

Glacier retreat in Sibinacocha's Basin- Multi temporal analysis and social perceptions

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Abstract

This research compares the social perceptions about glacier retreat with temporal analysis of satellite images of the Sibinacocha Glacier Lake (SGL) basin. The study is based on a multitemporal analysis (1992-2020) of Landsat 5 and 8 satellite images, in which, through spectral indices and manual corrections, an average retreat of 30% was estimated in the study basin. In addition, coincidences were identified between periods of retreat/ growth and periods of El Niño/La Niña events. The information related to social perceptions was collected from surveys carried out in November 2020 to 154 people from the town of Phinaya (located at 5 km from the SGL dam); the results reported that all of those surveyed identified a glacier retreat, more than 60 % expressed concern regarding the glacier retreat, while more than 70% identified a more accelerated retreat in recent years compared to the last two decades. The last finding was consistent with the glacier retreat slopes for the last 5, 20 and 25 years in the SGL basin suggesting that local population manages to perceive the changes in the glacial dynamics.

Keywords: Glacier retreat; Sibinacocha Glacier Lake; NDSI; Social perceptions

1. INTRODUCTION

Climate change has proven to be associated with the centennial-scale retreat of glaciers (Roe et al., 2016). In the last decade (from 2000- 2016), a study showed a glacier recession of 29% in the Peruvian tropical glaciers (Seehaus et al., 2019). The Cordillera Vilcanota, located between the regions of Cusco and Puno, Peru, is the second with the largest glacier cover in Peru (255.44 km²) (MINAM, 2017). From 1975 to 2015 the glacier cover of the northern region of this cordillera decreased in 48%, while a reduction of 81% was observed for the glacier area situated below 5000 m.a.s.l (Kozhikkodan Veettil & de Souza, 2016). The loss of this glacier mass results in the release of stored water that will no longer contribute to streams during the dry season, producing a transformation of downstream hydrology (Mark et al., 2017) that affects the relationship between natural resources and human activities. However, authors on the topic still identify the need for more in situ data and cultural analysis studies (Drenkhan et al., 2015).

The Sibinacocha Glacier Lake (SGL) is located in the Vilcanota sub-basin, in the upper zone of the Salcca river micro-basin, Canchis province- Cusco. The lake is situated at an altitude of 4870 m.a.s.l, it has an extension of approximately 30 km² and a depth of over 90m in some places (Michelutti et al., 2019). The SGL is fed mainly by the melting of the Chumpe or *Osjollo Anante* glacier and is dammed by the Machupicchu Electricity Generation Company S.A (EGEMSA for its acronym in Spanish) (MINAM, 2017). The lake represents a basic source of water for the nearby population and is of great importance from an economical and energetical point of view. Although the economic and social activities that depend on the SGL rely on the melting of the surrounding glaciers, the perception that the inhabitants of the area have regarding the glacier retreat in the SGL basin is still unknown. The present study seeks to analyze the glacier retreat within the SGL basin and to investigate whether the inhabitants of the area have been able to identify the changes in the glacier dynamics.

2. METHODS

2.1 Study area

The identification of the glacier areas was carried out in two study areas in the Cordillera Vilcanota, Cusco, Peru. The study areas were delimited taking into consideration the social studies developed by the Universidad Nacional de San Antonio Abad del Cusco (UNSAAC) in the Phinaya Community, within the framework of the PEGASUS project.

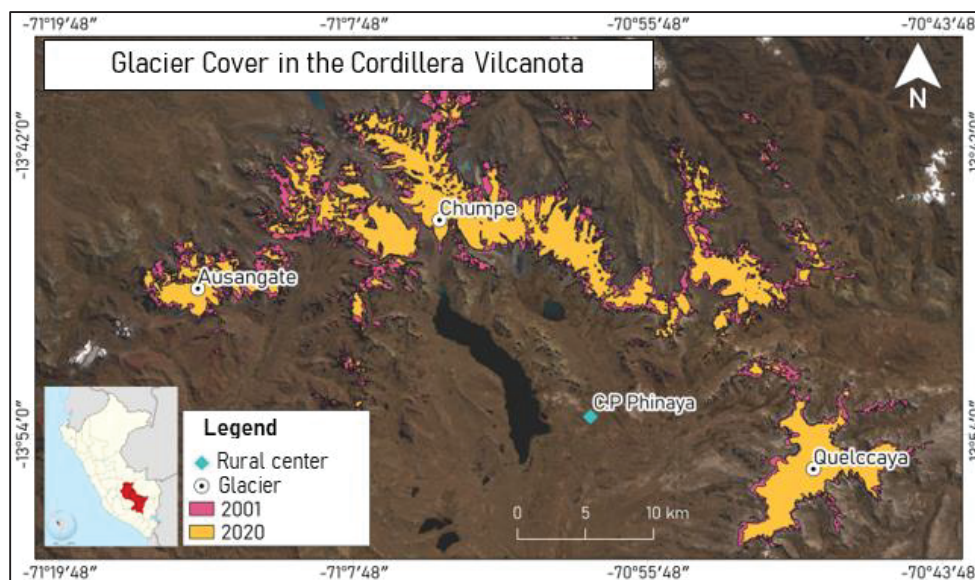


Figure 1. Macro Study Area

The macro study area covered the Cordillera of Vilcanota, including the following glaciers: Chumpe, Ausangate and Quelccaya (Figure 1). The macro study area was taken into consideration to contrast if the rate of change in the glacier surface (km^2/year) in the Cordillera behaved similarly to that of the SGL basin. The micro study area (Figure 2) covers the entire SGL basin and would be directly related to the perceptions of the Phinaya community, since it is this basin that contributes to the water volume of the lake and the operation of the hydroelectric plant. In addition, the basin encompasses the location of most of the families identified in the UNSAAC social study (blue houses on Fig 2).

2.2 Basin delimitation

The basin was delimited through Qgis 3.18.2 with GRASS 7.8.5. The elevation product used was the SRTM 90 m DEM Version 4. The basin was created starting from the outlet point of the lake, which coincides with the location of the hydroelectric. The detailed description of the methods used can be found in the references (Jenson & Domingue, 1988). After exporting the basin in SHP format, the results were compared with the contour lines (elevation) for the same area and manual improvements were made if necessary.

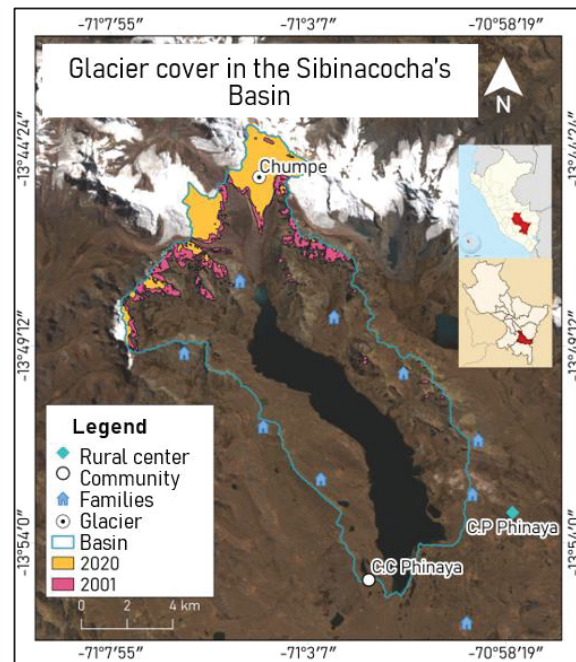


Figure 2. Micro Study Area

2.3 Surveys

A total of 200 people from 18 to 70 years old in the Phinaya community were surveyed by the UNSAAC team in November 2020 between men and women. Previously, this community has been identified at possible risk in case of Glacier Lake Outburst Floods. It should be noted that most of the people surveyed spent time both in the surroundings of the peasant community (within the SGL Basin) for agriculture or livestock purposes, and in the town/rural center where their main homes are located. Information such as sex, age and economic activity of the inhabitants was collected. On the other hand, closed questions were asked in relation to glacier melting in order to know the population's opinion and investigate whether they have identified an acceleration in the glacier retreat.

- A. In the last 20 years, more or less, have you observed a considerable decrease in the glacier area in your region?
- B. If you consider that there has been a decrease. How alarmed are you today about this glacier retreat?
- C. Considering more or less the last 5 years, do you think that the glaciers are melting faster?

2.4 Glacier area calculation

The calculation of the glacier areas was made on a single image of the macro study area per year from 1992 to 2020 (satellites Landsat 5 and 8), later the result was cut to the micro study area as seen in figures 1 and 2. It was expected to find a negative tendency for glacier areas (retreat) both in the micro and macro study areas with a slower acceleration in the first years of analysis.

The images were obtained through Google Engine using a time scale from May to September (dry season) to avoid taking into account temporary snow. A cloud cover filter of less than 10% was applied to guarantee the use of clear images. Less years were used in the macro study area since there were big patches of clouds that generated uncertainty and the year had to be eliminated. To identify the glacier area, the Normalized Difference Snow Index (NDSI) was used. This index works with the Green band and the Short-wave infrared (SWIR) band of each image through Eq. [1].

$$NDSI = \frac{Green - SWIR}{Green + SWIR} \quad [1]$$

The range of values of the index goes from -1 to 1, with 1 being the value with the greatest intensity of snow/white cover. Studies in the region often use NDSI threshold values from 0.5-0.6 (Kozhikkodan Veetil & de Souza, 2016), however for this study case the selected threshold was of 0.4 since a better differentiation

was observed with the uncovered or shaded areas. Also, a 0.4 threshold gives an overestimate of the glacier area rather than the underestimate that could occur by using a higher value, therefore glacier area results shown in this study could be less “alarming” than in similar investigations. Later, the areas were polygonised with a QGIS algorithm and corrected manually where needed, specially to erase small lakes or to add snow polygons hidden under mountain shadow.

3. RESULTS AND DISCUSSION

The following section will describe the relationship between the data collected from the survey and the calculation of the glacier areas from 1992 to 2020.

3.1 Glacier cover

Figure 5 confirms that the glacier cover in the macro and micro study areas shows a similar behavior through the years, specially starting 2005. This result allows to think that the SGL glacier cover behavior can be scaled to that of the Cordillera Vilcanota. The glacier cover reduced from 1992 to 2020 in both cases, peaked in 2001 and reached its minimum in 2020.

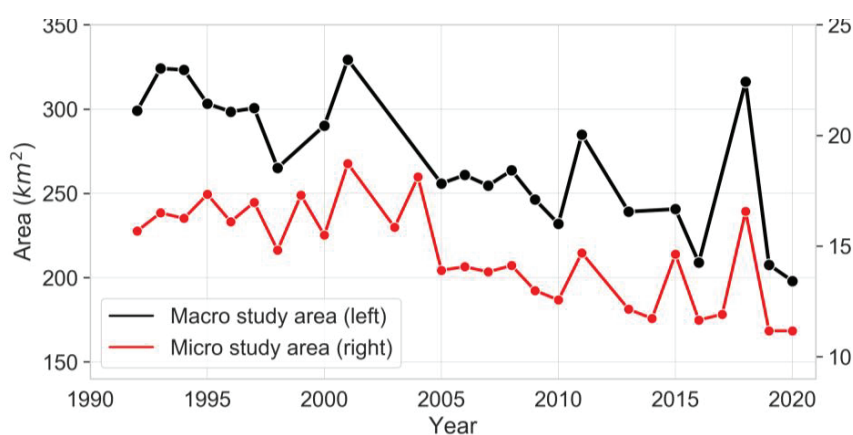


Figure 3. Glacier cover in the macro and micro study areas

Climatic events are related to the variation of the glacier cover. The El Niño events in 1997, 2002, 2004, 2006, 2009, 2015, 2016 and 2018, whether of a weak, moderate, strong or extraordinary category, were mostly related to a decrease in glacier cover, especially in 2002, 2004, 2015 and 2018. On the contrary, the La Niña events in the years 1996, 2010, 2013 and 2017 were mostly associated with an increase in glacier coverage, which is clearly evidenced in the increase in temporary snow from 2017 to 2018 (IGP, 2021; SENAMHI, 2014).

3.2 Tendencies

As can be seen in Figure 4, the slope of the trend lines for the multitemporal study increases with time. The rate of melting in the last 25 years is $0.21 \text{ km}^2/\text{year}$, in the last 20 years is $0.24 \text{ km}^2/\text{year}$ and in the last 5 years is $0.4 \text{ km}^2/\text{year}$. The slope of the last five years is steeper, in part, due to the glacier increase of 2014 and 2018 produced by La Niña events. The results shown in figure 3 and 4 agree with the surveys carried out among the residents of Phinaya.

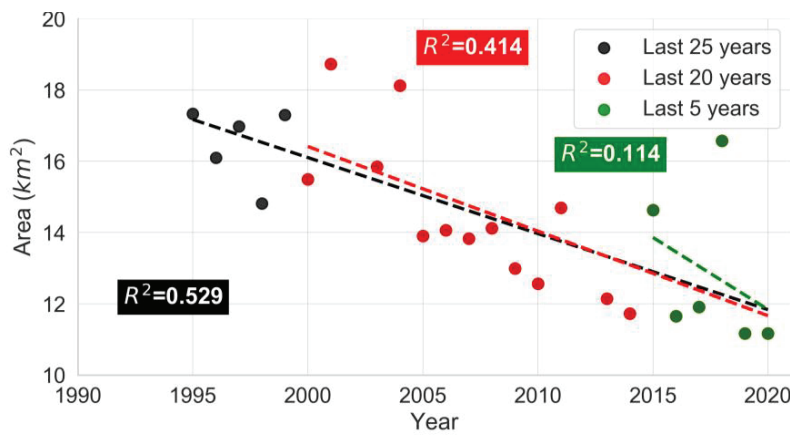


Figure 4. Tendencies of glacier retreat in the last 25 (1995-2020), 20 (2000-2020) and 5 years (2015-2020) on the SGL Basin.

3.3 Social perceptions

In order to obtain accurate information in the comparison of question A and C, the database was filtered to people over 30 years of age, since it was considered that at this age it is possible to have a certain notion about the speed of glaciers in the past. After applying the filter, a sample population of 154 people was obtained, 77% were men while 23% were women. Also, most of the surveyed (58%) had between 31 and 45 years, 33% had between 46 and 55 and 9% had more. Regarding the economic activities of the locals, almost 77% of the over 30-year population was mainly dedicated to livestock raising, only a few developed as technicians, housewives or merchants.

Regarding question A all inhabitants expressed that they had observed a considerable decrease in the glacier area of the region over the last 20 years.

Table 1. Results from Phinaya survey campaign

| | QUESTION B | | QUESTION C | |
|------------------|------------|----|------------|----|
| | FREQ | % | FREQ | % |
| NOTHING | 1 | 1 | 1 | 1 |
| LITTLE/SOMETHING | 37 | 24 | 8 | 5 |
| CONSIDERBALE | 98 | 64 | 109 | 71 |
| A LOT | 18 | 12 | 36 | 23 |
| TOTAL | 154 | | 154 | |

Question B shows that 12% of the surveyed felt really alarmed because of the glacier retreat that has been occurring in the past 20 years more or less, 64% felt considerably alarmed, while 24% felt little concern. Only one person didn't feel alarmed by the phenomenon. Question C shows that 23% of the surveyed thought that the glacier retreat in this past 5 years has accelerated a lot in comparison with the last 20 years, 71% thought that the retreat in the last 5 years was considerably higher, 5% thought it was a little bit higher, while only 1% said that it wasn't. The results of the calculation of glacier areas in the SGL allow us to identify if the social perceptions reflected in questions A, B and C are aligned with the behavior of the glacier. Table 2 shows that the answers to the questions are consistent with what was observed in reality.

Table 2. Relationship between social perceptions and glacier behavior

| QUESTION | PERCEPTION | RESULT |
|----------|---|--|
| A | All inhabitants expressed that they had observed a considerable decrease in the glacier area of the region over the last 20 years | Fig 3 and 4 show that there has been a decrease in the glacier area over the last 20 years or so. |
| B | More than half of the surveyed felt considerably alarmed because of the glacier retreat | The reaction is justifiable considering that a glacier retreat is observed both in the SGL Basin and in the Cordillera Vilcanota |
| C | 71% of the surveyed thought that the glacier retreat in this past 5 years has accelerated considerably in comparison with the last 20 years | The glacier retreat rate on the last 20 years, more or less (0.2 km ² /year), is half the one of the last 5 years (0.4 km ² /year) |

4. CONCLUSIONS

There has been considerable retreat of the glacier cover in the SGL basin which is likely to affect the relationship between natural resources and human activities. Changes in the glacier cover both in the Cordillera Vilcanota and in the SGL Basin are related to climatic events such as El Niño and La Niña. An increase in the effects of climate change can trigger different catastrophes, such as the flooding of Glacier Lake Outburst. The social perceptions in the Phinaya community center are consistent with the physical behavior of the glaciers in the Cordillera Vilcanota and in the Sibinacocha Glacier Lake Basin. However, information on the background of the respondents is lacking, so open-ended questions should be asked to find out people's perceptions.

5. ACKNOWLEDGEMENTS

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