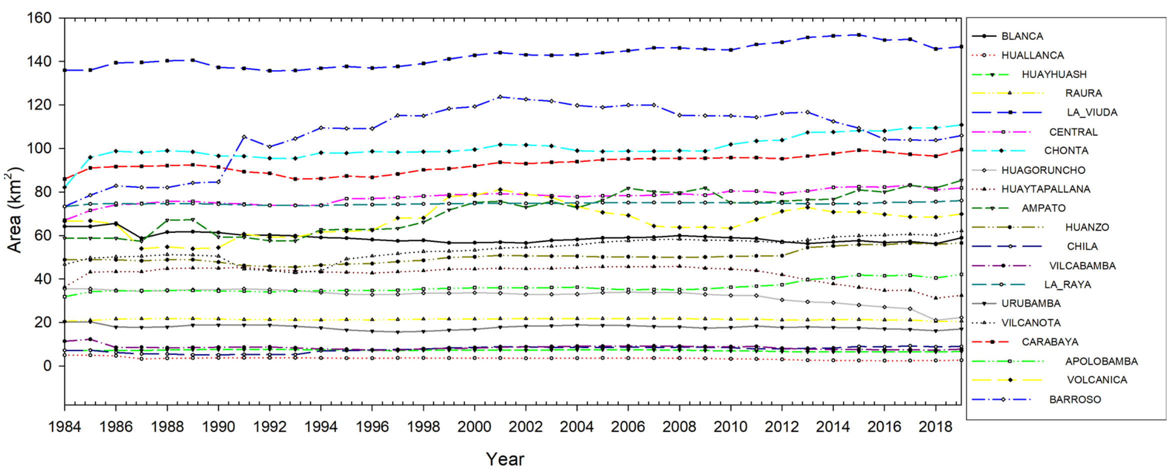
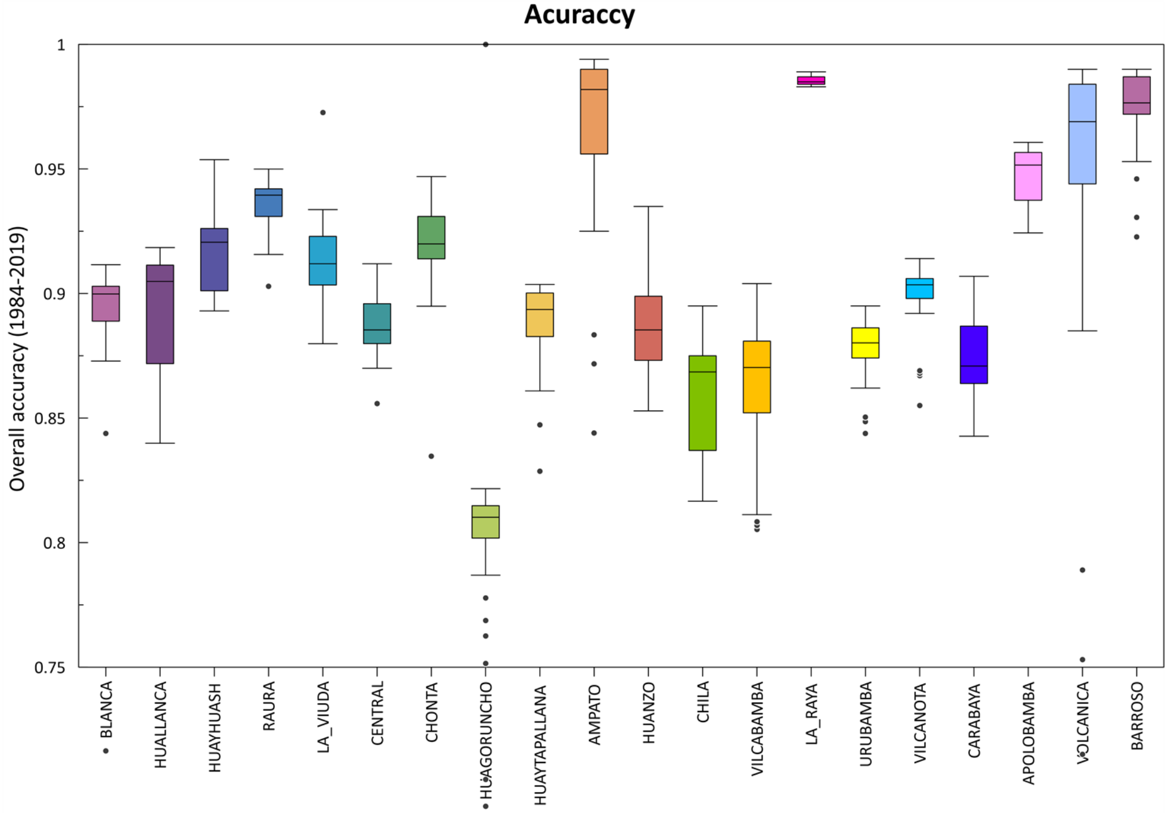


Figure 4. Glacial lakes area evolution in the 20 Cordilleras of the Peruvian Andes.



The results of image classification of glacial lakes in the period from 1984 to 2019 were subjected to multitemporal validation obtaining a global precision higher than 85%. Besides, it could be to observe that the years with low values in precision are related to problems in the quality of the mosaics and classification thresholds (Figure 5).

Figure 5. Box plot of thematic accuracies reached by Cordilleras in the period from 1984 to 2019.


Acuraccy
Overall accuracy (1984-2019)
1
0.95
0.9
0.85
0.8
0.75
BLANCA
HUALLANCA
HUAYHUASH
RAURA
LA_VIUDA
CENTRAL
CHONTA
HUAGORUNCHO
HUAYTAPALLANA
AMPATO
HUANZO
CHILA
VILCABAMBA
LA_RAYA
URUBAMBA
VILCANOTA
CARABAYA
APOLOBAMBA
VOLCANICA
BARROSO

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There are several methodologies to classify water bodies in satellites images, of which empirical decision trees are one most used due to their easiness of use and implementation (Souza et al. 2019, MapBiomas Amazonía 2019). However, empirical decision trees can be subjective in the parameters setting at each decision node, leading to temporally inconsistent results, requiring the application of different post-classification filters. For this research, it was decided to use empirical decision trees due to their superior quality when compared to other classifiers such as Random Forest in the Andes mountain range, where there is a general confusion between the classification of water and relief shadows.

The results of the glacial lakes classification in the period from 1984 to 2019 have overall accuracy greater than 85%. This indicates that the methodology is appropriate for the study area. It ought to be noted that the quality of the classification depends on the variables than are used in the decision tree as well as the quality of the annually composed mosaics. Topographic variables like slope and shadow are important variables for the classification of glacial lakes in environments with rugged relief, such as the Andes mountain range. In the results, the Barroso Cordillera shows greater temporal changes, caused by the damming of glacial lakes in view of, the water deficit of this mountain range, which is closely related to the direct and indirect effects of climate change. The results of this study have been compared to the work entitled Global Surface Water (Pekel et al. 2016) and demonstrated to have, greater temporal consistency, which can be explained by the temporal and spatial filters used in this study.

CONCLUSIONS

This study applied a methodology based on empirical decision trees, to the entire Andes mountains. The classification was based on Landsat satellite images and was carried out in the 20 Peruvian Cordilleras in the period 1984-2019. In general, in all Andes mountains, the overall accuracy surpassed 85%. This indicates that the results of this study are an important source of information for the analysis of glacial lakes, their evolution, and trends in the latest three decades.

AUTHOR INFORMATION

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ABSTRACT

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